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Evaluation of Generic Types of Drilling Fluid Using a Risk-Based Analytic Hierarchy Process

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ABSTRACT / The composition of drilling muds is based on a mixture of clays and additives in a base fluid. There are three generic categories of base fluid - water, oil, and synthetic. Water-based fluids (WBFs) are relatively environmentally benign, but drilling performance is better with oil-based fluids (OBFs). The oil and gas industry developed synthetic-based fluids (SBFs), such as vegetable esters, olefins, ethers, and others, which provide drilling performance comparable to OBFs, but with lower environmental and occupational health effects. The primary objective of this paper is to present a methodology to guide decision-making in the selection and evaluation of three generic types of drilling fluids using a risk-based analytic hierarchy process (AHP). In this paper a comparison of drilling fluids is made considering various activities involved in the life cycle of drilling fluids.This paper evaluates OBFs, WBFs, and SBFs based on four major impacts— operations, resources, economics, and liabilities. Four major activities— drilling, discharging offshore, loading and transporting, and disposing onshore— cause the operational impacts. Each activity involves risks related to occupational injuries (safety), general public health, environmental impact, and energy use. A multicriteria analysis strategy was used for the selection and evaluation of drilling fluids using a risk-based AHP. A four-level hierarchical structure is developed to determine the final relative scores, and the SBFs are found to be the best option.

Introduction

The primary objective of this paper is to present a methodology to guide decision-making in the selection and evaluation of three generic types of drilling fluids using a risk-based analytic hierarchy process (AHP). A comparison is made considering various activities involved in the life cycle of drilling fluids. The assumption in this comparison is that different drilling fluids can be used in place of each other for the same purpose. Before discussing the details of AHP methodology, a brief summary of drilling fluids is presented.

The composition of drilling muds is based on a mixture of clays and additives in a base fluid. There are three generic types of base fluids—water (WBFs), oil (OBFs), and synthetic (SBFs). The composition of mud used in a particular application depends on the well conditions and environmental regulations. Water-based muds or fluids are relatively environmentally benign, but drilling performance is better with OBFs. Implementation of advanced drilling techniques sometimes demands a fluid with better lubricating characteristics than WBFs can provide.

An OBF is a drilling fluid that consists of brine (seawater) contained as an emulsion in oil. This is in contrast to water-based fluid (WBF), which consists of small quantities of oils present as lubricants as an emulsion within brine. Oil-based fluids have been formulated with diesel and mineral oils. Drilling performance can differ markedly with drilling fluid, as the following example illustrates. When shale is drilled with an OBF, the oil is in contact with the shale and the fine nature of the shales prevents entry of oil and the integrity of the shale is maintained. Furthermore, reduction in shale water content occurs due to osmotic forces, which leads to a strengthening of the shale in the near wellbore region. In contrast, when WBF is used to drill shale, the water moves from the fluid into the water-wet shale. The support of the shale is thus lost and the shale can wash out of the wellbore (Hall 2000).

An important characteristic of OBFs is their high degree of natural lubricity. This is of great importance when drilling deviated and extended-reach wells because drag factors are reduced and consequently so is the risk of the drill pipe becoming stuck. In contrast to WBF, the lack of polarity of the continuous phase of an

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OBF means that the fluids do not react with other potentially troublesome formations, such as salt, gypsum, and anhydrite. Mineral oils also provide stable mud properties over a wide range of temperatures and hole conditions and have corrosion inhibiting properties (Meinhold 1998, Sadiq 2001).

OBF shows poor biodegradability in aerobic conditions and the degradation is extremely slow in anaerobic conditions, which are the typical conditions found within a drill cuttings pile. The initial legislation by the US Environmental Protection Agency (US EPA) on limiting discharge of oil- or diesel-based drilling fluid with cuttings was set at 15% of the total wet weight of cuttings discharged. This has led to a legacy in the Gulf of Mexico, for example, of drill cuttings piles, whose physicochemical properties have not appreciably changed since they were deposited 15–20 years ago, due to slow biodegradation rates (Hall 2000).

The discharge of oil-contaminated cuttings during drilling activity is one of the major contributors to oil industry impacts upon the marine environment. The early focus of efforts to reduce the environmental impacts was centered on reducing the volumes of drilling fluids discharged with the cuttings, as well as the generic toxicity of the base oil itself. By 1985, it became clear that regardless of the inherent levels of toxicity of the base oils, the cuttings piles persisted and continued to pollute for many years due to leaching of chemicals into the ambient environment (Hall 2000).

The US EPA (1999) suggested a product substitution (e.g., SBFs instead of OBFs) as the best way of reducing offshore oil environmental impacts. Furthermore, increasing public concern about environmental protection has led to stringent regulations on the use and disposal of OBFs and associated cuttings. Effluent discharge limitations introduced in some jurisdictions forced operators either to bring spent fluids and cuttings onshore for land-based treatment and disposal or to reinject these wastes into a well. In response, the oil and gas industry developed synthetic-based fluids, such as vegetable esters, olefins, ethers, and others, which provide drilling performance comparable to OBFs, but with far lower environmental and occupational health effects. Compared with OBFs, SBFs have negligible amounts of polyaromatic hydrocarbons (PAHs) and are thus less toxic, have lower bioaccumulation, and faster biodegradation potential. The substitution of SBFs for OBFs as a pollution prevention measure has been complemented by improvements in solid control equipment, such as shale shakers, hydrocyclones, and centrifuges (Anon 1999, Sadiq 2001, Thanyamanta 2003). Improvements to solid control equipment have resulted in lower amounts of contaminants on cuttings after treatment.

During drilling operations the rock cuttings from the well are mixed with the drilling mud and other fluids, such as water and formation oil. Ideally, the cuttings should be separated from the mud and other contaminants so that the cuttings can be discarded and the mud reused. In practice, the mud has to be renewed as its rheological properties break down. Further, limitations in separation treatment technology mean that some of the base fluids, mud particles, and perhaps crude oil are not removed from the cuttings and so become part of the solid waste stream. As a consequence, the drilling waste discharges of concern are spent drilling muds, and rock cuttings to which drilling fluids, mud particles, and formation oil adhere.

Drilling wastes associated with SBFs are less dispersible than WBFs and tend to sink to the seafloor, where they constitute a potential environmental hazard to the benthic community (settling and dispersion characteristics depend in part on the relative amount of adhering fluids). It is believed that environmental impacts include smothering by the drill cuttings, changes in grain size and composition, and anoxia caused by the decomposition of organic matter (US EPA 1999, Sadiq and others 2003). The environmental impacts associated with the zero discharge of OBFs can be more harmful than the discharge of SBFs due to non-water-quality environmental impacts, such as air pollution and groundwater pollution in the case of incineration and land-based disposal, respectively (US EPA 1999). A qualitative comparison of OBFs, WBFs, and SBFs for various offshore/onshore activities is provided in Table 1 The OBFs, WBFs, and SBFs are compared for four major impacts: operations, resources, economics, and liabilities. The operational impacts are categorized into four major activities: drilling, discharging offshore, disposing onshore, and loading and transporting. Each activity involves risks related to occupational injuries (safety), general public health, environmental impacts, and energy use. Further, each risk type is divided into elementary risk factors. The risk factors are ranked on a scale from 0 to 3. A higher value represents a greater risk potential of that activity (or a factor).

The next section will describe a risk-based analytic hierarchy process for decision-making. In the section after that, this method is applied for the selection and evaluation of drilling fluids.

Analytic Hierarchy Process for Multiple-Criteria Decision-Making

Decision-making is an integral part of all management issues and is part of our daily lives. Decision problems are diverse in nature and usually have con-

Table 1. Comparative assessment for drilling fluids [a] (modified after Meinhold 1998)

Impacts	Activity	Risk Type	Risk Factors	OBFs	WBFs	SBFs
Operational impacts	Drilling	Occupational	Accidents	2	3	2
			Chemical exposure	2	1	1
		Public	Air emissions	1	2	1
		Environmental	Air emissions	1	2	1
			Spills	2	1	1
		Energy use		1	2	1
	Offshore discharge/ solids control	Occupational	Accidents	2	1	1
			Chemical exposure	2	1	1
		Public	Bioaccumulation and ingestion	0	1	0
		Environmental	Water column effects	0	1	0
			Bioaccumulation and effect	0	1	0
			Benthic effects	1	1	1
		Energy use		1	1	1
	Loading and transportation	Occupational	Accidents	3	0	1
			Chemical exposure	2	0	1
		Public	Air emissions	1	0	0
			Accidents	1	0	1
		Environmental	Spills	3	0	1
			Water emissions	1	0	0
			Air emissions	2	0	0
		Energy use		2	0	0
	Onshore disposal	Occupational	Accidents	3	0	0
			Chemical exposure	2	0	0
		Public	Air emissions	2	0	0
			Groundwater contamination	1	0	0
		Environmental	Air emissions	2	0	0
			Groundwater contamination	1	0	0
		Energy use		2	0	0
Resource impacts (landfill space/ injection capacity)				2	1	0
Economic impacts (and cost)				3	1	2
Liabilities				3	1	1

[a]0: No risk because this activity is not involved or negligible value of risk is expected.
1: Low value of risk. 2: Medium value of risk. 3: High value of risk.

flicting criteria. In the last 30 years, the literature related to multiple-criteria decision-making (MCDM) in the fields of engineering, business and social sciences has grown enormously. Decision-making is broadly classified into MCDM and MODM (multiple objective decision-making). The MCDM is associated with problems whose alternatives are predefined, and the decision-maker is to select or rank various alternatives. The MODM designs the most promising alternative with respect to limited resources. Hwang and Yoon (1981) have critically reviewed methods and applications of MCDM/MODM for a single decision-maker. For more than one decision-maker, the problem becomes complex and the best solution is the one that will be accepted by all decision-makers. Hwang and Lin (1987) have also discussed group decision-making under multiple criteria.

An analytic hierarchy process (AHP) is the most widely used technique for multiple criteria decision-making. Saaty (1988) originally devised this method. An AHP develops a linear additive model for deriving weights and scores based on pairwise comparisons be-

Table 2. Fundamental scale used for developing priority matrix for AHP (Saaty 1988)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favour one activity over other
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over other
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of highest possible order of affirmation

tween criteria or between options (Ziara and others 2002). Thus for example, in assessing weights the decision-maker is asked a series of questions regarding how important one particular criterion is relative to another for the decision being addressed. At the core of AHP lies a method for converting subjective assessments of relative importance to a set of overall scores or weights. It has proved to be one of the more widely applied MCDM methods, (see e.g., Dey 2002, Golden and others 1989, Sadiq 2001, Saaty 2001). The pairwise comparisons of the attributes at each level in the hierarchy are arranged into a reciprocal matrix (Saaty 1996). The pairwise comparison of the criteria in the AHP method generates a set of matrices of the following form:

$$\hat{A} = (a_{mn}) \tag{1}$$

where $\hat{A}$ is the reciprocal matrix ($a_{\mathrm{mn}} = 1/a_{\mathrm{nm}}$). There are a number of ways to derive the vector of priorities (weights) from matrix $\hat{A}$, but emphasis on consistency of the matrix leads to

$$\hat{A}W = n(W) \tag{2}$$

where n is the number of attributes considered and W is the priority vector = $(w_1, w_2, \ldots, w_n)$. If we do not have a precise value of matrix $\hat{A}$, the problem reduces to

$$\hat{A}W = \lambda_{max}(W) \tag{3}$$

where $\lambda_{\max}$ is the maximum or principal eigenvalue of $\hat{A}$. The solution is obtained by raising the matrix to a sufficiently large power, then summing over the rows and normalizing to obtain the priority vector W. The process is stopped when the difference between the components of the priority vector obtained at the zth power and the (z + 1) power is less than some predefined small value. The vector of priorities is the derived scale associated with the matrix of comparisons. Saaty (2001) recommended an easy way to get an approximation to the priorities by normalizing the geometric means of the rows. The results coincide with the eigenvector for $3 \geq n$. A third method to obtain an approximation is by normalizing the elements in each column of the judgment matrix and then averaging over each row. We used the third method for our example in the next section for its simplicity.

Table 2 summarizes linguistic measures of importance based on pairwise comparisons (Saaty 1988). The scale varies from 1 to 9, where 1 represents equal importance and 9 represents extreme importance of one factor over the other. The fundamental input to the AHP is the decision-maker's answers to a series of questions of the general form: How important is one criterion relative to the other? These are termed pairwise comparisons. Questions of this type may be used to establish within AHP both weights for criteria and performance scores for options on the different criteria.

In AHP applications, this process allows a series of small sets of pairwise comparisons to be undertaken within segments of a value tree and then between sections at a higher level in the hierarchy. In this way, the number of pairwise comparisons to be undertaken does not become too great. In addition to calculating weights for the criteria in this way, full implementation of the AHP also uses pairwise comparisons to establish relative performance scores for each of the options on each criterion. In this case, the series of pairwise questions to be answered asks about the relative importance of the performance of pairs of alternatives in terms of their contribution towards fulfilling each criterion. Responses use the same set of nine index assessments as described before. With weights and scores all computed using the pairwise comparison approach just described, options are then evaluated overall using the simple linear additive model used for MCDM. All options will record a weighted score somewhere in the range of 0–1. The largest value is the preferred option, subject as always to sensitivity testing and

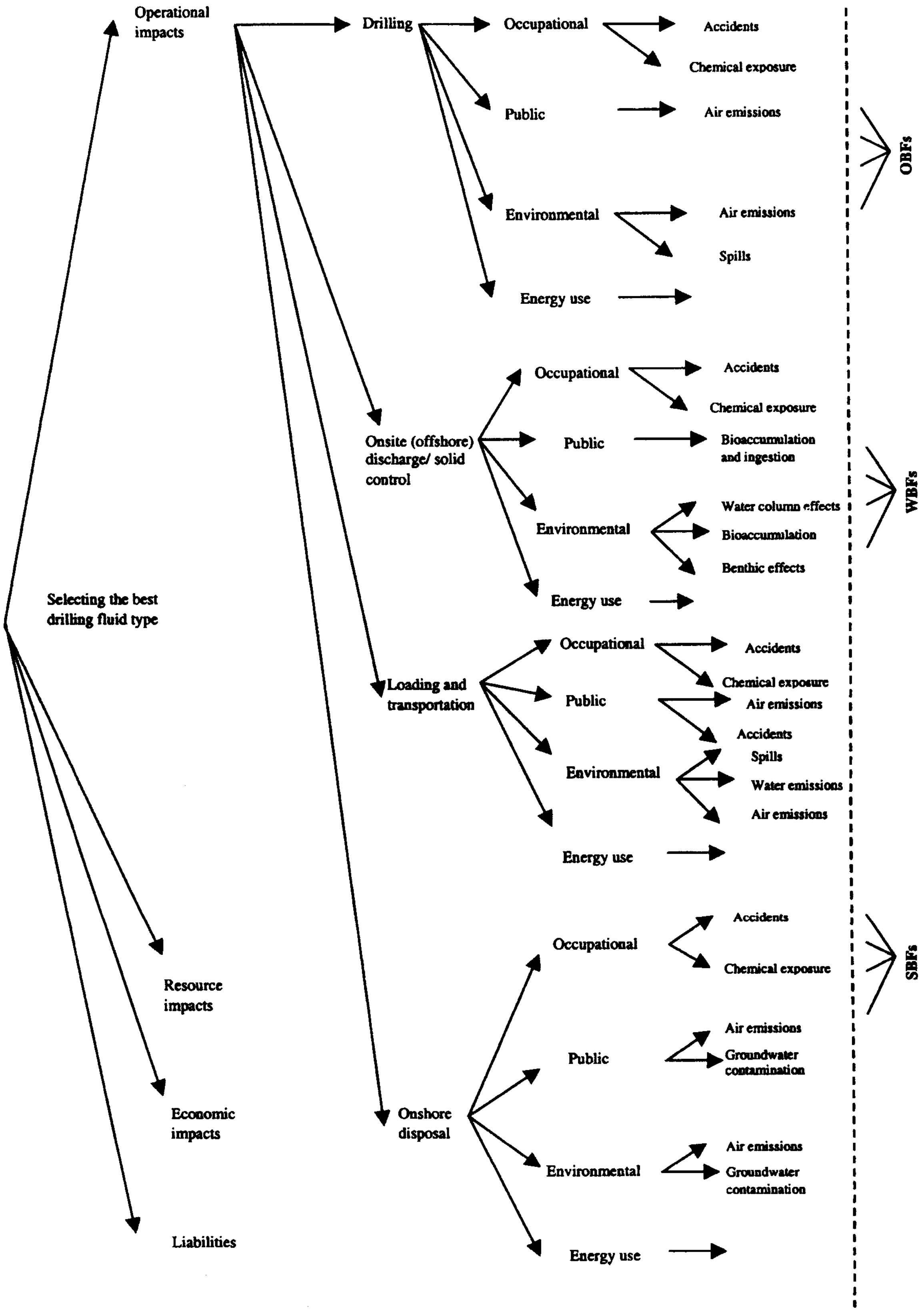

Figure 1. Hierarchical structure for comparison of drilling fluids.

Table 3. Weighting scheme for major impacts

Impacts	Operational	Resource	Economic	Liabilities	$W_1 = GP_1$
Operational	1.00	2.50	2.00	2.00	
Resource	0.40	1.00	1.00	1.00	
Economic	0.50	1.00	1.00	0.50	
Liabilities	0.40	0.50	0.50	1.00	
Normalized Index					
Operational	0.43	0.50	0.44	0.44	0.46
Resource	0.17	0.20	0.22	0.22	0.20
Economic	0.22	0.20	0.22	0.11	0.19
Liabilities	0.17	0.10	0.11	0.22	0.15

Table 4. Weighting scheme for major activities causing operational impacts

Impacts	Drilling	Offshore discharge	Transportation and loading	Onshore (land disposal)	W_2
Drilling	1.00	1.50	2.00	2.50	0.38
Offshore discharge	0.67	1.00	1.50	2.00	0.28
Transportation and loading	0.50	0.67	1.00	1.00	0.18
Onshore (land disposal)	0.40	0.67	1.00	1.00	0.17

$GP_2 = GP_2 \times W_2$

Table 5. Weighting scheme for major risk types involved in operational activities

Risk types	Occupational	Public	Environmental	Energy use	W_3
Occupational	1.00	0.50	1.00	1.50	0.20
Public	2.00	1.00	3.00	4.00	0.48
Environmental	1.00	0.33	1.00	2.00	0.20
Energy use	0.67	0.33	0.50	1.00	0.13

$GP_3 = GP_3 \times W_3$

other context-specific analysis of the ranking produced by the model. The weights are grouped at different hierarchy levels as follows:

$$GP_{j+1} = GP_j \times W_{j+1} \qquad j = 1,2,\ldots,n \tag{4}$$

where GP is the global preference weight, W is the weight estimated through pairwise comparison, and n is the number of hierarchy levels.

The global preference weight represents the contribution to the overall weighting scheme, where W is the local weight estimated from pairwise comparisons and its sum is unity for each comparison.

Evaluation of Drilling Fluids—An Application of AHP

The AHP technique is applied for the performance evaluation and ranking of drilling fluids for decision-making. Figure 1 shows a hierarchical structure of the risks involved in the use of three different types of drilling fluids. The hierarchical model has a four-level structure, in which four major impacts are grouped at the first level. At the second level, four activities related to these operational impacts are grouped. At the third level, the risk types related to various operational activities are grouped and finally, basic risk factors are grouped for different operational risk types.

Table 3 provides a pairwise comparison of impacts related to operations, resources, economics, and liabilities. The pairwise comparisons are made based on linguistic measures of importance suggested by Saaty (1988). The highest importance is assigned to operational impacts, which is 2.5 times more than resource impacts and 2 times more than the impacts of economics and liabilities. After developing matrix $\hat{A}$, the weights (W_1) are calculated for these impacts by normalizing the elements in each column of the judgment matrix and then averaging over each row. The sum of normalized weights is unity. The estimated weights for operations, resources, economics, and liabilities are 0.46, 0.20, 0.19, and 0.15, respectively (Table 3). The sum of weights is equal to unity and is also called the local weight (W_1). At the first level it is equal to the global preference weight (GP_1)

$$GP_1 = W_1 \tag{5}$$

Table 6. Weighting scheme for risk factors of various types (operational activities)[a]

Operational activities	Risk type	Risk factors	W_4
Drilling	Occupational	Accidents	0.67
		Chemical exposure	0.33
	Public	Air emissions	1.00
	Environmental	Air emissions	0.33
		Spills	0.67
	Energy use		1.00
Offshore discharge/solids control	Occupational	Accidents	0.67
		Chemical exposure	0.33
	Public	Bioaccumulation and ingestion	1.00
	Environmental	Water column effects	0.41
		Bioaccumulation and effect	0.22
		Benthic effects	0.37
	Energy use		1.00
Loading and transportation	Occupational	Accidents	0.67
		Chemical exposure	0.33
	Public	Air emissions	0.33
		Accidents	0.67
	Environmental	Spills	0.38
		Water emissions	0.25
		Air emissions	0.37
	Energy use		1.00
Onshore or land disposal	Occupational	Accidents	0.67
		Chemical exposure	0.33
	Public	Air emissions	0.50
		Groundwater contamination	0.50
	Environmental	Air emissions	0.50
		Groundwater contamination	0.50
	Energy use		1.00

[a] $GP_4 = GP_3 \times W_4$

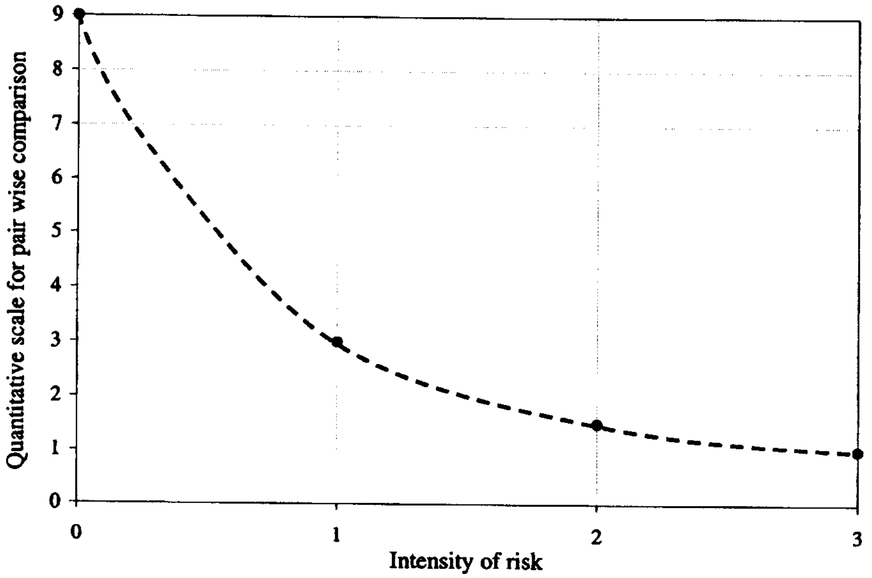

Figure 2. Translation of qualitative risk scale into weights for a pair-wise comparison.

The preference matrix and normalized weights W_2 are provided in Table 4 The operational impacts are caused by four major activities—drilling, discharging offshore, transporting and loading, and disposing on land. The normalized weights for these activities are 0.38, 0.28, 0.18, and 0.17, respectively. At the second

Table 7. Comparing risk factors and assignment of quantitative scales

Risk scale	Definition	Quantitative scale (Figure 2)					
0	No/negligible risk	1.00					
1	Low risk	1.50					
2	Medium risk	3.00					
3	High risk	9.00					
Pairwise comparisons[a]							
0 vs 0	1.00	1 vs 0	0.33	2 vs 0	0.17	3 vs 0	0.11
0 vs 1	3.00	1 vs 1	1.00	2 vs 1	0.50	3 vs 1	0.33
0 vs 2	6.00	1 vs 2	2.00	2 vs 2	1.00	3 vs 2	0.67
0 vs 3	9.00	1 vs 3	3.00	2 vs 3	1.50	3 vs 3	1.00

[a] After estimating quantitative values using Figure 2, the pairwise comparisons are made based on the ratio of two values, e.g., if OBFs have risk level of 2 and WBFs have 3, the comparison 2 Vs 3 will be 1.5 and 3 Vs 2 will be 0.67.

Table 8. Weight matrix (W_5) for three generic types of drilling fluids

Impacts	Activity	Risk type	Factors	OBFs	WBFs	SBFs
Operational impacts	Drilling	Occupational	Accidents	0.38	0.37	0.25
			Chemical exposure	0.20	0.40	0.40
		Public	Air emissions	0.40	0.20	0.40
		Environmental	Air emissions	0.40	0.20	0.40
			Spills	0.20	0.40	0.40
		Energy use		0.40	0.20	0.40
	Offshore discharge/ solids control	Occupational	Accidents	0.20	0.40	0.40
			Chemical exposure	0.20	0.40	0.40
		Public	Bioaccumulation and ingestion	0.43	0.14	0.43
		Environmental	Water column effects	0.43	0.14	0.43
			Bioaccumulation and effect	0.43	0.14	0.43
			Benthic effects	0.33	0.33	0.33
		Energy use		0.33	0.33	0.33
	Loading and transportation	Occupational	Accidents	0.08	0.69	0.23
			Chemical exposure	0.11	0.67	0.22
		Public	Air emissions	0.14	0.43	0.43
			Accidents	0.20	0.60	0.20
		Environmental	Spills	0.08	0.69	0.23
			Water emissions	0.14	0.43	0.43
			Air emissions	0.08	0.46	0.46
		Energy use		0.08	0.46	0.46
	Onshore disposal	Occupational	Accidents	0.06	0.47	0.47
			Chemical exposure	0.08	0.46	0.46
		Public	Air emissions	0.08	0.46	0.46
			Groundwater contamination	0.14	0.43	0.43
		Environmental	Air emissions	0.08	0.46	0.46
			Groundwater contamination	0.14	0.43	0.43
		Energy use		0.08	0.46	0.46
Resource impacts (landfill space/ injection capacity)				0.11	0.22	0.67
Economic impacts (and cost)				0.18	0.55	0.27
Liabilities				0.14	0.43	0.43

level, the global preference weights can be estimated by

$$GP_2 = GP_1 \times W_2 \tag{6}$$

Table 5 summarizes the preference matrix for major risk types involved in all operational activities. The normalized weights W_3 are estimated as 0.20, 0.48, 0.20, and 0.13 for occupational, public health, environmental, and energy use, respectively. The global preference

Table 9. Selection and evaluation of drilling fluids—final analysis

							OBFs		WBFs		SBFs	
W_1	W_2	GP_2	W_3	GP_3	W_4	GP_4	W_5	GP_5	W_5	GP_5	W_5	GP_5
0.46	0.38	0.17	0.20	0.03	0.67	0.023	0.38	0.009	0.25	0.006	0.37	0.009
					0.33	0.012	0.20	0.002	0.40	0.005	0.40	0.005
			0.48	0.08	1.00	0.084	0.40	0.034	0.20	0.017	0.40	0.034
			0.20	0.03	0.33	0.012	0.40	0.005	0.20	0.002	0.40	0.005
					0.67	0.023	0.20	0.005	0.40	0.009	0.40	0.009
			0.12	0.02	1.00	0.021	0.40	0.008	0.20	0.004	0.40	0.008
	0.28	0.13	0.20	0.03	0.67	0.017	0.20	0.003	0.40	0.007	0.40	0.007
					0.33	0.009	0.20	0.002	0.40	0.003	0.40	0.003
			0.48	0.06	1.00	0.062	0.43	0.027	0.14	0.009	0.43	0.027
			0.20	0.03	0.41	0.010	0.43	0.005	0.14	0.001	0.43	0.005
					0.22	0.006	0.43	0.002	0.14	0.001	0.43	0.002
					0.37	0.010	0.33	0.003	0.33	0.003	0.33	0.003
			0.12	0.02	1.00	0.015	0.33	0.005	0.33	0.005	0.33	0.005
	0.18	0.08	0.20	0.02	0.67	0.011	0.08	0.001	0.69	0.008	0.23	0.003
					0.33	0.005	0.11	0.001	0.66	0.004	0.22	0.001
			0.48	0.04	0.33	0.013	0.14	0.002	0.43	0.006	0.43	0.006
					0.67	0.026	0.20	0.005	0.60	0.016	0.20	0.005
			0.20	0.02	0.38	0.006	0.08	0.000	0.69	0.004	0.23	0.001
					0.25	0.004	0.14	0.001	0.43	0.002	0.43	0.002
					0.37	0.006	0.08	0.000	0.46	0.003	0.46	0.003
			0.12	0.01	1.00	0.010	0.08	0.001	0.46	0.005	0.46	0.005
	0.17	0.08	0.20	0.02	0.67	0.010	0.05	0.001	0.47	0.005	0.47	0.005
					0.33	0.005	0.08	0.000	0.46	0.002	0.46	0.002
			0.48	0.04	0.50	0.019	0.08	0.002	0.46	0.009	0.46	0.009
					0.50	0.019	0.14	0.003	0.43	0.008	0.43	0.008
			0.20	0.02	0.50	0.008	0.08	0.001	0.46	0.004	0.46	0.004
					0.50	0.008	0.14	0.001	0.43	0.003	0.43	0.003
			0.12	0.01	1.00	0.009	0.08	0.001	0.46	0.004	0.46	0.004
0.20	1.00	0.20	1.00	0.20	1.00	0.20	0.11	0.022	0.22	0.044	0.67	0.134
0.19	1.00	0.19	1.00	0.19	1.00	0.19	0.18	0.034	0.55	0.105	0.27	0.051
0.15	1.00	0.15	1.00	0.15	1.00	0.15	0.18	0.027	0.55	0.083	0.27	0.041
Sum =								0.211		0.385		0.408
Rank =								3		2		1

$GP_5 = GP_4 \times W_5$

weights can be estimated by

$$GP_3 = GP_2 \times W_3 \tag{7}$$

Table 6 summarizes the preference matrix for basic risk factors. In each risk type, the basic risk factors are weighted. For example, in drilling-related occupational risk, accidents, and chemical exposure (toxicity related) are grouped. Similarly, for environmental risk, air emissions and spills are grouped. The normalized weights W_4 are estimated and provided in Table 6 The global preference weights can be estimated by

$$GP_4 = GP_3 \times W_4 \tag{8}$$

The final step in AHP is to rate the lowest level item (basic risk factor) corresponding to available options—OBFs, WBFs, and SBFs. Table 1 is used to define the preference matrix for this purpose. Figure 2 is used to translate the intensity of risk (Table 1) into preference weights using an exponential function. Table 7 is then used for making pairwise comparisons. For example, if the risk values are 2, 3, and 2 for OBFs, WBFs, and SBFs, respectively (see Table 1), for accidents related to occupational activities during drilling, the preference matrix and the weights (W_5) will be

$$\begin{array}{r} \text{OBFs} = \\ \text{WBFs} = \\ \text{SBFs} = \end{array} \left| \begin{array}{ccc} 1 & 1.5 & 1 \\ 0.67 & 1 & 0.67 \\ 1 & 1.5 & 1 \end{array} \right| = \left| \begin{array}{ccc} 0.38 & 0.38 & 0.37 \\ 0.25 & 0.25 & 0.25 \\ 0.38 & 0.37 & 0.37 \end{array} \right| \Rightarrow \begin{array}{c} 0.38 \\ 0.25 \\ 0.37 \end{array} \tag{9}$$

Now the final global preference weights can be estimated by

$$GP_5 = GP_4 \times W_5 \tag{10}$$

The final AHP score can be estimated by adding GP_5 under each option

$$\text{Final score} = \sum \text{GP}_5 \qquad (11)$$

The option with the highest score is ranked the best. The final scores for OBFs, WBFs, and SBFs are 0.211, 0.385, and 0.408, respectively (see Tables 8 and 9). Under the assumptions made here for the weights, etc., the SBFs are the most desirable option, followed by WBFs and OBFs.

Summary and Conclusions

The analytic hierarchy process is a promising approach for decision-making. It is designed to select the best alternative among a number of options available on a rational and intuitive basis. In an AHP, a decision-maker carries out a pairwise comparison judgment, which is used to rank the alternatives.

This technique was applied here to the selection and evaluation of three generic types of drilling fluids. A four-level hierarchical structure model was developed for multicriteria decision-making. At the first level, the structure was divided into four major impacts—operations, offshore discharges, loading and transporting, and onshore disposal. The local weights W_1 (in the normalized form) were estimated using pairwise comparisons. The local weights were then converted into global preference weights, which represent the contribution to the overall decision tree. The grouping procedure was repeated at different levels to estimate the global weights GP_i from normalized weights W_2, W_3, and W_4. The final step in AHP was to determine the weights for the lowest level items (basic risk factors, W_5) with respect to available options—OBFs, WBFs, and SBFs. The global preference weights GP_5 were estimated by multiplying GP_4 with local weights of basic risk factors W_5. The alternatives were ranked based on the score estimated by summation of final global preference weights. The final scores for OBFs, WBFs, and SBFs were 0.211, 0.385, and 0.408, respectively. Under the assumptions made here in assembling the inputs, the SBFs were found to be the most desirable option, followed by WBFs and OBFs.

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