APPLICATION OF ANALYTIC HIERARCHY PROCESS IN UPSTREAM RISK ASSESSMENT AND PROJECT EVALUATIONS

A Thesis

by

FREDDY MOTA-SANCHEZ

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Petroleum Engineering

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Approved by:

Chair of Committee, W. John Lee
Committee Members, Duane McVay
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ABSTRACT

Application of Analytic Hierarchy Process in Upstream Risk Assessment and Project Evaluations. (August 2007)

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This report adapts the application of a methodology known as Analytic Hierarchy Process (AHP) to upstream Exploration & Production (E&P) project evaluations for the oil and gas industry. The method can be used to simplify the process of decision making, specifically when several parameters or variables—mostly uncertainties or risk variables—are being considered for different investment options. This method has been used in a large number of applications in several research areas where evaluation and decision making is a key issue. It simplifies the considerations that the evaluators must be aware of to assign probability or certainty factors to the parameters by using a relative intensity scale.

We apply the method to the quantification of the risk involved in typical upstream projects. Although a decision as large as investment in oil and gas projects can not be based solely on risk factors, it is true that the risk attitude of the investor will ultimately play a significant role. This method gathers all the possible factors that can affect a project at any stage and provides the user with a single number; it condenses all the considerations and preferences of the investor or decision maker and ranks the investment alternatives from a risk point of view.

A typical problem confronted with E&P project assessment (as well as in many other industries) is that the criteria selected may be measured on different scales, such as dollar value, stock-tank barrels, standard cubic feet, units of area, and so on. Some might even be intangible for which no scales exist, such as financial environment, management

problems, or social unsteadiness. Measures on different scales, obviously, can not be directly combined, and this is part of what makes an integral assessment of any project such a difficulty. It is up to the decision maker to put all these evaluations—which may be still in different or subjective scales—on an overall comparative basis. This is where the AHP becomes useful, by gathering criteria of different natures and dimensions, and putting them all together on a single scale, which is derived from the decisions maker's preferences and risk attitude.

To my parents: mom, dad and seño. Without your guidance, love, prayers and constant support, I would have not made it this far.

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Special thanks to Dr. Thomas Saaty, for his orientation, crucial for the fundamental application of this method and its potential uses. Hopefully it has opened another door for the application of his method, which will add to the currently vast uses that the AHP has found in different industries and disciplines.

Thanks to Dr. John Lee, for encouraging me to further look into this research topic and developing it much more than I expected, foreseeing that it can become a useful tool for the evaluation of projects in the oil and gas industry.

NOMENCLATURE

AHP: Analytic Hierarchy Process.

CR: Consistency Ratio.

E&P: Exploration and Production.

EOR: Enhanced oil recovery methods.

HCI: Harmonic Consistency Index.

HRI: Harmonic Random Index.

NPV: Net Present Value.

O&G: Oil and Gas.

OGIP: Original gas in place.

OOIP: Original oil in place.

P50: Proved + Probable reserves.

SEC: United States Security Exchange Commission.

SPE: Society of Petroleum Engineers.

WPC: World Petroleum Council.

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INTRODUCTION

As introduced by Zopounidis and Doumpos[1], Multi Criteria Decision Analysis is an evolving discipline during the past three decades. This is because a single objective or criterion can rarely be the sole basis of real world decisions. Several mathematical and operations research efforts have ended up in many usable frameworks that are applied in finance, mainly seeking the maximization of profits.

The importance and effect of factors not directly related to exploration and production (E&P) projects have increasingly shown the need for them to be considered in all the phases of any given project. Project economics and technical issues are no longer isolated or independent from environmental, social and geopolitical risk factors.

Traditional project evaluations and economic analyses perform well as evaluation tools if the problem is well stated, and if there is a single evaluation criterion. However, in reality, the modeling of financial problems is based on a different logic, which must take into consideration:

- Existence of multiple criteria for the selection.
- Existence of conflicting situations within these multiple criteria.
- The subjectivity of the evaluation process (such as probabilities).
- Uncertainty factors that have to be considered and that could drastically change the outcome of an investment.

One of the main concerns at the time of making E&P project evaluations is that there should be proper unbiased consideration given to the probability parameters, ultimately providing the required numbers on which the final decisions are based. A typical example is the probabilities assigned to important petrophysical and geological data, which yield the estimated resources in place.

This thesis follows the style of the SPE Journal.

These numbers are often assigned by estimators, based on their experience and judgment. Nevertheless, it still is one of the crucial sources of uncertainties in the appraisal of new discoveries, since original oil in place (OOIP) or original gas in place (OGIP) will be one of the key parameters used to estimate profitability of any project.

The origins of the AHP Theory

The AHP has its principle in a methodology developed in the late 1970s by Thomas Saaty, a professor at the University of Pittsburg. Since then, an increasing number of applications of the methodology are found, mostly in recent years. AHP has been widely used in studies and literature publications of household population forecasts, Pareto-optimal solutions for selecting automation options, setting of priorities and options for projects in the electric utility industry, federal government, medicine, politics and the most important and recognized application: business.

Several specialized journals have also published many articles dedicated to the approach of problems through the AHP in areas like Socio-Economic Planning Sciences, Mathematical Modeling and Operations Research, among others. The use and application of the AHP as a decision making tool for the oil and gas industry is very recent and not very widespread. Only the brief but helpful explanations of Chang *et al.*[2], and reservoir planning applications of Gerbacia and Al-Shammari[3] have been put into working models that aid the decision making process at different scales and levels of importance.

The AHP method combines quantitative and qualitative factors and classifies each into hierarchies. It derives dominance priorities from paired comparisons of homogeneous elements, considered to be under a common criterion or attribute. Non-homogeneous elements can also be clustered in order to extend the technique. Applications of AHP have included parallel hierarchies (for both benefits and costs) and solitary hierarchies (for projecting and planning resource allocation).

Objective

The main goal of this project is to identify how to apply the AHP to upstream E&P investments, in order to present a new way to quantitatively estimate and assess the different types and shades of risk associated with such projects. We will achieve this by developing the following sub-objectives:

- Explain how the AHP works.
- Establish a working procedure based on the risk hierarchy presented by Chang *et al.*[2] for upstream investments.
- Expand the applications of the methodology, by integrating the input of different decision makers, and explaining how to achieve good results with different estimates (non-consensual group decisions).
- Demonstrate the applicability of the method through a case study and calculate values that represent the risk level of hypothetical investment alternatives.

Importance

This methodology can lead us to a more direct, simple and less subjective method of identifying risks associated with upstream projects, with the further advantage of actually quantifying the risk, making it much easier to compare and rank the different alternatives.

Above all, the method can be used as a portfolio analysis tool for decision makers to rank and select the best investment among a set of alternatives. It allows projects that may underperform in some categories to be compensated by their better performance in other related risk criteria.

Elements that usually affect the upstream decision-making process are so widespread and come in so many forms and varieties, that they cannot be considered simultaneously thorough the use of a single scale. It would be extremely difficult for a decision maker to evaluate different aspects simultaneously, like OOIP, with more subjective criterion, such as environmental conditions or political scenarios from the investment alternatives, and base all on a single comparison scale (e.g. U.S. dollars). Furthermore, the assignment of absolute probabilities to such events can become a difficult task, even for a multidisciplinary evaluation team of experts.

Within the AHP method, the decision maker can rely on good judgment and experts' preferences of certain events over others, making relative-scaled comparisons at all levels of the hierarchies of the different elements involved (pairwise comparisons). This reduces uncertainty, while comparing two or more investment options, as the method will yield proper ranking results for the best opportunity to be taken. This is based on the opinion and criteria of the evaluator, but without requiring that the conductors define absolute probabilities for the affecting factors.

HOW DOES THE AHP WORK?

The AHP enables the user to expedite its natural decision making process by breaking down complex unstructured situations into their component parts, arranging these parts or variables into a hierarchic structure of variables—a working framework—from which it is clearer how the interaction or interdependence between them can affect the optimal decision for a given project.

Setting up the hierarchies

When solving any kind of complex problem or situation, the most logical way to begin to analyze it is by breaking it up into smaller, more manageable parts; but doing it in such a way that a general order is kept, from which the "big picture" can still be seen. By breaking up large complex elements, structuring their elements hierarchically and analyzing their components, judgments can be made that will conform to the general answer or proper solution to the proposed problem.

As Saaty[4-12] stated, the hierarchies must interconnect one to another, clustering those elements which have similar magnitudes and effects on our whole case. The approaches taken on how to constitute the hierarchies will depend of the type of decision to be made. For the case of upstream projects (with different characteristics), the analysis begins by listing the alternatives (projects); for each project, a comparative evaluation is performed. The next step takes us to a general comparison among the criteria used for judging the alternatives listed. Each of these criteria may have sub criteria, and so on, so each of these sub levels is broken into its respective sub criteria. The top level of this structure is represented by the objective of the analysis which, in this case, is to select the best project alternative.

The objective of the analysis is to grade the projects risk wise. The approach uses a hierarchy structure as a base framework, which can be seen in **Fig. 1.** This hierarchy modifies the work of Chang *et al.*[2], and divides the risk assessment of a project into three main areas of concerns for the investor:

- Social and economical environment of the location.
- Natural environment risks.
- Resource, management and technological risks.

The structure we present is completely flexible and may be modified and adapted to fit user needs. It is possible to add or remove some risk factors, depending on what types of risk characterize the projects or what drives the company risk attitude, and the knowledge that the user may have about them, without necessarily complicating the analysis.

Users may sometimes want to discard, unconsciously, some of the risks herein proposed at the beginning of their assessments, with the purpose to ease or reduce the extent of the evaluation process, or just because they do not have the proper knowledge of the related area, believing that many of these factors will not impact the development of a project. However, this is precisely what should be avoided. The decision maker should be encouraged to initially take into consideration all possible risks. Later, during the run and calibration of the model, a more accurate view of the general risk aversion of the company can be obtained, and some of these risk factors can be effectively discarded, once their individual weights or effects on the overall goal has been determined to be negligible.

It is important to identify and briefly define the typical risk factors that are being considered, the basis for their consideration, and why they ought to be taken into account for every assessment. Some of them are explicit by themselves (**Tables 1 through 3**).

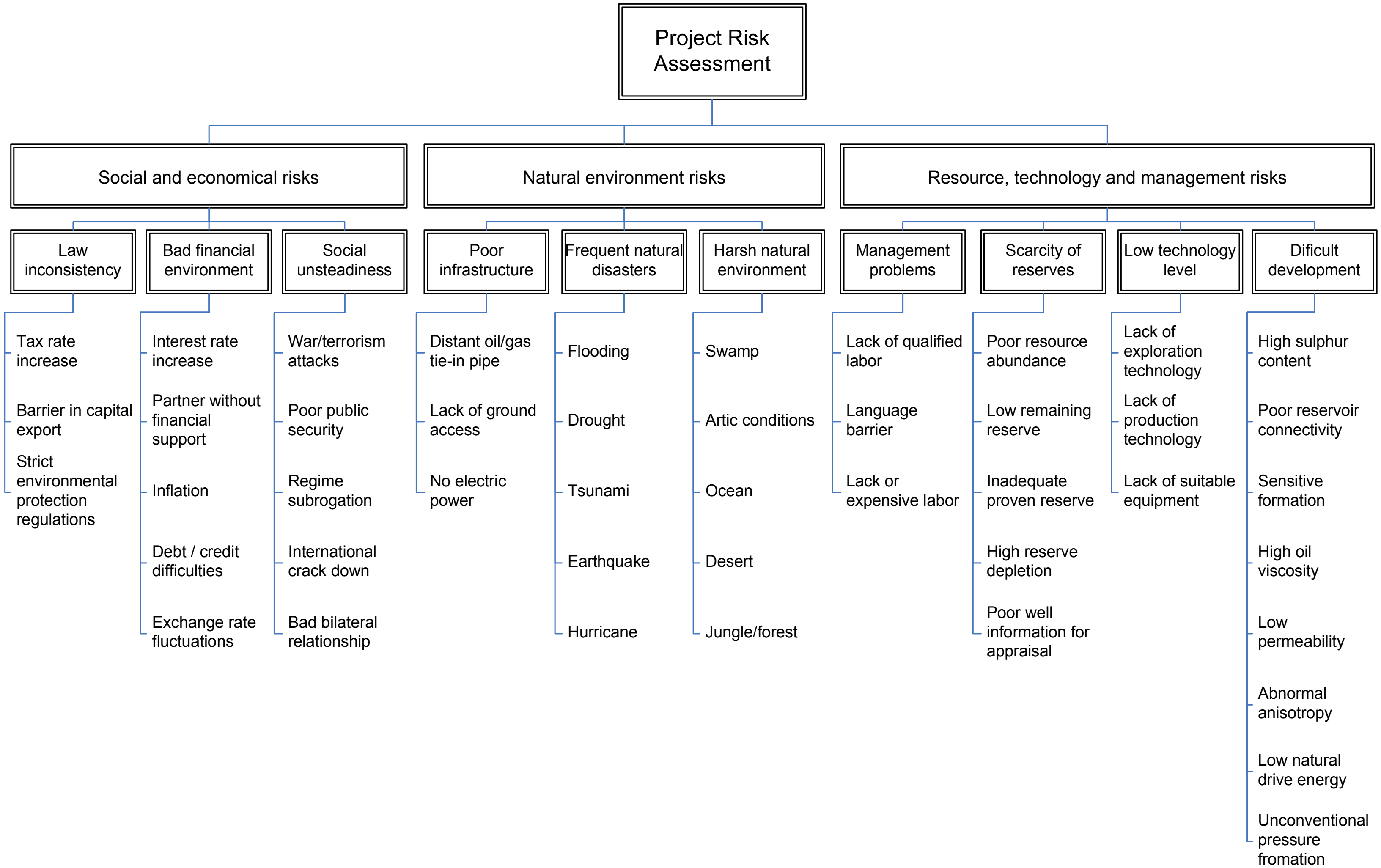

Figure 1—Proposed risk hierarchy to be used in this analysis

Modified after Chang *et al.* (2)

Table 1—Resource, technology and management risk factor description

Resource, technology and management risks	Management problems	Lack of qualified labor	Required amount of workforce is available but lacks adequate technical qualifications
		Language barrier	Makes smooth operations difficult or impossible
		Lack or expensive labor	Required workforce is technically capable but is either highly expensive or scarce
	Scarcity of reserves	Poor resource abundance	Preliminary information suggests small resource potential, which could imply small proved + probable (P50) reserves
		Low remaining reserve	The amount of effective proved reserves in not large enough to justify the investment by itself. Reserves could be increased through EOR methods
		Inadequately proven reserves	Calculation techniques and definitions used are different from those established by SEC or SPE/WPC, so availabe estimates could be misleading
		High reserve depletion	Previous production on same or nearby fields have depleted the reserves EOR and perhaps well stimulation techniques will be necessary to achieve commercial production levels
		Poor well information for appraisal	Currently available well/field data is insufficient to determine the real potential of the resource accurately
	Low technology level	Lack of production technology	The required technology to develop and produce from the prospect is either non-existent or out of economical reach for the investor. This can include ultra-deep reservoirs
		Lack of exploration technology	The required technology to carry out further detailed analyses (seismics, test wells, core sampling, etc) on the prospect is either non-existent or out of economical reach for the investor.
		Lack of suitable equipment	The required equipment to carry on exploration, drilling or production activities for the prospect are either scarce (like available rigs) or out of economical reach for the investor
	Difficult development	High sulphur contents	The presence of sulphur in the petroleum would require the use of more expensive materials on piping and equipment
		Poor reservoir connectivity	Poor connectivity could make field development more difficult
		High oil viscosity	Fluid flow through the reservoir rock will become more difficult, decreasing the recovery factor from the wells
		Sensitive formation	Some reservoirs with certain types of clays or carbonates (for example), can react adversely to water contact, producing adverse effects in production performance
		Low permeability	Low rock permeability increases the difficulty of high (commercial) production rates while also reducing drainage area. This characteristic is typical of unconventional reservoirs
		Abnormal anisotropy	Non-homogeneous characteristics/properties of the reservoir rock, can create misleading information in seismic interpretation, making it more difficult to properly interpret the data gathered
		Low natural drive energy	With this factor present, the potential need for artificial lift or well stimulation methods increases
		Unconventional pressure formation	Represents a problem specifically during the drilling phase, where the risks of blowouts, and formation damage (fractures) may be present if overpressured, while underpressured formations can have drilling fluid invasion into the rock, losing returns and generating skin damage

Most of the Development criteria shown in Table 1 are ultimately related to the recovery factor that can be expected from any given prospect. As mentioned before, this proposed hierarchy is totally flexible, and in cases where other relevant information — such as recovery factor—can be found readily, they should be included or even replace any of the criteria in the proposed hierarchy. Our intention is not to provide a rigid structure to follow, but to present the reader with the ideas of how this method can be focused for the specific requirements of E&P risk assessment.

Table 2—Social and economic risk factor description

Social and economic risks	Bad financial environment	Interest rate increase	Interest rates applied to debit and loans from which the cost structure of the project was developed
		Partner without financial support	Some countries require mixed participations to approve foreign investments. This case would represent the possibility of facing higher cost in capital interest rates from funding entities.
		Inflation	The effects of changing inflation on operating expenditures, would distort the forecasted cash flows
		Debt/credit difficulties	Refers to the economic rating of the investing company, which could increase the cost of capital and limit the availability of investment funds
		Exchange rate fluctuations	Can create variability in reported incomes and cash flows.
	Law inconsistency	Tax rate increase	Changing conditions in law or established agreements/contracts, such as royalties and income taxes
		Barrier in capital export	Impossibility of acquiring foreign currency from the local market, due to currency exchange controls or other economic policies set by the host government.
		Strict environment protection regulations	More stringent requirements could represent need for additional processes and equipment that would increase the necessary investments.
	Social unsteadiness	War/terrorism attacks	The possibility that any of these actions could destabilize a government, its population or threaten the integrity of the facilities, ultimately disrupting production
		Poor public security	This includes the effect off illegal tapping on pipelines, vandalism and possibility of racial conflicts among different groups of the country.
		Regimen subrogation	Forced acceptance of changed working conditions and previously established agreements, impossed by the government of the host country on the operating company
		International crack down	The effects of a regional market collapse or events that affect the general situation of the host country. The more solid the economy and government of a country, the better the chances of withstanding their effects
		Bad bilateral relationship	Refers to possible conflicts between the host country and the country of origin of the investing company

Table 3—Natural environment risk factor description

<table>
<tr><td rowspan="13">Natural environment risks</td><td rowspan="5">Harsh surroundings and natural environment</td><td>Swamp</td><td>Difficulty of access to the area</td></tr>
<tr><td>Arctic conditions</td><td>Difficult access affecting operating conditions and living environment for the operators</td></tr>
<tr><td>Ocean/costal conditions</td><td>Implies additional material specifications for the piping, structural steel and mechanical equipment, in addition to the possibility of requiring offshore facilities</td></tr>
<tr><td>Desert</td><td>Lack of water needed for drilling operations</td></tr>
<tr><td>Jungle/forest</td><td>Difficulty of access to the area</td></tr>
<tr><td rowspan="5">Frequent natural disasters</td><td>Flooding</td><td rowspan="5">Facing any of these events can disrupt operations in one way or another. High likelihood of some of them (like hurricanes or earthquakes) can also increase facility insurance costs and design requirements</td></tr>
<tr><td>Drought</td></tr>
<tr><td>Tsunami</td></tr>
<tr><td>Earthquake</td></tr>
<tr><td>Hurricane</td></tr>
<tr><td rowspan="3">Poor infrastructure</td><td>Faraway oil/gas tie-in pipe</td><td>Would represent the need to install dedicated pipeline in order to have access to markets, shipping ports, distribution centers and/or refineries</td></tr>
<tr><td>Lack of ground access</td><td>In harsh natural environments, this would represent the need to create such infrastructures.</td></tr>
<tr><td>No electric power</td><td>Implies the need to self-generate power to support operations if no electrical distribution grid is nearby.</td></tr>
</table>

By considering such a wide variety of possible risk factors, the AHP becomes a very useful tool for risk evaluation of portfolio balancing decisions. It allows projects that may underperform in some category, such as daily production due to low permeability or low reserves estimates, to be compensated by its better performance on other related risk criteria, such as availability of infrastructure (water, roads, etc.) or less stringent environmental regulations.

The use of scale for typically non-scaled variables

Even the most experienced decision maker can be have trouble coping with potential problems, which are not explained by linear cause and effect, but which are rather driven by complicated unmeasured interactions with other variables.

Science usually deals with issues that can be observed through our physical senses, and thus measured. But if a situation calls for dealing with ideas, rather than direct sense perceptions, the quantification of variables can become subjective as only words —from which meanings are imprecise—are mostly used. This is the point where variables arising from complex interactions among social, political and economical systems can be misjudged at the time of decision making.

Appropriately chosen numbers can represent perceptions and feelings from variables and events more objectively than words or rhetoric, leaving less chance of misunderstandings among the different individuals involved (who may comprise a decision making team), and thus less room for gray areas.

Numbers are used to some extent to reflect perceptions related to political, social, and economical matters. Typical scales of time, length, temperature, and money may represent many of the variables taken into consideration for a decision process. But what happens when we look at the same time into all these variables with different scales? The main challenge is to know how important could be, for instance in a given project, the impact of *x* percentage of royalties that are to be paid to a government, in contrast with the likelihood of natural disasters in the area of the development, possibilities of war or terrorists attacks, proper abundance of prospects' resources, or even the oil viscosity and permeability of the reservoir rock. It can be seen that there is not a single scale that could cover as many variables as decision makers confront, in typical scenarios of exploration and production projects.

A risk will be a risk only if the user perceives it as such and, in any case, the importance or quality that a person can assign a given risk, is not necessarily the same for another. Through AHP, the user is capable of devising a scale that enables him/her to measure intangible qualities, applying dimensionless scales to uncertainties where measures do not necessarily exist.

By use of relative scales, taken from experienced people, the decision-making framework can be shifted from a situation of high uncertainty, into another of measurable risk. Where a typical alternative can involve multiple input conditions, AHP can be used to combine such multiple criteria into a single measure.

It may be very difficult to estimate intensities, probabilities or chances of success of one event over another on an absolute basis, but it is certainly possible to compare among the available alternatives, and rank which one is better than the other and by how much.

Relative scales can be used to derive relative rankings. These relative values cannot be seen as indicators of high or low probabilities, but mainly to indicate ranking among other choices. When we compare the different project proposals, we can determine with high certainty, based on the relative comparison approach, which project would represent the highest—and lowest—risk[13]. Relative scales can also use information from standard scales by transforming measurements into a relative ratio through a normalization process. Relative scales are the best way to represent subjective understanding, related to intangible properties or characteristics.

Saaty[4-12] developed a 1 to 9 scale which is the basis of what is known as a pairwise comparison (**Table 4**). A pairwise comparison is a direct one-on-one comparison between two different elements. The 1 to 9 scale is used to quantify how much better (or worse) one element is than another. According to Saaty[11], studies have confirmed that the human brain is well adapted to discriminate intensities, initially into three basic levels: low, medium and high; and that subsequent discrimination within each of these ranks can also be well sorted into low, medium and high values. Thus, we have an appreciation scale of 3 times 3, which yields the 9-value basis used for the AHP process. This scale is used to compare each element at the same level and its contribution to the parent level.

Table 4—Pairwise comparison scale presented by Saaty

Intensity of importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the parent property or criterion
3	Weak importance of one element over the other	Experience and judgment slightly favors one element over the other
5	Essential or strong importance of one element over the other	Experience and judgment strongly favors one element over the other
7	Demonstrated importance of one element over the other	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over the other	Evidence that favors one element over the other is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgements	When some compromise is needed between judgements
Reciprocals	If *i* has one of the preceding numbers assigned to it when compared with *j,* then *j* must have the reciprocal value when compared to *i* in order to be consistent	

It is much easier for any decision maker involved in an analysis to estimate a reasonable value to weigh each of the factors concerned, using a subjective comparison. Given this approach for many factors of a single project, a judgment matrix can be built according to the relative importance of the elements in the same hierarchy. In the case of E&P investments, many different factors should be clustered around different hierarchies. Social-political characteristics, geologic and engineering features and economical factors would be the most important areas to analyze.

Absolute rating and dependency of alternatives

There is an important consideration related to the type of comparison that can be made among the available alternatives. One could pairwise compare each of the alternatives to a “hypothetical” option, which could be used as a fixed point (like measuring a length with a yardstick). This is called absolute measurement and is done in reference to an ideal option. This kind of comparison is used when the alternatives are expected to be independent of one another. It is a useful variant of the scaling process, which can give the AHP the capability of assisting decisions related to planning, forecasting and tracing of future corporate policies.

However, although the type of alternatives presented in the E&P industry initially seem to be independent, there would be a change in preference if, while having a given set of alternatives, suddenly one is replaced with a much better or worse option. Then the preferences for the remaining choices are expected to shift, making the previous ranking invalid. In other words, if an option that would not normally seem to be very a good alternative is compared with much worse options, then it could become the best among that group; but, if any of those are replaced by a far better alternative, then the preferences are once again displaced.

When alternatives are compared in pairs, they become structurally dependent. In such a case anything can happen to their priorities or their ranks when new ones are added. Therefore, if there is any change in the perception about the feeling of a given investment alternative (perhaps because of an improvement in certain conditions), then the model should be rerun, focusing on those judgments that concern the new or changed alternative. An iteration process can be also beneficial, acting as a sensitivity analysis, by allowing further refining of those judgments whose consistency may be low.

The AHP and consistency of judgments

One of the most critical issues (if not the most) required to develop a properly working model, is the consistency of the judgments made by the decision makers, which will be used as an input for the assessment.

The original calculation method that AHP uses is based on the calculation of eigenvectors and eigenvalues of the comparison matrices. The principal right eigenvector represents the weights of the different elements considered in the matrix. The calculation of this function can be cumbersome and lengthy in many cases, especially when dealing with large matrices.

An alternative calculation method, initially presented by Saaty, and called additive normalization[14], is far simpler to perform. By performing simple column normalization procedures and arithmetic means on the rows, a good approximation to the principal right eigenvector can be found. This requires that the judgments used as an input have a minimum degree of consistency. We will elaborate on this alternative method in further sections; to this point, the main concern should be to provide the model with proper and consistent data. As mentioned before, a high level of inconsistency would make the method useless, since it would be more of a random guess than an informed judgment.

Inconsistency can be explained in the following way: if risk A is twice as important as risk B (i.e., $A=2B$), and risk B is three times more important as risk C (i.e., $B=3C$), then in a fully consistent system, $A=6C$; the greater the deviation from this value, the greater the inconsistency. While this may sound obvious, behavioral studies that Saaty[11] referenced show that the brain has some tendency to inconsistency, making them look sometimes more like random guesses, than the judgments. In fact, as new experiences are incorporated into our daily lives, previously established relationships may change, while some consistency is lost. This is necessary up to some point, to integrate new ideas to our lives, which will tend to cause us to rearrange some of our old preferences.

But a high degree of inconsistency also reflects either a lack of experience or concentration at the time of performing the judgments. This can become especially true, when the number of items to be compared in a single matrix is large, it is suggested not to compare more than 9 elements in any given matrix; otherwise, we can expect higher inconsistency and more random values. Randomization must be avoided in the AHP; for such cases, other statistical methods that can deal effectively with randomization (such as Monte Carlo simulation) should be used.

Saaty[4-12] proposed the calculation of a consistency index to ultimately obtain a consistency ratio which, by rule of thumb, should not yield a value higher than 0.1 or 10%. Otherwise we risk falling out of the consistency area, and the simplified additive normalization method would yield misleading results of the calculated weights or priorities. This index is obtained from mathematical relations between a fully consistent eigenvalue (equal to the number of *n* elements being compared) with the actual eigenvector of the matrix in question.

Stein[14] proposed a more rapid computational method, based on the harmonic mean function, called the harmonic consistency index. This is the method we use in this study to reduce and simplify the calculations of such ratios when running the model in a spreadsheet.

The first step is to calculate the mentioned harmonic consistency index from Eq. 1:

$$HCI = \frac{[HM(s) - n](n+1)}{n(n-1)} \qquad \text{..................................... (1)}$$

where:

n= number of elements (from an n x n matrix)

s= sum of all the elements in each column, being s=(s1,…,sn)

HM(s)= harmonic mean of the elements within s

Having obtained the harmonic consistency index, we compare this value with the consistency that could have been obtained from using pure random judgments, called a harmonic random index. The random values are shown in **Table 5**.

Table 5—Random consistency index (from Stein[14])

Harmonic Random Index										
Number of elements [n]	1	2	3	4	5	6	7	8	9	10
HRI	0.000	0.000	0.550	0.859	1.061	1.205	1.310	1.381	1.437	1.484

These numbers are the result of the random simulation of 500 matrices, inputting random numbers within the 1 to 9 scale.

After having the *HCI* and the *HRI*, we then proceed to calculate the consistency ratio *CR = HCI/HRI*; this will yield a value that should be less or equal than 0.1 if the judgments were consistent.

This verification process will allow the analyst to know if the decision makers' answers—used as an input—are acceptably consistent or not, thus validating the results. Should the index fall far from the 10% recommended value, a revision of the particular set of answers for that matrix must be performed with the decision maker, by asking the person to carefully reconsider the answers given, without considering the previous set of results (i.e., a new run).

Prioritization and synthesis

We now present a simple example to explain how priorities are synthesized from the judgments performed in the pairwise comparisons.

Let us consider a hypothetical situation, in which we must decide which electric generator equipment to buy for an isolated drilling facility. We have received three quotes from different manufacturers: Ingersoll-Rand, Caterpillar and GE. Assuming that the required power output is met for all three options, we would like to reach our decision on the basis of post-service point of view. We create a matrix with the criterion "Post-Service" listed in the upper left corner, and list the manufacturers in both the left column and the top row, as shown in **Table 6**.

Table 6—Sample matrix for pairwise comparison

Post-Service	IR	Cat	GE
Ingersoll-Rand	1	1/2	1/4
Caterpillar	2	1	1/4
General Electric	4	4	1

The main diagonal positions are filled with *1*'s, since they refer to the value of each brand compared to itself (IR=IR). The matrix has six remaining entries to fill; the lower diagonal of the matrix will be filled with the reciprocals of the score given to the upper diagonal entries —three in the case shown here—. This leaves us with only three judgments to make, shown as the unshaded portion of the matrix. In general, if the matrix is dealing with n elements, the required number of judgments will be *(n x n – n) / 2*.

We begin by asking the expert/decision maker: How much better is the post-service performance of Ingersoll-Rand compared to Caterpillar? According to the judgments of the expert, IR scores one-half of Cat and one-fourth of GE, or *IR = 1/2Cat* and *IR = 1/4Cat*, respectively. This means that IR underperforms the other alternatives. Recalling these judgments in the definitions in Table 3, the service from Cat is *slightly better* than IR, and GE is *slightly to strongly better* than IR. Consequently we also obtain the reciprocal values of 2 for Cat over IR, and 4 for GE over IR.

It is important to take into consideration that the elements in the left column are compared over the elements in the top row, so the value is given to the element in the column as it is compared on how much better (or worse) it is with respect to the element in the row. Since IR is not favored compared with the other two alternatives, the entries are 1/2 and 1/4, while the reciprocal values, 2 and 4, will correspond to the transpose positions in the matrix.

It is interesting to note that we chose a criterion that is rather difficult to scale, since it is mostly an unmeasured criteria, in contrast with others such as price or fuel consumption. Nevertheless, a knowledgeable person with experience in maintenance would be able to provide a "relative" score on which is better compared to the other (a pairwise comparison). AHP analyses can be carried out with several other criteria, even at the same time. This shows how the relative scale can combine measurable criteria—like price— with more intangible ones, like post-service performance.

When operational information is present for the selection criteria, the judgments can be obtained by the ratio of performance of one alternative compared to the other. For example in this case, we refer to a quantifiable criterion like price, or fuel consumption. In such cases, instead of making a judgment, a more objective comparison can be obtained by calculating the ratio of performance. If the price of an Ingersoll-Rand generator is $130,000 and a GE generator is priced in $170,000, then the ratio of IR/GE would be 130,000/170,000 or 13/17, and this number would go directly into the pairwise comparison matrix for the weighing process.

In our next step, we proceed to synthesize the judgments to obtain the weight or prioritization of our alternatives (brands) with respect to post-service criteria. We begin by adding the values in each column, as shown in **Table 7**.

Table 7—Synthesizing the judgments

Post-Service	IR	Cat	GE
Ingersoll-Rand	1	1/2	1/4
Caterpillar	2	1	1/4
General Electric	4	4	1
Column Total	7.00	5.50	1.50

We then divide each of the entries by the totals of their respective columns (**Table 8**). This will give us a result known as a normalized matrix, from which the addition of all the elements on each column sums to 1.

Table 8—Normalized matrix

Post-Service	IR	Cat	GE
Ingersoll-Rand	1/7	1/11	1/6
Caterpillar	2/7	2/11	1/6
General Electric	4/7	8/11	2/3

Finally, we calculate an average of each row of the normalized matrix, by dividing the addition of its elements by the number of elements in each row:

$$\frac{1/7+1/11+1/6}{3}=\frac{0.40}{3}=0.13$$
$$\frac{2/7+2/11+1/6}{3}=\frac{0.63}{3}=0.21$$
$$\frac{4/7+8/11+2/3}{3}=\frac{1.97}{3}=0.66$$

These numbers represent the overall relative priorities. In this case, GE has the best "Post-service" ranking (66%) compared to Ingersoll-Rand and Caterpillar (13 and 21% respectively).

General procedure

The main steps required to complete an analysis are outlined below:

1. **Setup and calibration of the model to the actual risk attitude of the decision maker**. This should be a one-time process, provided that the risk preferences of the decision makers will not change, regardless of the numbers and quality of the alternatives presented in a one-time analysis. This is achieved through the following steps:

    1.1. Define the problem by stating the alternatives and solution desired.

    1.2. Decompose the goal into its constituent parts. List the selection or risk criteria, progressing from general to specific.

    1.3. Build a structure from all the component parts in which the main goal, the criteria and alternatives are organized in levels (the hierarchy proposed in Fig. 1 can be used, or a different one be developed).

    1.4. Construct the pairwise comparison matrices to obtain the impact of each element with respect to its governing criterion as well as the weights or priorities for each of the criteria.

2. **Comparison of investment alternatives.** The weighted information from the previous steps is put into the model. Each alternative is compared to the other and the overall priorities are calculated, as shown previously.

3. **Verification of the consistency of the results.** This step is actually not a requirement, but can help in refining the solution if the inconsistency is found to be high. Consistency checks should be performed on each of the matrices generated in steps 1.4 and 2.

If the process needs to be repeated for a totally new set of investment alternatives at a later time, it is reasonable to assume that risk attitude of the decision makers could have changed, and thus we recommend that the decision maker performs the complete analysis again to account for any changes.

We will go through detailed explanation and expansion of these steps with a case study in the following section.

REAL CASE DECISION MAKING: USING THE AHP WITH GROUPS

Although we have mentioned that the AHP can be used by individuals to clarify the risk level of project alternatives or make specific decisions, the full potential of the methodology is achieved if the process is applied with the contribution of a small group of well informed decision makers. We have also seen how the process can be lengthy, and working in group can make it even longer; this also calls for motivation, patience and willingness to obtain good results.

If a group decision process is to be used for generating the input data, it would be advisable to involve the same group in the construction and development or review of the hierarchy to be used, where the input of all the participants is used to brainstorm hierarchies or complement existing ones.

It should be taken into consideration, however, that the more people involved, the greater the range of ideas; thus, if too many people are involved in establishing priorities, the analysis can become time consuming.

Fortunately, real-case decision making is normally performed by a limited group of people, who can make more careful judgments, thus increasing the validity of the results. It is essential that the group be led by a person with certain knowledge of the basis of AHP. In this way, the evaluation process can be adapted to properly fit the ongoing situation and group characteristics, and the group can choose effectively between different evaluation and input methods.

Experience, power and influence of the participants

When talking about group decision making, issues like influence, experience and power of one participant over other can affect the results. Prioritizing should be done by reaching consensus whenever possible or by means of voting. More experienced individuals would usually have a stronger opinion about their judgments; so, when time allows, the best way to obtain input data should be on a debate basis, allowing each of the individuals involved to state their opinion and justify their decisions. The most experienced people should be able to present the most convincing arguments, in order to reach a consensus. Nevertheless, it is important that all the ideas be addressed, regardless of the "level" of the originator; this is especially important if the hierarchy is being developed or modified to consider possible risk factors.

When time is of the essence

If time is a major constrain, the debate can be waived and each individual opinion recorded individually. In this case, the questionnaire method is the best way to proceed. When input from different people must be considered, the final values to be used in the element pairwise comparisons can be obtained by geometric mean[11]. For example, if values of 2, 3 and 7 are recorded from three different evaluators, the mean would be $\sqrt[3]{2x3x7} = 3.48$ which would be 3 on the pairwise comparison scale. The geometric mean is used because it is not affected significantly by extremely small or large elements. For those cases where the experience of one of the contributors is highly regarded, a hierarchy can be developed among the members of the group, where their input scores will be assigned also a weight, which will make it count more or less in determining the final input value. This "member hierarchy" can take into account different ranking factors that could be related to company rank, influence, expertise and experience, etc.

When each method should be used

Consensus is not as important at lower levels of the hierarchies, where averaging can be used to better advantage (timewise) but should be exercised at the higher levels whenever possible.

The questionnaire method should also be used if the number of elements to be considered, and the overall work process, is too extensive (such as in the case of this study).

In cases where the expertise and interests of each of the members is well defined, they can be separated into subgroups, each dealing with their topic of major concern. This can also aid in speeding up the process.

CASE STUDY

How initial project perceptions can be misleading

Let us assume we have two mutually exclusive projects for which a certain amount of funds are available. For a mid-size non-integrated oil and gas company, who can't afford to take high risk projects because of its limited investment portfolio, the decision makers would naturally expect to choose among the best of the available investment alternatives with great care; one that will not only provide a reasonable NPV (according to the decision makers), but would also like to consider that the risks confronted are tolerable.

In this hypothetical case, the team of decision makers is presented with two alternatives. The first (Project A) is an undeveloped, offshore, mid-size field that requires ultra deep technology drilling and building of a platform; the quality of the crude is medium to light, but the location is far away from coast and any connection tie-ins to deliver the crude by pipeline; the labor force can be considered highly qualified but also expensive. The second investment (Project B) is an onshore field it's a larger heavy crude field with good reserves in place. Infrastructure is relatively close, with access roads previously developed by neighboring fields from other companies, pipelines and power supply distribution to which the new investor could connect are also present; labor hand in the area is relatively cheap and well qualified.

At first glance option B seems to be a great investment idea, with not much to think about. But what if the first investment happens to be located in the Gulf of Mexico, off the coast of Louisiana, and the second turns out to be in the Venezuelan Orinoco Heavy Oil belt? For a company that can't handle much risk, Project B alternative would just represent too much of it, coming not from the technical side (the project would very likely have a good NPV, even with a lower investment), but from fluctuating political, economical and taxation issues which arose lately in this country.

Would it still be a good idea to go with a much less expensive but riskier project B, than the high cost but lower non-technical risks of project A? Considering the new facts, it would be necessary to perform a thoughtful analysis on both. An analysis that covers not only the technical and typical economical issues, but also other risk factors associated with each project. It will depend ultimately on the risk aversion of the decision makers to provide the answer. By means of a proper set of questions, the proposed model can be "calibrated" to give importance to those elements that would matter the most for the decision makers. Furthermore, the risk criteria hierarchy can be modified to include other considerations that are most valued by the investors and exclude those of less importance. The AHP would then provide the best option to consider from their input.

Case study

Based on the previously mentioned investor profile (mid-sized, non-integrated oil company), we will evaluate three hypothetical cases. The description of the regions and conditions stated can differ somewhat in reality; however, the alternatives have been described as close to reality as possible, according to actual prospects located in the countries where they originate from. The technical costs shown correspond to 2004 values.

Considering that AHP should be performed by knowledgeable experts on the area, the evaluating members of this work were asked to provide their input over the three main risk areas to be assessed: social-economical; natural environment and resource, technology and management. A questionnaire was given to each, in which direct pairwise comparisons are asked between the elements of each hierarchy; these comparisons are done from the point of view of larger parent criteria. A complete set of these questionnaires can be found in Appendix A. **Fig. 2** shows an example of one of the questions used to evaluate potential riskiness of harsh natural environments:

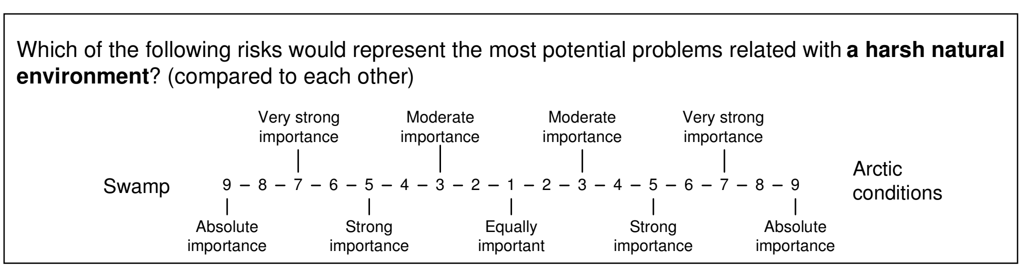

Figure 2—Sample question used in questionnaire for judgment gathering

The hypothetical project alternatives are described below:

<u>Prospect A:</u>

- Country: Venezuela.
- Location: onshore.
- Very large potential of unconventional resources (extra heavy oil = high sulphur content + high viscosity); as part of a super giant oil field.
- Relatively stable society (low internal conflicts).
- Mild climate. Site is relatively close to similar facilities so infrastructure (roads, water, electricity, etc.) is somewhat available and fully depreciated.
- Highly qualified - relatively cheap- personnel.
- Low technical costs per bbl (close to 10$/bbl).
- Investing environment has shown signs of ever increasing policies and law uncertain changes that go against investors, with currency exchange restrictions.

<u>Prospect B:</u>

- Country: Nigeria.
- Location: offshore.
- Abundant resources (medium to light oil).
- Social unrests and occasionally conflicts among the internal governments or local tribes.
- Ordinary climate, but coastal conditions require facilities designed to withstand the elements.
- Relatively cheap labor but high qualification is difficult to find.
- Very low production costs (8 to 9$/bbl).
- Internal struggles between factions occasionally result in adverse actions taken against personnel working in the area.

- Local port for product sell/dispatching is relatively close, but no other infrastructure facilities are available, since it is offshore.

Prospect C:

- Country: United States.
- Location: onshore Alaska.
- Moderate resources, mostly medium grade oil (lower resources than options A and B).
- Steady social environment.
- Arctic climate and harsh conditions at the site area (no important infrastructure is present).
- Labor is qualified but also expensive.
- Higher production costs (11$/bbl). But relatively close to a pipeline that could be used to transport the product to storage and refinery areas.
- Heavy competition between other international firms that also struggle to tap the resources of the area. In addition, potential local investors lack of technical preparation for this specific project.

Application of the AHP to quantify risk

1. **Setup and calibration:** this phase requires the input of the decision maker(s), to determine the risk attitude of the company related to each of the criteria shown in the proposed hierarchy of **Fig. 3.** Before performing this step it is best that the decision makers are aware of the characteristics of the investment alternatives, as well as the goal and major objectives of the business unit making the decision. This will provide the participants with an idea when calibrating the model by making them aware of the situation before getting started. This process ultimately defines the risk attitude of the company towards making a decision.

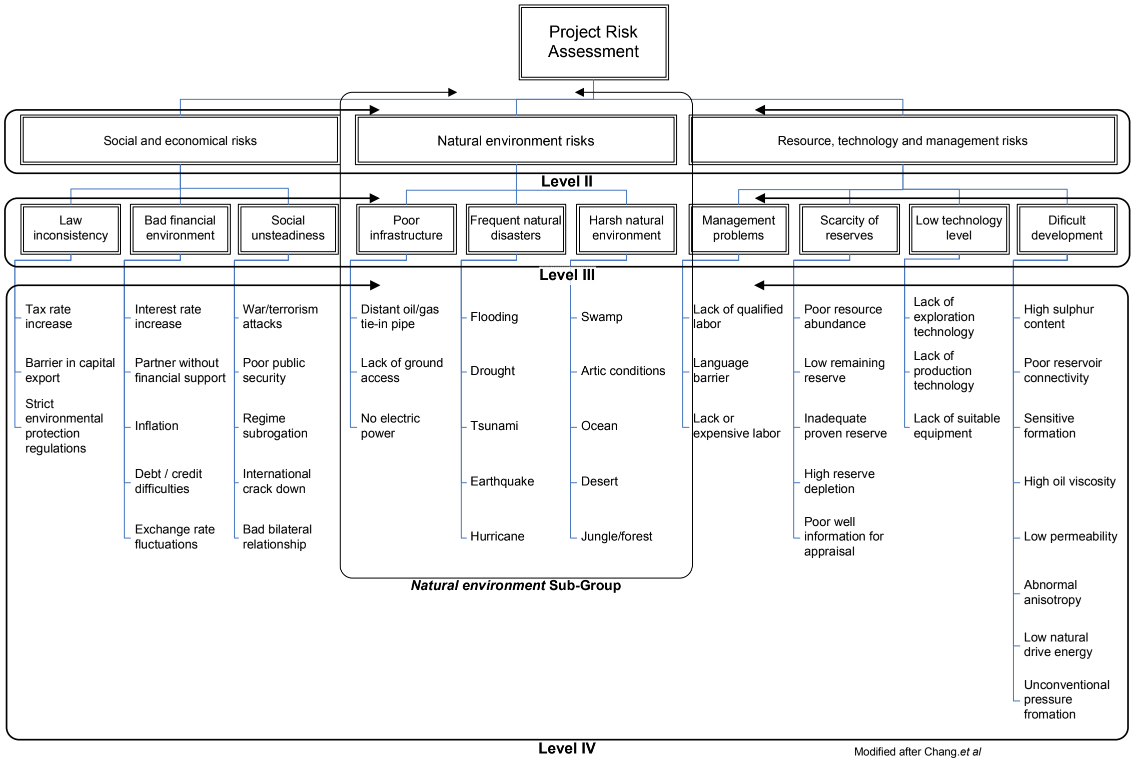

Figure 3—Proposed risk hierarchy separated by levels of analysis

In order to ease the explanation process, we show the full calculation procedure for the *Natural Environment Risks* sub group or branch from our hierarchy model. Complete tables with inputs and results for the other main branches of the hierarchy, can be found in the Appendix B.

From the received questionnaires we compared the factors on level III of the hierarchy; the following priorities were obtained (**Table 9**):

Table 9—Synthesizing of judgments for criteria of Level III of the hierarchy

Natural Environment	Poor infrastructure	Freq Nat Disast	Harsh Nat Environ	**Priority**
Poor infrastructure	1	1/7	1/5	**0.07**
Frequent natural disasters	7	1	6	**0.71**
Harsh natural environment	5	1/6	1	**0.22**
Total	13.00	1.31	7.20	0.076

The core of the AHP resides in the prioritization, and in order to obtain useful results these must be checked for consistency. Consistency ratio values are shown in the lower right cell of each matrix. As previously stated, this value must lie close to 0.1 or 10% of inconsistency, in order to have trustworthy results.

We then move one step lower into the hierarchy, by comparing the sub criteria of each of the factors on level III with their peers of the same category (level IV as seen in Fig. 3) and same parent criteria (**Table 10**).

Table 10—Synthesizing of judgments for sub criteria of Level IV of the hierarchy

Poor infrastructure	Distant tie-in	Ground access	Electric power	**Priority**
Distant oil/gas tie-in pipe	1	1/5	3	0.19
Lack of ground access	5	1	7	0.72
No electric power	1/3	1/7	1	0.08
Total	6.33	1.34	11.00	0.024

Frequent natural disasters	Flooding	Drought	Tsunami	Earthquake	Hurricane	**Priority**
Flooding	1	7	1/5	1/5	1/3	0.10
Drought	1/7	1	1/7	1/7	1/7	0.03
Tsunami	5	7	1	3	5	0.43
Earthquake	5	7	1/3	1	7	0.30
Hurricane	3	7	1/5	1/7	1	0.13
Total	14.14	29.00	1.88	4.49	13.48	0.098

Harsh natural environment	Swamp	Arctic	Ocean	Desert	Jungle / forest	**Priority**
Swamp	1	1/5	1/5	5	7	0.17
Arctic Conditions	5	1	1/2	5	6	0.30
Ocean	5	2	1	5	5	0.40
Desert	1/5	1/5	1/5	1	5	0.09
Jungle / forest	1/7	1/6	1/5	1/5	1	0.04
Total	11.34	3.57	2.10	16.20	24.00	0.077

Next, we calculate the final (overall) weight of each sub criterion, by multiplying the parent weight by the weight of each of their sub factor. For example: *No Electric Power* (individually weighted as 0.08), is a sub factor of *Poor Infrastructure* (individually weighted as 0.07), so the actual weight of *No Electric Power* within the complete hierarchy, will be the product of both weights (parent and son), or 0.08 x 0.07 = 0.01. The same calculations for the other sub factors are shown in **Table 11**.

Note that the sum of all of the weights is equals *1*. This means that, the priorities are normalized.

Table 11—Overall weights of the criteria on the Natural Environment risks branch

Poor infrastructure	Priority
Distant oil/gas tie-in pipe	0.01
Lack of ground access	0.05
No electric power	0.01

Frequent natural disasters	Priority
Flooding	0.07
Drought	0.02
Tsunami	0.31
Earthquake	0.22
Hurricane	0.09

Harsh natural environment	Priority
Swamp	0.04
Arctic Conditions	0.07
Ocean	0.09
Desert	0.02
Jungle / forest	0.01

At this point of the AHP analysis—the calibration of the model—we have the option to take a closer look at the priorities, and discard those risk criteria whose weight could be considered to be of negligible impact against the final objective of the analysis. We could consider any cut-off value from which to accept or neglect any of the criteria used, say 0.05 or 5% weight. If this were the case, then in our ongoing analysis we could be able to put aside risk factors such as: *Distant oil/gas tie-in pipe* (0.01), *No electric power* (0.01), *Drought* (0.02), *Desert* (0.02) and *Jungle/forest* conditions (0.01); and then renormalize the remaining criteria (dividing each remaining weight by the sum of all remaining). However this is an optional consideration, it should be properly reviewed with the decision makers, in order to agree on the cut-off value and understand the implications of these factors that would be out of consideration. For the sake of explanation of the method we will carry on with all the risk factors, regardless of their weight.

Likewise, by applying the previously described procedure to the other major branches of *Social-Economical* and *Technology, Resource and Management Risks*, we can appreciate the weights of all the conforming criteria in **Fig. 4**.

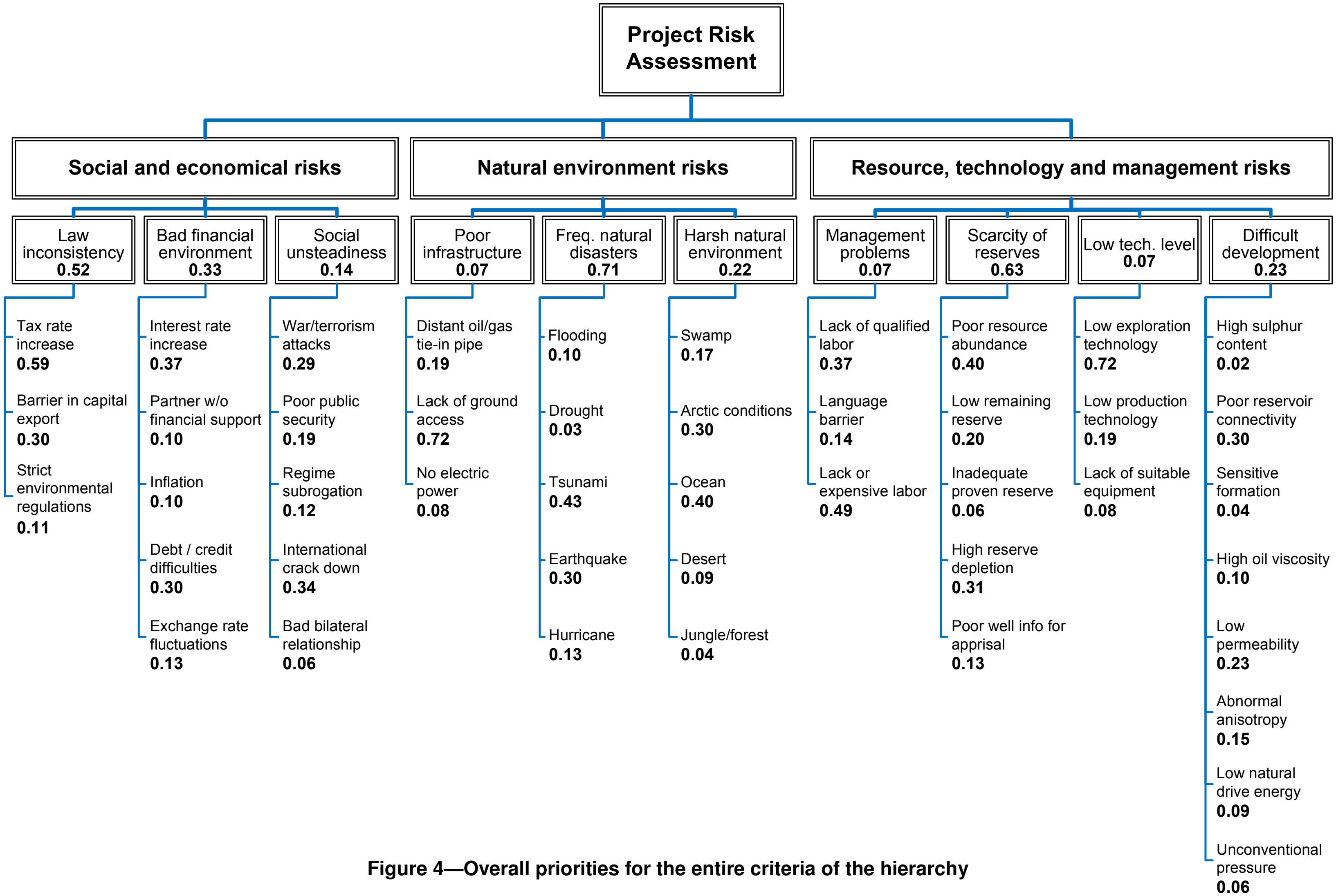

Figure 4—Overall priorities for the entire criteria of the hierarchy

2. **Comparison of investment alternatives**: direct pairwise comparisons are made in this phase among each of the investment alternatives. Now we rate, in a pairwise way, each alternative from the point of view of each of the risk factors we are ultimately considering in our analysis.

   The comparisons are preformed on similar questions asked for the criteria ranking; such as: “From the point of view of *Lack of ground access,* which of the following investment options would represent the most potential problems/risks?” After consideration of our options, we obtained the following priorities **(Tables 12, 13 and 14)**:

Table 12—Pairwise comparison of project alternatives for Poor infrastructure sub group (from the Natural Environment risks branch)

Poor infrastructure					
Distant oil/gas tie-in pipe	Project A	Project B	Project C	**Priority**	**HCR**
Project A	1	1/7	1/5	0.08	
Project B	7	1	2	0.59	
Project C	5	1/2	1	0.33	0.007
Lack of ground access	Project A	Project B	Project C	**Priority**	
Project A	1	1/6	1/5	0.08	
Project B	6	1	1/3	0.32	
Project C	5	3	1	0.60	0.091
No electric power	Project A	Project B	Project C	**Priority**	
Project A	1	1/7	1/4	0.08	
Project B	7	1	3	0.66	
Project C	4	1/3	1	0.26	0.014

Table 13—Pairwise comparison of project alternatives for Frequent natural disasters sub group (from the Natural Environment risks branch)

Frequent natural disasters					
Flooding	Project A	Project B	Project C	**Priority**	**HCR**
Project A	1	6	4	0.69	
Project B	1/6	1	1/3	0.09	
Project C	1/4	3	1	0.22	0.024
Drought	Project A	Project B	Project C	**Priority**	
Project A	1	4	2	0.56	
Project B	1/4	1	1/3	0.12	
Project C	1/2	3	1	0.32	0.013
Tsunami	Project A	Project B	Project C	**Priority**	
Project A	1	1/6	1	0.12	
Project B	6	1	8	0.77	
Project C	1	1/8	1	0.11	0.003
Earthquake	Project A	Project B	Project C	**Priority**	
Project A	1	4	3	0.59	
Project B	1/4	1	1/4	0.11	
Project C	1/3	4	1	0.30	0.082
Hurricane	Project A	Project B	Project C	**Priority**	
Project A	1	1/6	3	0.17	
Project B	6	1	8	0.75	
Project C	1/3	1/8	1	0.08	0.022

Table 14—Pairwise comparison of project alternatives for Harsh natural environment sub group (from the Natural Environment risks branch)

Harsh natural environment					
Swamp	Project A	Project B	Project C	**Priority**	**HCR**
Project A	1	1/2	2	0.30	
Project B	2	1	3	0.54	
Project C	1/2	1/3	1	0.16	0.008
Arctic Conditions	Project A	Project B	Project C	**Priority**	
Project A	1	1	1/9	0.09	
Project B	1	1	1/9	0.09	
Project C	9	9	1	0.82	0.000
Ocean	Project A	Project B	Project C	**Priority**	
Project A	1	1/7	1/3	0.08	
Project B	7	1	9	0.77	
Project C	3	1/9	1	0.15	0.055
Desert	Project A	Project B	Project C	**Priority**	
Project A	1	1	1	0.33	
Project B	1	1	1	0.33	
Project C	1	1	1	0.33	0.000
Jungle / forest	Project A	Project B	Project C	**Priority**	
Project A	1	1/2	2	0.30	
Project B	2	1	3	0.54	
Project C	1/2	1/3	1	0.16	0.008

The far right column shows the consistency ratio of each matrix, notice that in each case it is close to, or less than 10%. A summary of all the priorities for each alternative is shown below **(Table 15)**:

Table 15—Summary of project priorities for each risk factor

Criteria Weight	Criteria	Project A	Project B	Project C
0.01	Distant oil/gas tie-in pipe	0.08	0.59	0.33
0.05	Lack of ground access	0.08	0.32	0.60
0.01	No electric power	0.08	0.66	0.26
0.07	Flooding	0.69	0.09	0.22
0.02	Drought	0.56	0.12	0.32
0.31	Tsunami	0.12	0.77	0.11
0.22	Earthquake	0.59	0.11	0.30
0.09	Hurricane	0.17	0.75	0.08
0.04	Swamp	0.30	0.54	0.16
0.07	Arctic Conditions	0.09	0.09	0.82
0.09	Ocean	0.08	0.77	0.15
0.02	Desert	0.33	0.33	0.33
0.01	Jungle / forest	0.30	0.54	0.16

Finally, we calculate the overall weight of each alternative with respect to each criterion by multiplying the results obtained in the previous step by the individual weight of each of the criterion (**Table 16**).

Table 16—Overall project weight by criteria for the Natural environment branch

Overall alternative weight by criteria	Project A	Project B	Project C
Distant oil/gas tie-in pipe	0.00	0.01	0.00
Lack of ground access	0.00	0.02	0.03
No electric power	0.00	0.00	0.00
Flooding	0.05	0.01	0.02
Drought	0.01	0.00	0.01
Tsunami	0.04	0.24	0.03
Earthquake	0.13	0.02	0.06
Hurricane	0.02	0.07	0.01
Swamp	0.01	0.02	0.01
Arctic Conditions	0.01	0.01	0.05
Ocean	0.01	0.07	0.01
Desert	0.01	0.01	0.01
Jungle / forest	0.00	0.00	0.00

Adding up the scores of each investment alternative, we obtain the total risk level of each project, shown in **Table 17**:

Table 17—Total project alternative weight from the Natural environment risks point of view

Total Weight for Natural Environment Risks	Project A	Project B	Project C
	0.28	0.48	0.24

Similarly, for our other risk branches we have obtained the following weights (**Table 18**):

Table 18—Total project alternative weight from the Social and Economical and the Resource, technology and management risks point of view

Total Weight for Social Environment Risks	Project A	Project B	Project C
	0.48	0.37	0.14
Total Weight for Resources, Technology and Management Risks	Project A	Project B	Project C
	0.24	0.33	0.43

The overall project alternative weights are obtained from the arithmetic mean of all the criteria for each project. These weights represent the risk level of each option. The difference of this number from unity would represent the preference score obtained by each alternative (**Table 19**).

Table 19—Overall project alternative weight

	Project A	Project B	Project C
Total Risk Weight for alternatives	0.34	0.39	0.27
Ranking (preference) of alternatives	0.66	0.61	0.73

Analysis of results

The numbers used in the initial calibration process, represent the risk attitude of the decision makers towards the specific risk factors.

Based on the results obtained, **Fig. 5** shows that the option in Nigeria would have the highest overall risk, followed by Venezuela and finally Alaska (U.S.). If our hypothetical company would base its decision solely on the riskiness of the projects, the investment preference would be U.S., Venezuela and Nigeria. Of course, the decision maker must consider many other factors to be taken into account such as benefits, costs and opportunities along with risks, as part of an integral decision process in order to choose the best option for the company.

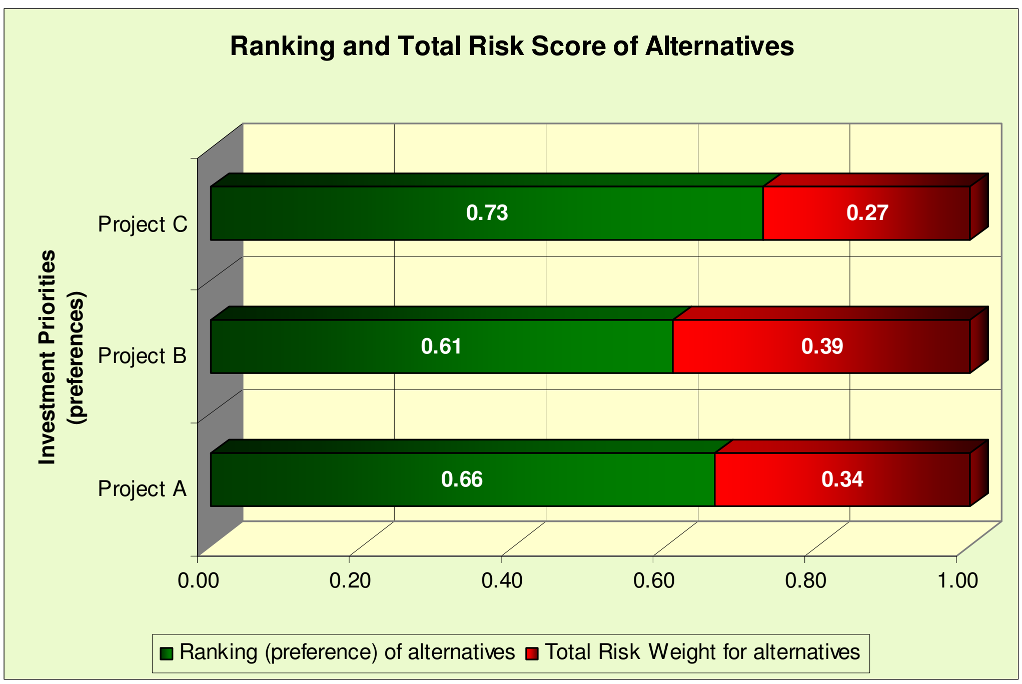

Figure 5—Graphical representation of the results, showing scores for risk (red) and preference (green)

The numbers obtained, reflect the integration of all the risk factors that typically affect, in one way or another, upstream exploration and production projects. Most of these factors have well-known effects in the final outcome of a project; thus the importance of a method that can consider the most possible events in one single analysis, giving the proper weight to each of the criteria considered.

What would be the best decision in a case where the AHP yields similar score results with little or no difference at all among the project alternatives? This does not mean that the alternatives would perform in the same way, or that the same risks would affect them in the same way and intensity. This would mean that, from a risk point of view, the group of alternatives may have similar inherent overall values. If such case should occur, then the selection process should rely mostly on other comparative evaluation methods such as benefits, costs and opportunities that each project would represent for the company, since risk alone is not enough to account for that decision.

A good property of the method is that even when overall risk scores are the same for all the alternatives, for any investment that is chosen, we could identify in which areas it would be riskier and by how much, when compared to its peers. This is thanks to the individual score tables, where scores of every alternative is expressed in regard to each of the selection criteria (see Tables 15, 16 and similar case tables in Appendix B).

SENSITIVITY ANALYSIS OF RESULTS

In order to determine the stability the method, as well as its results, we performed a sensitivity analysis on the results of our case study. By analyzing the behavior or variability of the results; we wanted to see if the judgments used to evaluate among the different investment alternatives would vary within a range of two notches (either up or down) of the risk scale score assigned to them during the analysis (**Table 20**). We asked ourselves: what would be the effect on the overall risk scores?

Table 20—Pairwise comparison scale used in our case study

Intensity of importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the parent property or criterion
3	Weak importance of one element over the other	Experience and judgment slightly favors one element over the other
5	Essential or strong importance of one element over the other	Experience and judgment strongly favors one element over the other
7	Demonstrated importance of one element over the other	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over the other	Evidence that favors one element over the other is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgements	When some compromise is needed between judgements
Reciprocals	If *i* has one of the preceding numbers assigned to it when compared with *j*, then *j* must have the reciprocal value when compared to *i* in order to be consistent	

We performed our sensitivity analysis with the help of *Precision Tree®* Software from Palisade Corporation. This software—originally designed as an Excel® add-on to perform decision tree evaluation processes—includes a useful tool for sensitivity analyses. By indicating the target or “Cell to Analyze” (**Table 21**) and the “Cells to Vary”, the software aids in the construction of explicit charts—which we will se below—that help understand the effect of variation of the “cells to vary” over the end results on the “cell to analyze”.

Table 21—Cells to analyze

	Project A	Project B	Project C
Total Risk Weight for alternatives	0.34	0.39	0.27
Ranking (preference) of alternatives	0.66	0.61	0.73

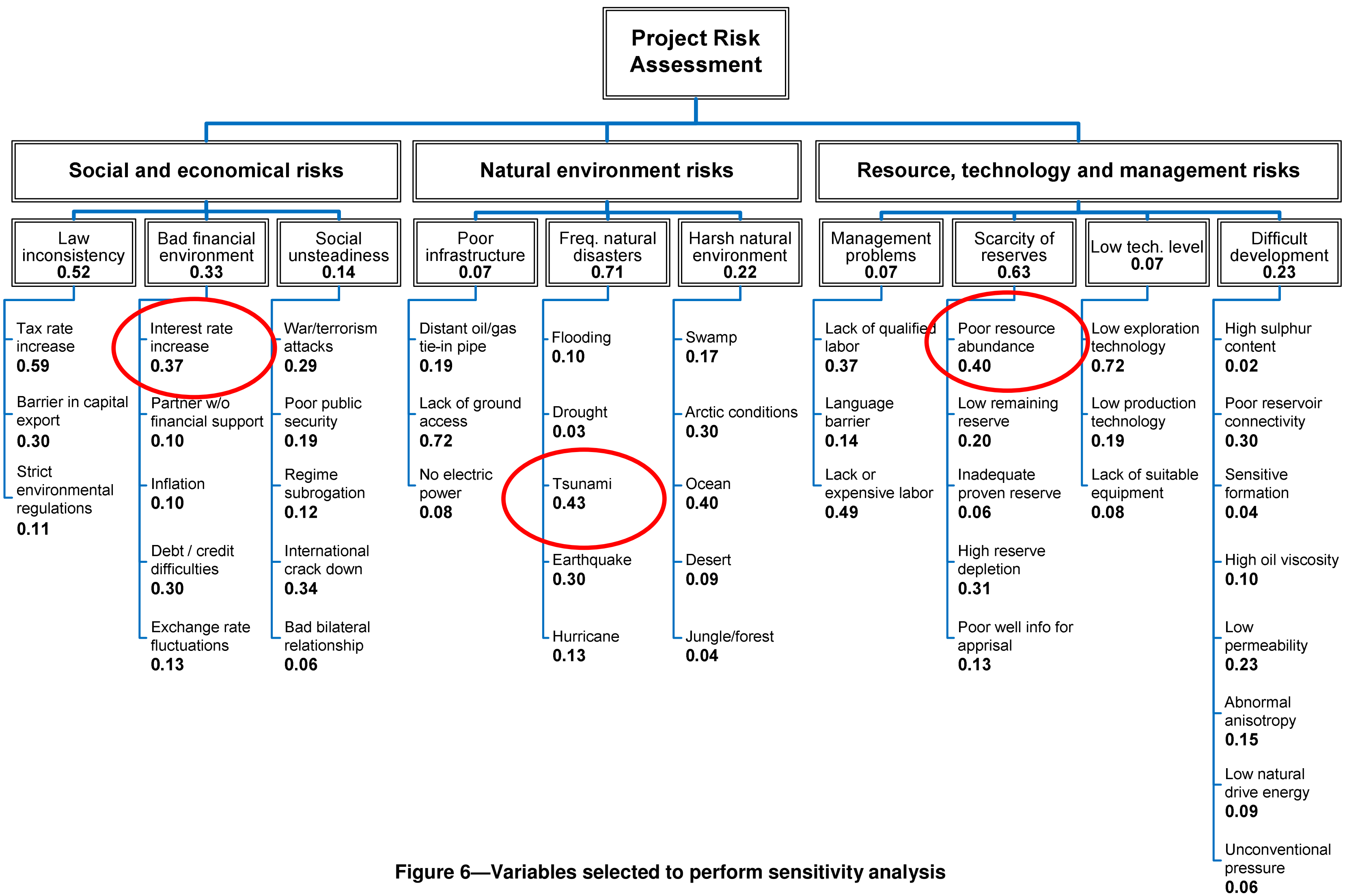

Figure 6—Variables selected to perform sensitivity analysis

Based on the weights and risk profile shown on **Fig. 6**, we selected one variable from each risk category, those with the highest weight among their peers. Given this structure and its weights, the variables selected for the sensitivity analysis were:

- Tax rate increase.
- Tsunami.
- Poor resource abundance.

Each of these variables is composed of three judgments, one for each project compared to another (A/B, A/C and B/C), so the total number of judgments to vary is 9.

It is important to state that the software works by assigning random numbers within user-established limits. A full randomization of the variables along the entire scale (i.e., from 1 to 9) would bring up issues with the consistency of the process as described earlier. Therefore, we have established a maximum variance of +/- 2 notches in the scale from the base or original value. A variability this big accounts well for the base values; it still represents the main idea of the preference of the user, while allowing a range which we study to see the effects on the final output of the model. For instance, if a judgment has an original base value of 5 (strong importance of one element over another), the sensitivity analysis will study the effects of the score shifting from 3 (moderate importance of one element over another) up to 7 (demonstrated importance of one element over another), as seen in **Fig. 7**.

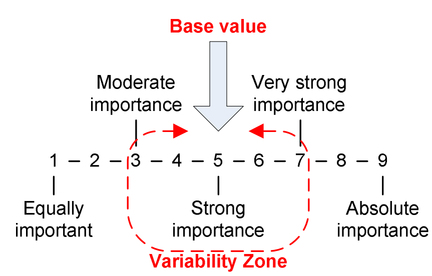

Figure 7—Base value and variability area (+/- 2)

Another important consideration for the proper use of the software are the reciprocal numbers, which are represented in our risk scale as fractions. In order to have the Precision Tree move along a uniform and equally-spaced set of numbers, fraction and/or decimal inputs should be avoided; otherwise the analysis would yield misleading results. This is solved—for the purpose of this sensitivity analysis—by representing fraction risk scores, such as 1/2, 1/3, 1/4, etc. as negative numbers: -2, -3, -4, etc. So, if a judgment A/B has a value of 5, then its reciprocal for the case B/A is 1/5; which is represented as -5 in the sensitivity analysis.

The results obtained can be represented on the following figures (**Figs. 8 through 13**):

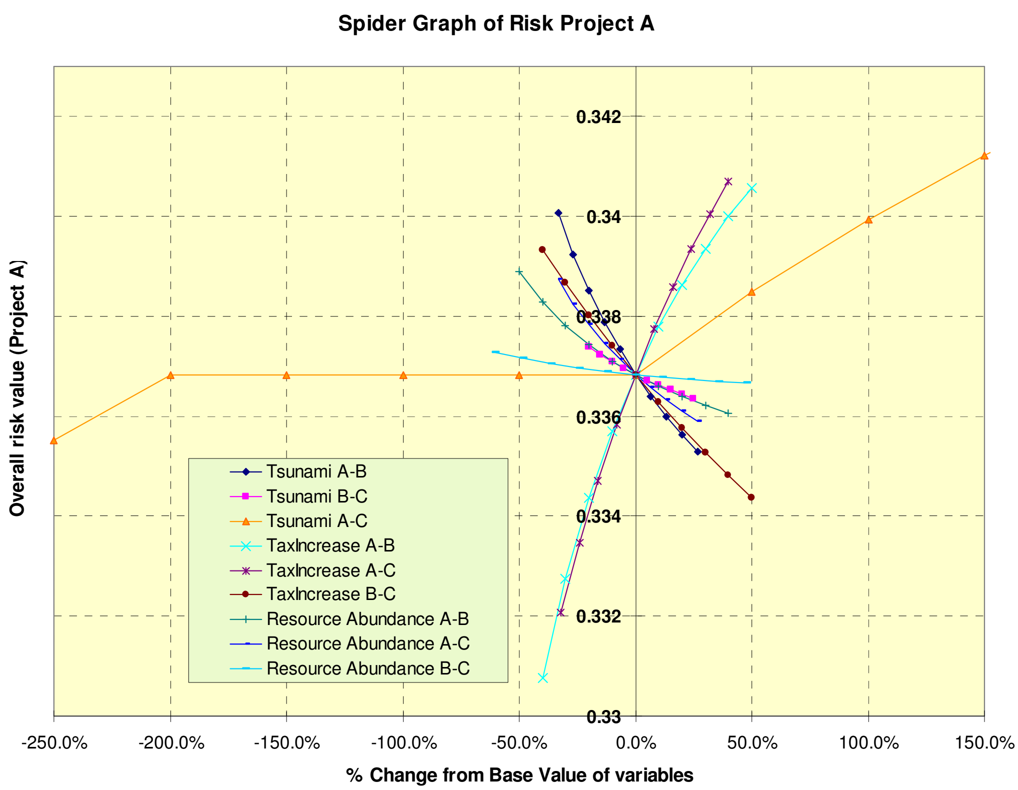

Figure 8—Spider graph of risk variability (Project A)

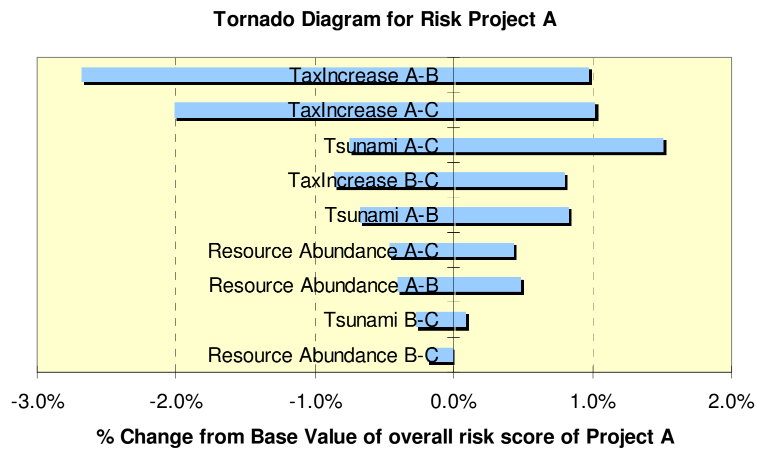

Figure 9—Tornado diagram for risk variability (Project A)

The maximum variation obtained for Project A was -2.6% of the reported overall risk value (0.34). It is mainly caused by the *Tax rate increase* variable of Project A, with respect to Project B (Tax Increase A/B). This represents a drop from 0.34 to 0.3307 on the overall risk score of Project A (as seen in Fig 8). Not a significant change in the value that would alter the final judgments on the risk ranking of alternatives.

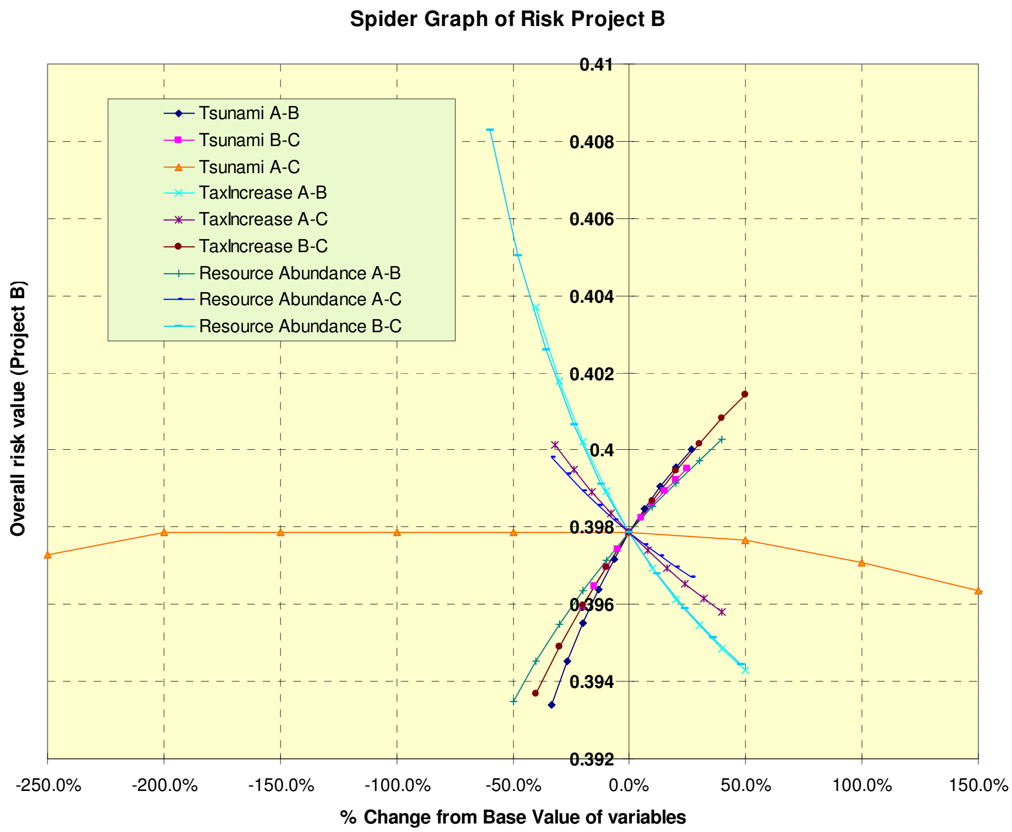

Figure 10—Spider graph of risk variability (Project B)

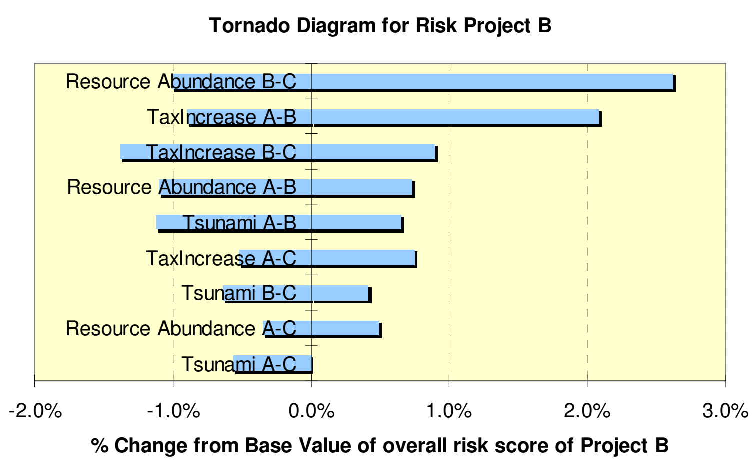

Figure 11—Tornado diagram for risk variability (Project B)

The maximum variation obtained for Project B was 2.6% of the reported overall risk value (0.39). It is mainly caused by the *Resource abundance* variable of Project B, with respect to Project C (Resource Abundance B/C). This represents a change from 0.39 to 0.4083 on the overall risk score of Project B (as seen in Fig 10). Not a significant change in the value that would alter the final judgments on the risk ranking of alternatives.

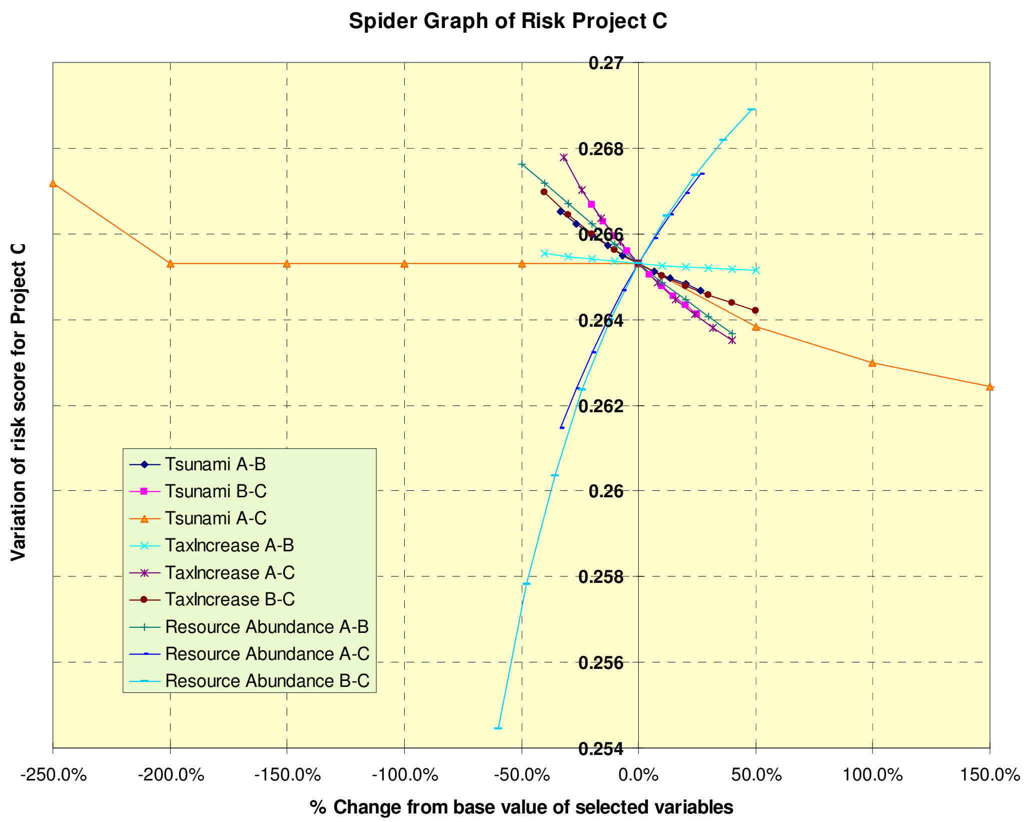

Figure 12—Spider graph of risk variability (Project C)

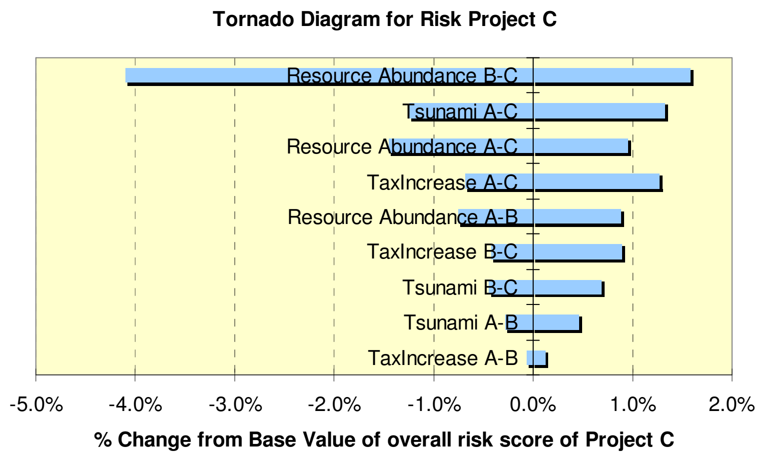

Figure 13—Tornado diagram for risk variability (Project C)

The maximum variation obtained for Project B was -4% of the reported overall risk value (0.27). It is mainly caused by the *Resource abundance* variable of Project B, with respect to Project C (Resource Abundance B/C). This represents a change from 0.27 to 0.2544 on the overall risk score of Project C (see Fig 12). Not a significant change in the value that would alter the final judgments on the risk ranking of alternatives.

Interpretation of sensitivity analysis results

This analysis provides a good insight on what would happen if the judgments where shifted a couple of notches in the risk scale. From the results of the sensitivity analysis we can learn that the model and the results obtained for this case study are stable. Variations in the judgments within reasonable consistency (not as random guesses) still present the same results with very little alterations in the numbers.

The largest variation found—of about 4%—in the end numbers related to Project C (Alaska), represents less than two points in the overall risk score of the project.

Based on the above, we can say that even if having input from different people, the general results would still be the same. One may not have the exact same judgments as others on the same matter, but just by having the same notion of which alternative represents grater risk for certain situations—considering educated judgments by knowledgeable people—it would still prove the results from the AHP as valid.

This is also related to the handling of subjectivity/objectivity of the process and its results. While it is normal that judgments may differ from one person to another (i.e., being based on personal appreciation), the final numbers would yield the same results because the general notion or idea (riskiness in our case) is still present for the people making the comparisons.

Finally, it is also worth noting the particular behavior of the curves on the spider graphs. The majority of these are either straight lines (with a slope) or a slight concave curve.

Concave curves denote the behavior that the variables would have. This means an increasing effect on the final results as the judgments shift further away from the original value, which translates into more randomness in the judgment and less consistency; hence the shape of these lines.

One particular variable with a unique behavior among the rest is the Tsunami A/C. Some segments are seen as completely flat (horizontal) in the portions closest to the center of the graph. This is because the base value of this variable in our original analysis is *1*. The horizontal portion represents the area between *1* and -*1*, which the Precision Tree includes in its analysis but has no effect on the final result. Any number that falls within this range of *1* to -*1* from the sensitivity analysis of Precision Tree is just considered as *1* for the AHP calculation process (equally importance of one alternative over another). Therefore the flat portion on the graph represents no variation at all on the final results along this interval.

CRITIQUES AND DRAWBACKS OF THE METHOD

Up to now we have presented the AHP as a way to address decision making processes and, in the particular case of this work, to quantify risk.

Nevertheless, like most things in life, this methodology is not flawless and like many other widely used methods, the AHP has its supporters and detractors. The idea of this study is to present the AHP as a tool, and denote its advantages. However, in order to be as objective as possible, we also took a look into some of the literature in which authors such as Belton and Gear[15], Hazelrigg[16] and Holder[17] point out possible drawbacks of this and other common decision making methods, with good basis and supportive examples as well as suggestions on how to deal with the main problems. To increase the validity of the results and make it even more stable under most of the circumstances that this application of AHP could encounter, we analyzed those main issues making our own adaptations to the original method to avoid such problems.

One of the issues pointed out by Belton and Gear as well as Holder, refers to the use of verbal descriptions to establish the relative importance or pairwise comparisons that need to be done. Both references mainly state that the use of a semantic scale by the decision maker and then adapted to a numeric scale by the analyst, hinders to the user the real nature of the pairwise comparisons, which is to establish ratios of weight for the pairs of criteria. This original procedure of obtaining the data for the model in a verbal way, can be easily fixed by presenting the decision maker with the numerical scale directly (as presented in this work), in lieu of having the additional process of converting the verbal (and more subjective) appreciation into a numeric judgment (see Table 20); this presents the user with a more “visual” scale, closing in to the real feeling of the judgment process. In addition, we have previously mentioned that whenever numbers related to real scales such as areas, depths, and other quantifiable items are available, the judgment process should be replaced with direct ratio comparison of the performance or values of one alternative over the other between such items (i.e., oil viscosity of A / oil viscosity of B).

Another issue related with the scale and addressed by Holder[17] is the restrictiveness of the 1-9 scale. Because of the "arbitrary" cutoff at the value of 9, the author suggests that no boundaries be placed to the limits of the scale, and that even a multiplicative scale could be used instead (i.e., A is 7 times preferable or riskier than B). However we don't fully agree with this point of view, because although it may seem to be a more natural way of comparing or making judgments, Saaty[11] has clearly stated that elements or criteria that are compared, and which are largely different from each other, should belong to different hierarchy levels and should be clustered with items of similar order of magnitude. If the multiplicative scale would be used, this would mean that the user is grouping items that could be up to 1000% different, according to the viewers' appreciation (considering a 1 to 10 times scale). Although the 1-9 scale could be confusing at the beginning by its own, we believe that if used in conjunction with the equivalent verbal meanings of the numbers, as previously presented, can minimize ambiguity of the true meanings of the scale that represent the judgments. The 1-9 scale has its own intrinsic logic as mentioned in previous sections of this work; it is determined on the ability of individuals to appreciate the differences between elements in low, medium and high levels; and being able to further subdivide into low, medium and high sublevel within each of them (**Fig. 14**).

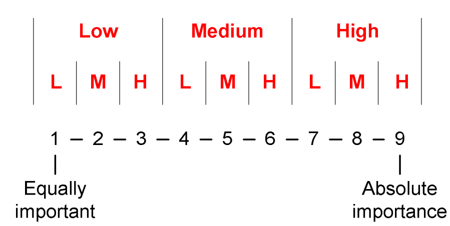

Figure 14—Meaning of the 1 to 9 scale

Hazelrigg[16] further suggests the allowance of negative numbers in the scale. We believe that for this particular case where we handle risk, such observation with is not applicable. Risk is either present up to some degree or nonexistent (which would even be an ideal condition); but the use of a negative scale would not go hand in hand with the logics of risk evaluation.

Probably the most addressed issue by all of the cited references is the so-called *Rank Reversal*. According to Holder[17], this issue was first reported by Belton and Gear[15] and has since been widely discussed in related literature. It is based on the introduction (and even removal in some cases) of options or selection alternatives (investment options) from the decision set. Some of the referred authors have proved how this would create a modification in the rankings or option preferences (the results of the method), because even when the new included option would not provide any additional information on the relative rating of the existing ones, the results could change if the AHP is used in second runs with new information.

The different interpretations provided by several authors around the topic have created two currents of opinions. One initiated by the observations of Belton and Gear[15; 18] and another by Saaty and Vargas[19; 20]. The discussion of such issue has been going on for several years, during which papers and publications with explanations, replies, comments, examples and counter examples are dissected and analyzed in detail (see references [15-21]).

According to Belton and Gear[15; 18], when a new alternative is considered (or an existing one removed) the relative weights of the selection criteria—what we call the calibration phase—should be revised. If criteria weights remain fixed, a rank reversal could occur. Holder states that this problem can be addressed by having the candidates' performance in mind before the weighting of the criteria is done; in which case, the weights should be re-derived whenever there is an introduction of new alternatives. The origin of this could come from the dependency of the selection criteria preferences with the evaluated alternatives. They also provide a simple solution based on the normalization of the alternative weight priorities vector, obtained from the pairwise comparison of the alternatives done for each criterion considered.

Saaty and Vargas[19] explain when rank reversal can take place, by describing the effects of introducing new alternatives in the option set. Let's assume we have initially three alternatives A, B and C, and then a fourth one (D) is added after the initial analysis; let us also assume that the results of our initial analysis yield preferences in the following order B > A > C:

1. If a new alternative (D) is strongly dominated by the least preferred alternative (C) for every criterion, then it is not likely to affect rank order (B > A > C > D).

2. If the newly introduced alternative (D) scores oscillate between two existing alternatives for every criterion (say B and C), then it is expected that its final rank will also fall between these two alternatives, with rank being reversed elsewhere (A > B > D > C notice a rank reversal has occurred between A and B).

3. If a new alternative D dominates the most preferred alternative for every criterion, then in general it is not likely to affect rank order (D > B > A > C).

From our point of view, rank reversal can indeed happen as explained clearly by the examples set by Belton and Gear[15; 18] and Schoner and Wedley[21]. However, we believe that rank reversal should be acceptable in our case. This method is used to make a decision at a specific given moment and conditions where these projects would take place, therefore the preferences or risk attitude towards these criteria at that specific moment should remain unchanged and would not be dependent on the addition or removal of investment options. It must be recalled that, in this study, we are talking about strategic risk concerns of an O&G company; therefore we see as acceptable that an addition to the set of investment options could bring along a change in the final preferences of the alternatives (a rank reversal). This can also be shown with an example from Saaty and Vargas[19]:

> *Consider two investment opportunities A and B, which give different cash flows for four time periods. Assume that the net present value of A is greater than the net present value of B at time 0, but that if we choose B, we have more cash in period 1 than if we had chosen A. Hence A is preferred to B in present value terms. However, suppose that we have a third investment opportunity C which requires cash flow for periods 2, 3 and 4. It is clear that if one wishes to invest in C, then B should be preferred to A, hence selecting A or B is influenced by the appearance of C and a rank reversal takes place.*

Nevertheless, considering also the points of view form some of the critics, the risk attitude of a company may change in time, and thus if a new decision needs to be taken at a later moment, the best approach would be to run the whole judgment and appreciation model with the decision makers.

PROPOSAL FOR FURTHER DEVELOPMENT

Throughout the development of this study, it can be seen how the AHP can be a useful tool in the quantification of investment risks. Nevertheless, proper investment decisions can not be based solely on the level of risk of the alternatives. As discussed previously, depending on the risk attitude of a company, a high level of it could be tolerated depending also on the benefits, the costs and the opportunities that any given investment can present to the company.

Further steps taken into the development of this tool require, that this model be transformed into an integral evaluation method, from which the evaluation of risk is only one of the cornerstones of a complete analysis of any project. By incorporating in a single analysis tool the evaluation of benefits, costs, opportunities and risk; the decision maker can arrive to a much better informed and integral alternative ranking of its investments.

The computational problem is how to integrate such a large amount of criteria into one tool. And what happens if by using AHP, the preferences or levels of one of the benefits criteria could also impact the costs criteria? In other words, dependencies arise among the used criteria, further complicating the AHP process.

As an example, suppose we have an investment alternative that has a certain risk of containing high sulphur levels. We already know from this study, that this issue would generate some risk, by representing additional costs on material and equipment. But in addition, the presence of sulphur also poses a commercial issue, since the product will typically have to sell cheaper, because of additional refining processes that are required to obtain final products within specifications. Thus lower cash flows can be expected from the same issue.

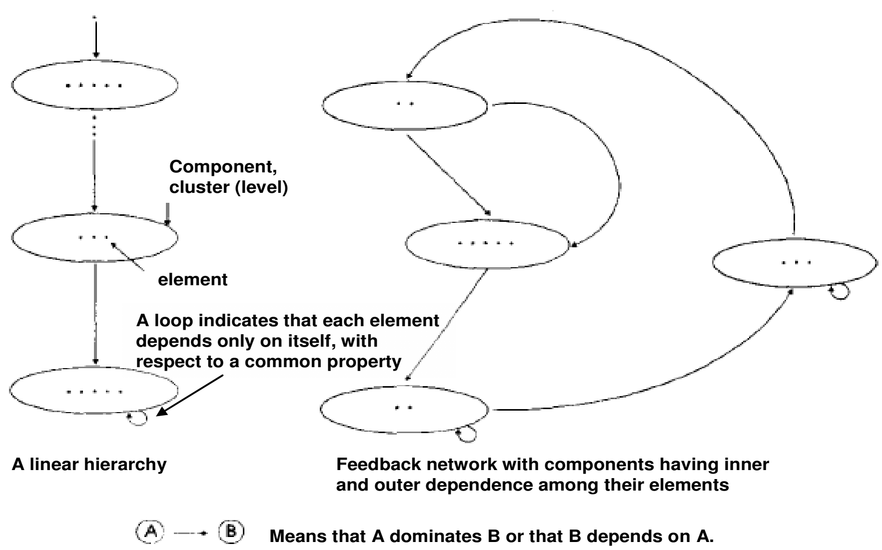

Figure 15—Structural difference between a linear and non-linear network (ANP)[12]

In the mid 80s, Saaty[6] developed a variant of his already existing analytical hierarchy process, for cases where interaction between criteria could be seen even at different levels. This new method called the Analytical Network Process (ANP), can deal with intricate relationships, where evaluating criteria is organized in clusters rather than levels. Each cluster could affect others in any way; in addition of being able to account the effect of feedback information that could even affect the originating cluster itself (**Fig. 15**).

A good starting point could be the clusters of criteria shown in **Table 22**. Notice how the new considerations broaden up the scope of the ANP as and integral assessment tool.

Table 22—Clustered criteria for project benefits, costs, opportunities and risk

Benefits	**Costs**
• NPV • Payback time • Profitability index (PI) • Internal rate of return (IRR) • Growth rate of return (GRR) • Technology transfer (from partnerships)	• Number of initially projected wells • Production costs [$/bbl] • Initial investment • Availability of rigs to perform the job • Availability of EPC contactors to develop the facilities
Opportunities	**Risks**
• Final market destination of product (FOB/CIF prices) • New markets to conquer or better positions to be gained in existing ones • Ease of farm out conditions, if needed (contractual ties and government requirements) • Possibility of gaining extra benefits through carbon emission credits • Reserve reposition rate	• Commercial (depending on sulphur content and viscosity) • Social and economical • Natural environment • Resource, technology and management

Several commercial and even some limited freeware software are available in the market. These programs can save time to the analyst, by presenting him/her with pre-structured questionnaires and better consistency indicators, which can help zero in the exact question that has the highest inconsistency among a cluster of criteria.

This could be a fascinating opportunity to present the industry with a well rounded and integral evaluation tool. Unfortunately the ANP falls out of the scope and available timeframe of this investigation, but the path is open now for further development.

CONCLUSIONS

1. The Analytic Hierarchy Process can be used to break down complex problems into their component parts, allowing systematic contemplation of the situation. This stage is the most critical part of setting up a good working model that will accomplish its purpose.

2. By application of the proposed hierarchy (or any other proper modification of it), the AHP has proved to be a powerful tool for risk and portfolio management of large investments.

3. The AHP can be seen as an iterative process. Model reruns with adjusted perceptions in the judgment of alternatives can become sensitivity analyses, while also reducing inconsistency. This becomes imperative if any of the conditions affecting an investment alternative are changed, or if a new alternative is considered.

4. A reversal in the ranks of investment alternatives can be expected if new options are added to the decision set. However, this should be acceptable if done using the same decision process. For new decision sets, independent assessment of the alternatives and their criteria should be performed in a new run of the model.

5. The AHP has proved to be useful in many different types of industries and applications. The flexibility of the method allows it to be applied in the smaller and ordinary decision making processes of the O&G industry by properly building applicable hierarchies including decision criteria not necessarily related to risk.

6. In cases where the consistency of the input data is good enough (i.e., consistency ratio close to zero), the results of an AHP analysis can be used to determine the split of available resources destined for non-mutually exclusive projects, providing not only the ranking of preferences, but also the percentage of resources to put into any given investment option.

7. Through the further use and expansion of this methodology into the Analytic Network Process, there is a potential of evolution of the method, from mere measurement of risk levels into a fully integrated tool that can consider all the factors that actually comprise a complete decision making process: Benefits, Costs, Opportunities and Risks.

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APPENDIX A

Questionnaires

The questionnaires used to gather the information that served for the evaluation process of the Natural environment risks are shown below. The questions are arranged to conform pairwise comparisons; there is a direct comparison of every element against each other, from the point of view of larger, parent criteria.

For the calibration phase of the model (identified as Part A), this process goes down from Level III (as shown on Fig. 3) down to Level IV. Similar questionnaires were applied to evaluate the other risk branches (*Social and economical* and *Resource, technology and management* risks).

Part B is intended to gather judgments for the pairwise comparison of the different investment alternatives; comparing each of the alternatives with each of the criterion of the model. Notice that the questions are addressed in such a way that the responder must focus on the potential risk of each alternative, associated with the according criterion, not on which of the options is actually better than the other.

Proper formulation of the questions to be used, from the point of view of the final objective, can make the difference between a realistic evaluation and garbage data.

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Part A: Model calibration

Which of the following risks would represent the most potential problems, from the **Natural environment** point of view? (compared to each other)

	Very strong importance (7), Moderate importance (3), Moderate importance (3), Very strong importance (7)	
Poor infrastructure	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Frequent natural disasters
	Absolute importance (9), Strong importance (5), Equally important (1), Strong importance (5), Absolute importance (9)	
Poor infrastructure	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Harsh natural environment conditions
Harsh natural environment conditions	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Frequent natural disasters

Which of the following risks would represent the most potential problems related with **frequency of natural disasters**? (compared to each other)

	Very strong importance (7), Moderate importance (3), Moderate importance (3), Very strong importance (7)	
Flooding	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Drought
	Absolute importance (9), Strong importance (5), Equally important (1), Strong importance (5), Absolute importance (9)	
Flooding	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Tsunami
Flooding	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Earthquake
Flooding	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Hurricane
Drought	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Tsunami
Drought	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Earthquake
Drought	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Hurricane
Tsunami	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Earthquake
Tsunami	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Hurricane
Earthquake	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Hurricane

Which of the following risks would represent the most potential problems related with **poor infrastructure**? (compared to each other)

	Very strong importance (7) — Moderate importance (3) — Moderate importance (3) — Very strong importance (7)	
Faraway oil/gas tie-in pipe	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Lack of ground access
	Absolute importance (9) — Strong importance (5) — Equally important (1) — Strong importance (5) — Absolute importance (9)	
Faraway oil/gas tie-in pipe	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	No electric power
Lack of ground access	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	No electric power

Which of the following risks would represent the most potential problems related with **a harsh natural environment**? (compared to each other)

	Very strong importance (7) — Moderate importance (3) — Moderate importance (3) — Very strong importance (7)	
Swamp	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Arctic conditions
	Absolute importance (9) — Strong importance (5) — Equally important (1) — Strong importance (5) — Absolute importance (9)	
Swamp	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Ocean
Swamp	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Desert
Swamp	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Jungle / Forests
Arctic conditions	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Ocean
Arctic conditions	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Desert
Arctic conditions	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Jungle / Forests
Ocean	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Desert
Ocean	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Jungle / Forests
Desert	9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9	Jungle / Forests

Part B: Comparison of investment alternatives

From the point of view of **a faraway location of oil or gas tie in pipe (for transportation and distribution to markets)**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **lack of proper ground access to the site of the prospect**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of a **lack of electric power supply to the site of the prospect**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **flooding possibilities**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **drought possibilities**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **tsunami possibilities**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **earthquake possibilities**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **hurricane possibilities**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **a swamp environment condition**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **arctic environment conditions**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **oceanic (offshore) conditions**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

Project B 9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 Project C

From the point of view of **desert environment conditions** , which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A   9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9   Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A   9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9   Project C

Project B   9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9   Project C

From the point of view of **deep jungle or forest environment**, which of the different investment alternatives (Project A, B, C), represent the greatest potential risk?

Very strong importance | Moderate importance | Moderate importance | Very strong importance

Project A   9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9   Project B

Absolute importance | Strong importance | Equally important | Strong importance | Absolute importance

Project A   9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9   Project C

Project B   9 – 8 – 7 – 6 – 5 – 4 – 3 – 2 – 1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9   Project C

APPENDIX B

Complete Tables from Case Study

The following information is extracted from the model developed in MS Excel®. The information shown corresponds to the branches of Social and economical and Resource, technology and management risks, which complement the Natural environment risks calculations, previously shown in the body of this work.

Resources, Technology and Management Risks

1.- Weight factors on level III through pairwise comparison

Resources, Technology and Management Risks	Manage ment prob	Scarcity of reserves	Low tech level	Difficul dvelpmnt	**Priority**
Management problems	1	1/7	1	1/5	**0.07**
Scarcity of reserves	7	1	7	7	**0.63**
Low tech level	1	1/7	1	1/5	**0.07**
Difficult development	5	1/7	5	1	**0.23**
Total	14.00	1.43	14.00	8.40	0.077

2.- Compare the sub criteria of each of the factors on III with their peers of the same cathegory (level IV) under the same parent criteria

Management Problems	Labor qualif	Lang	Lack/exp labor	**Priority**
Lack of qualified labor	1	2	1	0.37
Language barrier	1/2	1	1/5	0.14
Lack / expensive labor	1	5	1	0.49
Total	2.50	8.00	2.20	0.076

Scarcity of reserves	Resoruce abund.	Low reserves	Inadeq proven reservs	High depletion	Poor well info	**Priority**
Poor resource abundance	1	4	5	2	3	0.40
Low remaning reserves	1/4	1	3	2	2	0.20
Inadequate proven reserves	1/5	1/3	1	1/3	1/5	0.06
High reserve depletion	1/2	1/2	3	1	4	0.21
Poor well info for appraisal	1/3	1/2	5	1/4	1	0.13
Total	2.28	6.33	17.00	5.58	10.20	**0.103**

Low tech level	Prod tech	Explor tech	Suitable equip	**Priority**
Lack production tech	1	1/5	3	0.19
Lack exploration tech	5	1	7	0.72
Lack of suitable equip	1/3	1/7	1	0.08
Total	6.33	1.34	11.00	0.024

Difficult development	Sour gas	Reserv conn	Sensitive form	High viscosity	Low prem	Anisotro	Low energy	Unconv press	**Priority**
High sulphur content	1	1/7	1/3	1/5	1/7	1/3	1/5	1/5	0.02
Poor res. Connectivity	7	1	5	5	3	3	3	5	0.30
Sensitive formation	3	1/5	1	1/3	1/5	1/5	1/2	1/3	0.04
High oil viscosity	5	1/5	3	1	1	1/3	1/2	3	0.10
Low permeability	7	1/3	5	1	1	5	5	5	0.23
Abnormal anisotropy	3	1/3	5	3	1/5	1	2	5	0.15
Low natural energy drive	5	1/3	2	2	1/5	1/2	1	2	0.09
Unconv pressure formation	5	1/5	3	1/3	1/5	1/5	1/2	1	0.06
Total	36.00	2.74	24.33	12.87	5.94	10.57	12.70	21.53	**0.104**

3.- Get final weight of each sub criterion, by multiplying parents weight by each sub factor
Note that the sum of ALL of the weights is =1

Management Problems	Priority
Lack of qualified labor	0.02
Language barrier	0.01
Lack / expensive labor	0.03

Scarcity of reserves	Priority
Poor resource abundance	0.26
Low remaning reserves	0.13
Inadequate proven reserves	0.04
High reserve depletion	0.13
Poor well info for appraisal	0.08

Low tech level	Priority
Lack production tech	0.01
Lack exploration tech	0.05
Lack of suitable equip	0.01

Difficult development	Priority
High sulphur content	0.01
Poor res. Connectivity	0.07
Sensitive formation	0.01
High oil viscosity	0.02
Low permeability	0.05
Abnormal anisotropy	0.03
Low natural energy drive	0.02
Unconv pressure formation	0.01

4.- **Optional:** If required/desired, we could discard those subcriteria with lower comparative weight
As an example, we could assume the following criteria to be neglected:

Neglected criteria	Weight
High oil viscosity	0.01
High Sour gas content	0.01
Ultra deep reservoir	0.02
Sensitive formation	0.02
Low natural drive energy	0.02
Unconv pressure formation	0.02
Lack of suitable equip	0.02

5.- **Optional:** Prioritize again the remaining alternatives (in order to add up to one). Divide each remaining priority by the total (sum) of all

Total of remaining criteria 0.88

Management Problems	Priority
Lack of qualified labor	0.03
Language barrier	0.01
Lack / expensive labor	0.04

Scarcity of reserves	Priority
Poor resource abundance	0.29
Low remaning reserves	0.14
Inadequate proven reserves	0.04
High reserve depletion	0.15
Poor well info for appraisal	0.10

Low tech level	Priority
Lack production tech	0.01
Lack exploration tech	0.05

Difficult development	Priority
Poor res. Connectivity	0.08
Low permeability	0.06
Abnormal anisotropy	0.04

6.- Prioritize each of the alternatives (projects) to each of the selected representative subcriteria

	Management Problems					HCR
0.02	Lack of qualified labor	Project A	Project B	Project C	Priority	
	Project A	1	1/4	1	0.16	
	Project B	4	1	6	0.71	
	Project C	1	1/6	1	0.14	0.009
0.01	Language barrier	Project A	Project B	Project C	Priority	
	Project A	1	4	1/4	0.24	
	Project B	1/4	1	1/6	0.09	
	Project C	4	6	1	0.67	0.047
0.03	Lack / expensive labor	Project A	Project B	Project C	Priority	
	Project A	1	2	1/5	0.17	
	Project B	1/2	1	1/7	0.09	
	Project C	5	7	1	0.74	0.005

	Scarcity of reserves					
0.26	Poor resource abundance	Project A	Project B	Project C	Priority	
	Project A	1	1/4	1/6	0.09	
	Project B	4	1	1/3	0.27	
	Project C	6	3	1	0.64	0.026
0.13	Low remaning reserves	Project A	Project B	Project C	Priority	
	Project A	1	1/3	1/5	0.11	
	Project B	3	1	1/3	0.26	
	Project C	5	3	1	0.63	0.022
0.04	Inadequate proven reserves	Project A	Project B	Project C	Priority	
	Project A	1	2	3	0.52	
	Project B	1/2	1	3	0.33	
	Project C	1/3	1/3	1	0.14	0.043
0.13	High reserve depletion	Project A	Project B	Project C	Priority	
	Project A	1	1/3	1/6	0.10	
	Project B	3	1	1/3	0.25	
	Project C	6	3	1	0.65	0.009
0.08	Poor well info for appraisal	Project A	Project B	Project C	Priority	
	Project A	1	1/3	4	0.26	
	Project B	3	1	7	0.66	
	Project C	1/4	1/7	1	0.08	0.014

	Low tech level					HCR
0.01	Lack production tech	Project A	Project B	Project C	Priority	
	Project A	1	3	1/2	0.33	
	Project B	1/3	1	1/3	0.14	
	Project C	2	3	1	0.52	0.043
0.05	Lack exploration tech	Project A	Project B	Project C	Priority	
	Project A	1	1/6	1/4	0.09	
	Project B	6	1	4	0.67	
	Project C	4	1/4	1	0.24	0.047
0.01	Lack of suitable equip	Project A	Project B	Project C	Priority	
	Project A	1	1/4	2	0.22	
	Project B	4	1	3	0.62	
	Project C	1/2	1/3	1	0.16	0.074

	Difficult development					
0.01	High sulphur content	Project A	Project B	Project C	**Priority**	
	Project A	1	4	7	0.70	
	Project B	1/4	1	3	0.21	
	Project C	1/7	1/3	1	0.09	0.013
0.07	Poor res. Connectivity	Project A	Project B	Project C	**Priority**	
	Project A	1	2	3	0.54	
	Project B	1/2	1	2	0.30	
	Project C	1/3	1/2	1	0.16	0.008
0.01	Sensitive formation	Project A	Project B	Project C	**Priority**	
	Project A	1	3	4	0.62	
	Project B	1/3	1	2	0.24	
	Project C	1/4	1/2	1	0.14	0.012
0.02	High oil viscosity	Project A	Project B	Project C	**Priority**	
	Project A	1	3	7	0.64	
	Project B	1/3	1	5	0.28	
	Project C	1/7	1/5	1	0.07	0.028
0.05	Low permeability	Project A	Project B	Project C	**Priority**	
	Project A	1	4	6	0.69	
	Project B	1/4	1	3	0.22	
	Project C	1/6	1/3	1	0.09	0.024
0.03	Abnormal anisotropy	Project A	Project B	Project C	**Priority**	
	Project A	1	1	1	0.33	
	Project B	1	1	1	0.33	
	Project C	1	1	1	0.33	0.000
0.02	Low natural energy drive	Project A	Project B	Project C	**Priority**	
	Project A	1	2	5	0.57	
	Project B	1/2	1	4	0.33	
	Project C	1/5	1/4	1	0.10	0.015
0.01	Unconv pressure formation	Project A	Project B	Project C	**Priority**	
	Project A	1	2	4	0.54	
	Project B	1/2	1	4	0.35	
	Project C	1/4	1/4	1	0.11	0.036

Summary of weights for Resources, Technology and Management Risks

Criteria Weight	Criteria	Project A	Project B	Project C
0.02	Lack of qualified labor	0.16	0.71	0.14
0.01	Language barrier	0.24	0.09	0.67
0.03	Lack / expensive labor	0.17	0.09	0.74
0.01	Lack production tech	0.33	0.14	0.52
0.05	Lack exploration tech	0.09	0.67	0.24
0.01	Lack of suitable equip	0.22	0.62	0.16
0.26	Poor resource abundance	0.09	0.27	0.64
0.13	Low remaning reserves	0.11	0.26	0.63
0.04	Inadequate proven reserves	0.52	0.33	0.14
0.13	High reserve depletion	0.10	0.25	0.65
0.08	Poor well info for appraisal	0.26	0.66	0.08
0.01	High sulphur content	0.70	0.21	0.09
0.07	Poor res. Connectivity	0.54	0.30	0.16
0.01	Sensitive formation	0.62	0.24	0.14
0.02	High oil viscosity	0.64	0.28	0.07
0.05	Low permeability	0.69	0.22	0.09
0.03	Abnormal anisotropy	0.33	0.33	0.33
0.02	Low natural energy drive	0.57	0.33	0.10
0.01	Unconv pressure formation	0.54	0.35	0.11

7.- Get final (overall) weight of each alternative respect to each criteria by multiplying the results obtained in the previous step by the individual weight of each of the criterion (calculated ini steps 3 - 5)

Overall alternative weight by criteria	Project A	Project B	Project C
Lack of qualified labor	0.00	0.02	0.00
Language barrier	0.00	0.00	0.01
Lack / expensive labor	0.01	0.00	0.02
Lack production tech	0.00	0.00	0.01
Lack exploration tech	0.00	0.03	0.01
Lack of suitable equip	0.00	0.00	0.00
Poor resource abundance	0.02	0.07	0.16
Low remaning reserves	0.01	0.03	0.08
Inadequate proven reserves	0.02	0.01	0.00
High reserve depletion	0.01	0.03	0.09
Poor well info for appraisal	0.02	0.05	0.01
High sulphur content	0.00	0.00	0.00
Poor res. Connectivity	0.04	0.02	0.01
Sensitive formation	0.01	0.00	0.00
High oil viscosity	0.01	0.01	0.00
Low permeability	0.04	0.01	0.01
Abnormal anisotropy	0.01	0.01	0.01
Low natural energy drive	0.01	0.01	0.00
Unconv pressure formation	0.01	0.01	0.00

Total Weight for Resources, Technology and Management Risks	Project A	Project B	Project C
	0.24	0.33	0.43

Social-Economic Risks

1.- Weight factors on level III through pairwise comparison

Social-Economical Risks	Law Inconsist	Bad finance environment	Social unsteady	**Priority**
Law inconsistancy	1	2	3	**0.52**
Bad financial environment	1/2	1	3	**0.33**
Social unsteadiness	1/3	1/3	1	**0.14**
Total	1.83	3.33	7.00	0.043

2.- Compare the sub criteria of each of the factors on III with their peers of the same category (level IV) under the same parent criteria

Law inconsistancy	Tax rate increase	Barrier in capital export	Environ regulation	**Priority**
Tax rate increase	1	3	4	0.59
Barrier in capital export	1/3	1	4	0.30
Strict environmental regulation	1/4	1/4	1	0.11
Total	1.58	4.25	9.00	0.082

Bad financial environment	Interest rate increase	Partner w/o financial support	Inflation	Debt/credit difficulties	Exchange rate fluctuations	**Priority**
Interest rate increase	1	5	3	2	2	0.37
Partner w/o financial support	1/5	1	1/2	1/4	2	0.10
Inflation	1/3	2	1	1/4	1/2	0.10
Debt/credit difficulties	1/2	4	4	1	3	0.30
Exchange rate fluctuations	1/2	1/2	2	1/3	1	0.13
Total	2.53	12.50	10.50	3.83	8.50	0.077

Social unsteadiness	War/terrori sm attacks	Public security	Regimen subrogation	Intnl crackdown	Bad bilateral relationship	**Priority**
War/terrorism attacks	1	3	3	1/2	4	0.29
Poor public security	1/3	1	3	1/3	4	0.19
Regimen subrogation	1/3	1/3	1	1/2	3	0.12
International crackdown	2	3	2	1	3	0.34
Bad bilateral relationships	1/4	1/4	1/3	1/3	1	0.06
Total	3.92	7.58	9.33	2.67	15.00	0.097

3.- Get final (overall) weight of each sub criterion, by multiplying parents weight by each sub factor
Note that the sum of ALL of the weights is =1

Law inconsistancy	Priority
Tax rate increase	0.31
Barrier in capital export	0.16
Strict environmental regulation	0.06

Bad financial environment	Priority
Interest rate increase	0.12
Partner w/o financial support	0.03
Inflation	0.03
Debt/credit difficulties	0.10
Exchange rate fluctuations	0.04

Social unsteadiness	Priority
War/terrorism attacks	0.04
Poor public security	0.03
Regimen subrogation	0.02
International crackdown	0.05
Bad bilateral relationships	0.01

4.- **Optional:** If required/desired, we could discard those subcriteria with lower comparative weight
As an example, we could assume the following criteria will be neglected:

Neglected criteria	Weight
International crackdown	0.05
Bad bilateral relationships	0.01
War/terrorism attacks	0.04

5.- **Optional:** Prioritize again the remaining alternatives (in order to add up to one). Divide each remaining priority by the total (sum) of all

Total of remaining criteria	0.90

Law inconsistancy	Priority
Tax rate increase	0.35
Barrier in capital export	0.17
Strict environmental regulation	0.06

Bad financial environment	Priority
Interest rate increase	0.14
Partner w/o financial support	0.04
Inflation	0.04
Debt/credit difficulties	0.11
Exchange rate fluctuations	0.05

Social unsteadiness	Priority
Poor public security	0.03
Regimen subrogation	0.02

6.- Prioritize each of the alternatives (projects) to each of the selected representative subcriteria

	Law inconsistancy					HCR
0.31	Tax rate increase	Project A	Project B	Project C	**Priority**	
	Project A	1	4	5	0.67	
	Project B	1/4	1	3	0.23	
	Project C	1/5	1/3	1	0.10	0.043
0.16	Barrier in capital export	Project A	Project B	Project C	**Priority**	
	Project A	1	4	6	0.67	
	Project B	1/4	1	4	0.24	
	Project C	1/6	1/4	1	0.09	0.047
0.06	Strict environmental regulation	Project A	Project B	Project C	**Priority**	
	Project A	1	3	1/4	0.23	
	Project B	1/3	1	1/5	0.10	
	Project C	4	5	1	0.67	0.043

	Bad financial environment					
0.12	Interest rate increase	Project A	Project B	Project C	**Priority**	
	Project A	1	1/2	4	0.33	
	Project B	2	1	5	0.57	
	Project C	1/4	1/5	1	0.10	0.015
0.03	Partner w/o financial support	Project A	Project B	Project C	**Priority**	
	Project A	1	1/4	3	0.23	
	Project B	4	1	5	0.67	
	Project C	1/3	1/5	1	0.10	0.043
0.03	Inflation	Project A	Project B	Project C	**Priority**	
	Project A	1	4	7	0.69	
	Project B	1/4	1	4	0.23	
	Project C	1/7	1/4	1	0.08	0.030
0.10	Debt/credit difficulties	Project A	Project B	Project C	**Priority**	
	Project A	1	1/2	2	0.30	
	Project B	2	1	3	0.54	
	Project C	1/2	1/3	1	0.16	0.008
0.04	Exchange rate fluctuations	Project A	Project B	Project C	**Priority**	
	Project A	1	1/5	1/3	0.11	
	Project B	5	1	3	0.63	
	Project C	3	1/3	1	0.26	0.022

	Social unsteadiness					HCR
0.04	War/terrorism attacks	Project A	Project B	Project C	**Priority**	
	Project A	1	1/4	2	0.19	
	Project B	4	1	6	0.70	
	Project C	1/2	1/6	1	0.11	0.004
0.03	Poor public security	Project A	Project B	Project C	**Priority**	
	Project A	1	2	6	0.58	
	Project B	1/2	1	5	0.34	
	Project C	1/6	1/5	1	0.08	0.015
0.02	Regimen subrogation	Project A	Project B	Project C	**Priority**	
	Project A	1	4	4	0.66	
	Project B	1/4	1	2	0.21	
	Project C	1/4	1/2	1	0.13	0.032
0.05	International crackdown	Project A	Project B	Project C	**Priority**	
	Project A	1	1/4	3	0.23	
	Project B	4	1	5	0.67	
	Project C	1/3	1/5	1	0.10	0.043
0.01	Bad bilateral relationships	Project A	Project B	Project C	**Priority**	
	Project A	1	5	7	0.72	
	Project B	1/5	1	3	0.19	
	Project C	1/7	1/3	1	0.08	0.024

Summary of weights for Resources, Technology and Management Risks

Criteria Weight	Criteria	Project A	Project B	Project C
0.31	Tax rate increase	0.67	0.23	0.10
0.16	Barrier in capital export	0.67	0.24	0.09
0.06	Strict environmental regulation	0.23	0.10	0.67
0.12	Interest rate increase	0.33	0.57	0.10
0.03	Partner w/o financial support	0.23	0.67	0.10
0.03	Inflation	0.69	0.23	0.08
0.10	Debt/credit difficulties	0.30	0.54	0.16
0.04	Exchange rate fluctuations	0.11	0.63	0.26
0.04	War/terrorism attacks	0.19	0.70	0.11
0.03	Poor public security	0.58	0.34	0.08
0.02	Regimen subrogation	0.66	0.21	0.13
0.05	International crackdown	0.23	0.67	0.10
0.01	Bad bilateral relationships	0.72	0.19	0.08

7.- Get final (overall) weight of each alternative respect to each criteria by multiplying the results obtained in the previous step by the individual weight of each of the criterion (calculated in steps 3 - 5)

Overall alternative weight by criteria	Project A	Project B	Project C
Tax rate increase	0.21	0.07	0.03
Barrier in capital export	0.10	0.04	0.01
Strict environmental regulation	0.01	0.01	0.04
Interest rate increase	0.04	0.07	0.01
Partner w/o financial support	0.01	0.02	0.00
Inflation	0.02	0.01	0.00
Debt/credit difficulties	0.03	0.05	0.02
Exchange rate fluctuations	0.00	0.03	0.01
War/terrorism attacks	0.01	0.03	0.00
Poor public security	0.02	0.01	0.00
Regimen subrogation	0.01	0.00	0.00
International crackdown	0.01	0.03	0.00
Bad bilateral relationships	0.01	0.00	0.00

Total Weight for Social Environment Risks	Project A	Project B	Project C
	0.48	0.37	0.14

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