Reliability&Risk Management

STOCHASTIC INTEGRAL METHODOLOGY FOR EVALUATION OF EXPLORATION PROJECTS, CONSIDERING UNCERTAINTY OF INFORMATION AND THE PROBABILISTIC INTERDEPENDENCE BETWEEN PROSPECTS AND DIFFERENT LAYERS/GEOLOGICAL TARGETS - MEIVAE

"STOCHASTIC INTEGRAL METHODOLOGY FOR EVALUATION OF EXPLORATION PROJECTS, CONSIDERING UNCERTAINTY OF INFORMATION AND THE PROBABILISTIC INTERDEPENDENCE BETWEEN PROSPECTS AND DIFFERENT LAYERS/GEOLOGICAL TARGETS"

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This methodology, fully stochastic in nature, is designed to evaluate and optimize exploration projects that integrate multiple opportunities or prospects, and to generate a Risk Mitigation Options portfolio with specific actions that affect the critical variables in order to:

- ✓ Improve Return on Investment of Exploratory Projects
- ✓ Increase Success Probability in Geological Exploratory Campaign
- ✓ Reduced the OPEX in Exploration Projects

The key differentiators of the proposed methodology are:

- ✓ Considers the natural uncertainty of information in the exploratory stage and incorporates different techniques to make valid statistical inference with different types, qualities and quantities of information, with emphasis on poor, diffuse or uncertain information.
- ✓ Establishes optimal drilling sequence that maximizes the value promise associated with a set of opportunities, for which considers:
  - Optimal selection of prospects that will integrate the project to be developed, seeking the best combination of maturity, models definition level and resources needed to incorporate them.
  - Evaluation of multiple possible sequences of activity taking into account the availability of drilling equipment, mobilization costs, availability of facilities, among others.
- ✓ Allows the generation of Stochastic Production Forecasts and Investment in Exploration Wells along with their respective development Wells in case of success, based on the concept of Well-Type. It includes the probability tree that considers the geological success probability for each exploratory location, as well as for the development Wells. It also includes the effect of probabilistic dependence between exploration opportunities and between the different geological targets.

Keywords: Exploration, Resources, Stochastic Estimation, Analog Data, Prospect, Geological Success, Geological Objective, Geological Interdependence, Stochastic Optimization, Drilling, Montecarlo Simulation

1. Introduction

Exploration is the term used in the petroleum industry to describe the search for hydrocarbons. From the beginning of oil exploration to date new and complex technologies have been developed to infer the presence of hydrocarbons. They have focused on reducing risk factors, however, it has not yet managed to develop an inference method to define or secure the presence of hydrocarbons. That is why to verify the existence of hydrocarbons it should be resorted to the drilling of exploratory wells, only then you can make sure that what was defined as a "prospect" is and functions as a "hydrocarbon reservoir."

The "exploration", in the context of the oil industry, is by its nature, the stage at which they handle higher levels of uncertainty, and paradoxically it is also the stage where decisions are made that affect most (for better or worse) the project economics.

Historically, the challenge to economically "assess" exploration and production projects, from the exploratory phase, was developed with various methodological approaches that have evolved over time and from different angles try to deal with the need to justify high investments with models that feed on scant, uncertain or fuzzy information.

This feature of the exploratory stage implies:

✓Use of probability and statistical inference as pillars for the possibility estimation.

✓Use of decision models that take into account the uncertainty of the variables, that is, models based on concepts of risk [1],[2].

The use of probability and statistical inference in statistical exploration has evolved from traditional to Bayesian statistics [1], [2].

NOTE: Bayesian statistics has many applications, but in the context of exploratory world has two particularly important applications:

1. Conditional probabilities that apply to model the dependence between prospects and geological targets. This application will be explained in detail later in the document.
2. Treatment of poor, uncertain and/or vague information, explained below.

The traditional statistics is the science of "experience" and we could say that is the art of mathematically shape the experience, however, a typical problem of our time is that we need to make estimates about processes or "new" situations on which have no experience or history, or if we do, it is poor or insufficient. In these cases, we draw on similar experiences of "others" that can serve as a reference, it is filtered and adapted to our reality using our common sense, and then we estimate, analyze and decide. It is important to mention that we almost never decide based entirely on the experience of others, and we do not based only on common sense or experience. The most usual is to combine both.

Bayesian statistics, through the Bayes theorem allows us to make these combinations, in a structured way, and mathematically supported. The theorem allows to treat the experience of "others" as "prior knowledge", usually represented by a probability distribution, and our experience (own data) or common sense (expert opinion) as "evidence". Both are mathematically combined to obtain a modified probability distribution known as "posterior, improved or updated knowledge"

Meanwhile decision making has gone from using qualitative risk models to intensive quantitative risk analysis [3],[4].

NOTE: Risk Analysis has two distinct schools or trends; Qualitative or Subjective Indexes School, and Quantitative School.

The Qualitative or Subjective Indexes School uses as a basic tool of analysis a Matrix of multiple attributes, whose main product is a "risk rating (high, medium, low)." The main virtue of this trend is the speed and ease of analysis, but its weakness is the subjectivity and its limitation to be audited.

Quantitative school otherwise uses as a basic tool of analysis The Probabilistic Characterization of Information of Variables and the Stochastic Modeling Process. The product is a "risk measurement"; its main virtue is the subjectivity reduction and improves the traceability of the analysis, while its weakness is the complexity.

The "explorers" are for the oil and gas industry, the pioneers in the use of stochastic models and the formalization of risk analysis as the support science for decision-making. Clear examples of the above are shown in the following works:

- ✓ Newendorp P.D.[5],"Decision Analysis for Petroleum Exploration", de1975.
- ✓ Capen E.C.[6], "The Difficulty of Assessing Uncertainty", de 1976
- ✓ Megill R.E.[7], "An Introduction to Risk Analysis", de 1984
- ✓ Rose, Peter R.[8] Dealing with Risk and Uncertainty in Exploration de 1987
- ✓ Rose, Peter R.[9], "The Business of Petroleum Exploration" de 1992.
- ✓ S.K. Peterson, J.A. Murtha, F.F. Schneider.[10], "Risk Analysis and Monte Carlo Simulation Applied to the Generation of Drilling AFE Estimates" de 1993.
- ✓ Murtha J.A.[11], "Estimating reserves and Success for a prospect with geologically dependent layers" – de 1995
- ✓ Galli A., Armstrong M., Jehl B.[12], "Comparing Three Methods for Evaluating Oil Projects Option Pricing, Decision Trees, and Monte Carlo Simulations" de 1999.
- ✓ Wang B., Kokolis G., Litvak L.B., Rapp W.J.[13], "Dependent Risk Calculations in Multiple-Prospect Exploration Evaluations" de 2000.
- ✓ Falla L.C.[14]," Probabilistic Model To Develop Multilayer Gas and Oil Prospects" de 2001
- ✓ Coordinating Committee for Offshore Prospecting in Asia.[15], "Guidelines for Risk Assessment of Petroleum Prospects" de 2001

These works propose approaches that clearly show the evolution in the use of techniques for modeling uncertainty and risk ranging from simple, to conditional probabilities, Bayesian probabilities, probability trees, Monte Carlo simulation and finally combination of decision trees with Monte Carlo simulation and probabilistic interdependence.

Additionally, these works separately attend various aspects such as:

- ✓ Probabilistic Estimation of Resources and Reserves
- ✓ Probability estimation of discovering or Geological Success Probability.
- ✓ Probabilistic Dependence among prospects, and Layers/Geological Targets.
- ✓ Production Forecast associated to a group of opportunities.
- ✓ Economic Evaluation of an Exploration Project.

In this paper, we present a methodology that addresses all the above aspects in an integrated manner, and adds key features to give even more sense of reality to the economic evaluation of projects and tools to generate a Risk Mitigation Options Portfolio comprised with specific actions that affect the critical variables and aim to:

- ✓ Improve Return on Investment Exploratory Projects
- ✓ Increase Success of Geological Exploratory Campaigns
- ✓ Reduced the OPEX in Exploration Projects

The key differentiators of the proposed methodology are:

- ✓ Considers the natural uncertainty of information in the exploratory stage and incorporates different techniques to make valid statistical inference with different types, qualities and quantities of information, with emphasis on poor or uncertain information.

- ✓ Allows the generation of feasible scenarios for resources and reserves incorporation, and facilitates quick assessment and reduction of technically feasible options to a reasonable number

- ✓ Establishes optimal drilling sequence that maximizes the value promise associated with a set of opportunities, for which considers:

  - Optimal selection of prospects that will integrate the project to be developed, seeking the best combination of maturity and level of definition of the models, and resources needed to incorporate them.
  - Evaluation of multiple possible sequences of activity taking into account the availability of drilling equipment, mobilization costs and availability of facilities, among others.

- ✓ Allows the generation of Stochastic Production Forecasts and Investment in Exploration Wells along with their respective development Wells, based on:

  - The concept of similar Well-Type and the probability tree that considers the geological success determined for each exploratory location, the likelihood of success of its development Wells and the effect of probabilistic dependence between exploration opportunities, and between different geological targets.

- Works with double probability in the simulation, one for the exploratory well, and another for each of the estimated development Wells required for the reservoir exploitation, if exploratory localization results successful (geological and commercially).

✓ Stochastic Economic Evaluation for each stage of incorporation of reserves and resources.

2. Proposed Methodology:

Stochastic Integral Methodology for Evaluation of Exploration Projects, Considering Uncertainty of Information and the Probabilistic Interdependence between Prospects And Different Layers/Geological Targets", can be divided into the following stages:

1. Evaluate multiple scenarios for the incorporation of resources and select a set of technically feasible ones.
2. For each scenario of incorporation of resources:

   2.1. Perform the probabilistic estimation of Volumes and Resources for each prospect that integrates the exploration portfolio.

   2.2. Estimate the probability of geological success (Pg) for each prospect that integrates the exploration portfolio, considering probabilistic dependencies between prospects and geological targets.

   2.3. Generate a Scheduled and Optimized Drilling program based on:

   ✓ Optimal selection of prospects that will integrate the project to be developed, seeking the best combination of maturity and models definition level, and the resources to be incorporated by them.

   ✓ Evaluation of multiple possible sequences of activity taking into account the availability of drilling equipment, mobilization costs and availability of facilities among others.

   ✓ Stochastic Production and Investment Generation for the Optimized and Scheduled Drilling Activity,:

   ✓ Daily and Cumulative Production of Oil, Water and Gas.

   ✓ Investments in Exploratory and Development Wells based on the concept of the model of “Well-Type”.

   2.4. Probabilistic Economic Evaluation for the Optimized Activity.

3. Ranking of the evaluated scenarios, and selection of the optimal resource incorporation one.

The following lines describe and list the most important technical aspects of each of the stages:

Stage 1: Evaluate multiple scenarios for the incorporation of resources and select the set of technically feasible ones.

Stage 2: Stochastic Evaluation of each selected scenario.

Stage 2.1: Perform the probabilistic estimation of Volumes and Resources [11],[13],[14],[16],[17], for each prospect that integrates the exploration portfolio.,

The methodology considers the probabilistic estimation of volumes and resources for each exploratory location based on the procedure described in Chapters 5 and 6 of the "Guidelines for the Evaluation of Petroleum Reserves and Resources SPE 2001”[16]. Figure 1 shows a schematic of the procedure previously mentioned:

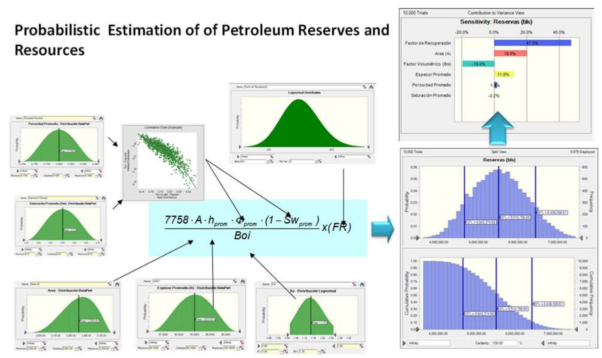

Figure 1 – Scheme of the Procedure for Probabilistic Estimation of Volumes and Resources based on Chapters 5 and 6 of the "Guidelines for the Evaluation of Petroleum Reserves and Resources SPE 2001"

Aspects requiring particular attention at this stage are:

✓ Address rigorously the criteria and concepts of the system of classification of Prospective Resources expressed in the document "Petroleum Resources Management System PRMS", endorsed by SPEE: Society of Petroleum Evaluation Engineers, SPE: Society of Petroleum Engineers, WPC: World Petroleum Council and AAPG: American Association of Petroleum Geologists. [18]

✓ Appropriate probabilistic characterization for each of the variables involved in the calculation. The characteristic of the information in the exploratory stage involves using "analog data" and "expert opinion" because there is "little evidence or own data of the location". This involves intensive Bayes Theorem usage [1], [2], [3], [4]. Figure 2 outlines the use of the aforementioned theorem to estimate the probability distributions of averages of properties involved in the estimation of resources.

✓ Consider probabilistic correlations between properties where applicable, and appropriate truncation of probability distributions in ranges that are "physically possible"

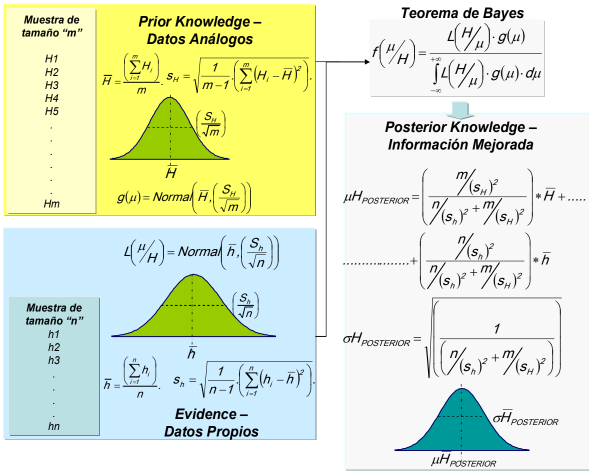

Figure 2 - Diagram of the Procedure for Probabilistic Characterization of the Averages Values of the Properties (porosity, saturation, thickness), from Insufficient Evidence and Analog Data, with Bayes' Theorem"

- ✓ Properly treat probabilistic dependence between "multiple" geological targets or "layers" within the same prospect. References [11], [13], [14] are excellent papers that address the issue mentioned in detail.
- ✓ In case of requiring the sum of resources, it is important to consider the dependence between prospects and the level of uncertainty of each estimate, the item is treated in detail in Chapter 6 of reference [16], and is considered a key aspect to calculate resources.

Stage 2.2: Estimating the Probability of Geological Success or Probability of Discovering (Pg) for each prospect that integrates the Exploration Portfolio, considering interdependence between prospects and geological targets.

To estimate the Probability of Geological Success (Pg), it is established the ranges of probability of existence of each of the processes that are required for the oil system to operate:

- ✓ Presence of a reservoir or reservoir rock.
- ✓ Presence of a Trap
- ✓ Presence of a Hydrocarbon Charge System
- ✓ Effective retention of oil after migration.

Consequently, the model to estimate the Probability of Detection (Pg) is based on four probabilistic parameters:

- ✓ **P1:** Probability of the presence of an effective reservoir or reservoir rock.
- ✓ **P2:** Probability of the presence of an effective Trap.
- ✓ **P3:** Probability of the presence of a Hydrocarbon Loading System.
- ✓ **P4:** Probability of an effective retention of oil after migration.

Finally, the Probability of Discovering (Pg), is estimated with the following model:

Pg= P1 x P2 x P3 x P4 (1)

Pg= P(Reservoir Rock) x P(Trap) x P(Charge) x P(Retention)

NOTE: The following explains with more detail each of these probabilistic parameters:

- ✓ **P1: Probability of the presence of an effective reservoir or reservoir rock.**

This probability includes two aspects:

The first aspect **(P1a):** is the probability of existence of the facies in the reservoir with the minimal properties such as net / gross and thickness.

The second aspect **(P1b):** is the probability that the reservoir rock has effective properties of porosity, permeability and hydrocarbon saturation.

Finally: **P1= P1a x P1b** (2)

P2: Probability of the presence of an effective Trap:

This probability includes two aspects:

The first aspect **(P2a)**: is the probability of existence of a reservoir rock volume

The second aspect **(P2b)**: is the probability that there is an effective seal mechanism for the structure and the trap had formed.

Finally: **P2= P2a x P2b** (3)

P3: Probability of the presence of a Hydrocarbon Charging System.

This probability includes two aspects:

The first aspect **(P3a):** is the probability of existence of a source or generating rock

The second aspect **(P3b)**: is the probability of efficient migration from the source rock to the trap.

Finally: **P3= P3a x P3b** (4)

P4: Probability of an effective retention of oil after migration: evaluates the probability that the trap has been filled with hydrocarbon in a given period in time.

The "Guidelines for Risk Assessment of Petroleum Prospects" [15], addresses in detail the issue of estimating each of the parameters involved in the estimation of the (Pg).

The estimate of (Pg) for each of the prospects that are part of an exploratory portfolio is a known and dominated aspect by exploratory organizations in the industry; however, one aspect that requires special attention in the estimation of the (Pg) is to consider the *effect of dependency between prospects and dependence between different geological targets.*

NOTE: The probabilistic dependency or "interdependence between exploration opportunities or prospects" implies that the result of the drilling of any of the prospects (with success or failure), impacts the likelihood of discovery of the others.

The independence between prospects can be assumed for example in the case that they belong to different geological plays, but if they belong to the same play, then they should be considered interdependent.

Such probability calculations are based on conditional probabilities and are governed by the so-called Bayes Theorem [1], [2], [3], [4], [15].

To illustrate the effect of the interdependence, an example of 5 prospects "X" located in an exploratory area and that are considered exploratory dependent is shown. As explained in the equations (1), (2), (3) and (4) to estimate the (Pg) is necessary to consider multiple probabilistic parameters.

In the case of interdependent prospects, the factors of the above equation must be separated into two groups; common factors to all prospects, generating a probability P (S), and factors that are not common to the different prospects under analysis, generating different probabilities denoted as P (X / S). In this case, by applying Bayes Theorem [1], [2], [15] in its meaning to the treatment of conditional probabilities, the probability of finding a certain prospect "X", is expressed as:

P(X)=P(S) x P(X|S) (5)

Table 1 shows the estimation of the individual probabilities P (X) for the example of 5 prospects.

Probabilistic Factors		Prospect A	Pospecto B	Prospect C	Prospect D	Prospect E
P1a	Reservoir Facies	0.8	0.8	0.8	0.8	0.8
P1b	Porosity	0.6	1.0	0.5	0.8	0.9
P2a	Trap Identification	1.0	0.9	0.9	0.7	0.6
P2b	Seal	0.9	0.9	0.8	1.0	1.0
P3a	Mature Sorce Rock	0.7	0.7	0.7	0.7	0.7
P3b	Migration	1.0	0.8	0.9	0.8	0.8
P4	Retention	1.0	1.0	1.0	1.0	1.0
P(S)=P1a x P3a x P4	Common Factors	0.56	0.56	0.56	0.56	0.56
P(X/S)=P1b x P2a x P2b x P3b	Independent Factors	0.54	0.648	0.324	0.448	0.432
P(X)=P(S) x P(X/S)	Individuial Probability	0.3024	0.3629	0.1814	0.2509	0.2419

Table 1 - Shows factors P1a, P3a and P4 common for five prospects, and P1b, P2a, P2b and P3b, uncommon or independent for the 5 prospects. This is calculated by P (S) = P1a x P3a x P4, and P (X / S) = P1b x P2a x P2b x P3b, for each prospect, to finally obtain the individual probabilities P (A), P (B), P (C), P (D) and P (E) using the equation of Bayes P (x) = P (S) x P (x / S).

With the results summarized in Table 1, now it can be estimated how the individual probabilities are affected, for example in the case of success of Prospect A, using the tree shown in Figure 3.

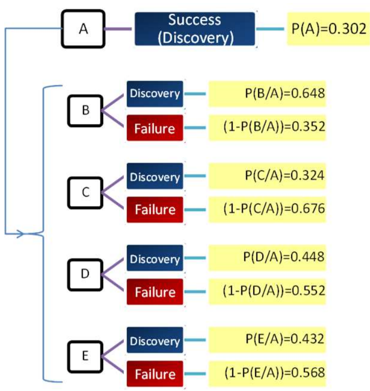

Figure 3 – Trees of Conditional Probabilities if Prospect A is successful.

If Prospect A is a successful discovering, the probability of making discoveries in B, C, D and E increases because the common factors are confirmed, that is P (S) = 1, so that P (X) = P (X / S), which means that the probability of detection in B, C, D and E is governed by the non-common or independent factors.

It can be also calculated how the individual probabilities are affected in the case that Prospect A fails using the above mentioned Bayes theorem [1], [2], [15] to construct a tree of conditional probabilities as figure 4 shows.

If the prospect is a failure, the probability of making discoveries in B, C, and D is substantially reduced but there is still a remaining probability. To calculate this probability it is derived from Bayes Theorem [1], [2], [15], the following expression:

$P(X|\bar{A}) = (P(X) \times [1-P(S_A)])/[1-P(A)]$ (6)

The expression implies that the remaining probability of success in a prospect X since A was a failure, P (X | A) is the probability of success P (X) affected by the likelihood that failure of "A" is due to independent factors [1-P (SA)].

Applying equation (6) to the prospects B, C, D and E, it is obtained:

- ✓ Probability of Prospect B being successful given that A was a failure:

P (B|Ā) = [0.3639 x (1 – 0.54)] / (1 – 0.3024) = 0.239

- ✓ Probability of Prospect C being successful given that A was a failure:

P (C|Ā) = [0.1814 x (1 – 0.54)] / (1 – 0.3024) = 0.120

- ✓ Probability of Prospect D being successful given that A was a failure:

P (D|Ā) = [0.2509 x (1 – 0.54)] / (1 – 0.3024) = 0.165

- ✓ Probability of Prospect E being successful given that A was a failure:

P (E|Ā) = [0.2419 x (1 – 0.54)] / (1 – 0.3024] = 0.160

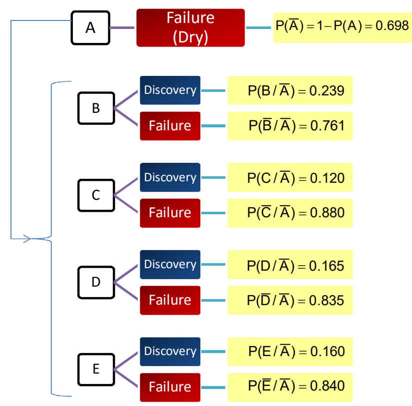

Figure 4 – Trees of Conditional Probabilities if Prospect A is a failure.

Finally, the probabilistic model for the five (5) prospects analyzed is summarized in probability tree shown in Figure 6.

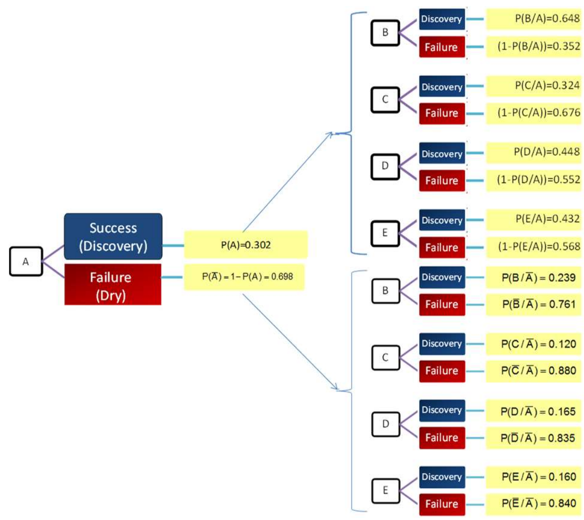

Figure 6 – Tree of Conditional Probability of Prospects B, C, D and E depending on the result in A.

Stage 2.3: Generate a Scheduled and Optimized Drilling Activity.

One factor that contributes most to the success of geological, volumetric and economic of exploration campaigns is the selected sequence of drilling activity. The natural tendency is to focus the efforts on those prospects in which it is estimated a greater accumulation of hydrocarbons and where there is a suspicion of hydrocarbon of interest to the business strategy, but in this regard, there are several questions:

- ✓ Have these prospects the best defined models?
- ✓ How robust is the information used to define the models?

- ✓ What geological risk was defined for each prospect?
- ✓ Are there any nearby facilities to manage production in case of having a successful discovery?
- ✓ Is there drilling equipment available for the estimated drilling date?
- ✓ What are the costs of transportation and conditioning required for the area to be drilled?

To answer these questions and address and some others in the search for a sequence of activities that aim to maximize value, the proposed methodology considers two key activities or stages:

Stage 2.3.1: Optimal selection of prospects to integrate the project to be developed. It seeks for the best combination of maturity and models definition level and resources to be incorporated.

The Reliability or Maturity Index is an indicator that allows determining the level of definition, reliability, maturity, robustness, and model uncertainty of a prospect. This index or indicator improves prospects ranking.

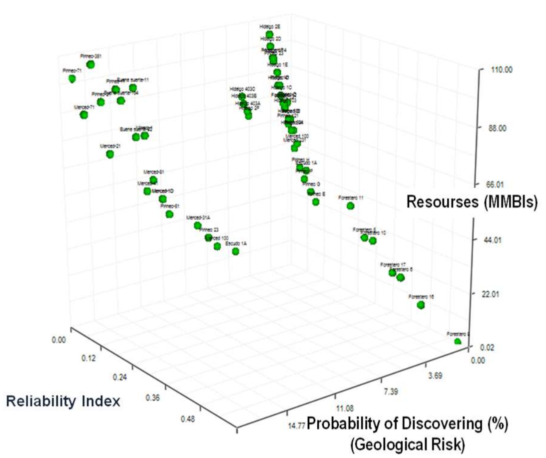

Figure 7 - Model (3D Matrix) of hierarchy that considers resource to incorporate, Reliability and Geological Risk Index for each exploratory location in the exploration portfolio.

From this matrix is possible to select the set of prospects that have the best combination of resource to incorporate, Probability of geological success (Pg), and Reliability Index.

The set of selected prospects constitutes the activity that now must be scheduled; but, in which order should these Wells be drilled in order to obtain maximum profitability?. This question is answered in the next stage.

Stage 2.3.2: Evaluation of multiple possible sequences of activity selected in the previous stage taking into account the availability of drilling equipment, mobilization costs and availability of facilities among others.

To achieve the "optimal sequence" thousands of combinations are performed by a powerful simulation algorithm until obtaining the combination of activities (sequence) that maximizes profitability.

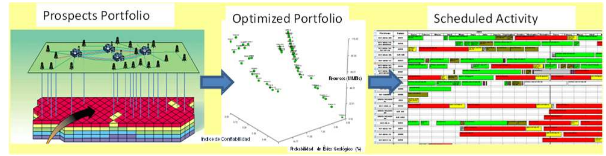

Figure 8 - From the optimized portfolio achieved in the previous stage, the optimal sequence or scheduled activity is generated, by evaluating multiple possible sequences of activity taking into account the availability of drilling equipment, mobilization costs, and the availability of facilities.

Stage 2.4: Generation of Stochastic Production Forecasts of Oil, Water and Gas and Investment in Exploration Wells and Development Wells.

This stage is based on the following elements:

- ✓ The Concept of Analog Well – Probabilistic.

NOTE: The production forecast in the life cycle of the well is obtained from the initial quota of production that is “declined” at a rate equivalent to a factor (D) known as “decline factor or rate of decline”. The resulting profile is also known as "the well decline curve."

The production decline curve represents a dynamic method to predict the approximated future production capacity of wells, reservoirs and fields.

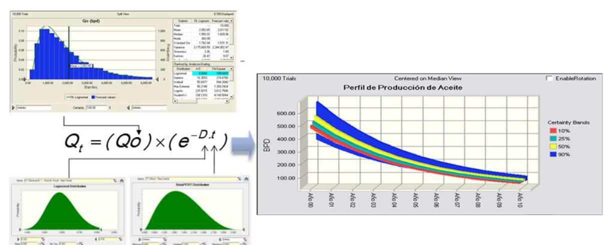

Figure 10 - Forecast of production following an exponential decline model. Note that the initial quota of production (Qo), the declination (D) and the Well Life time (t) are probabilistically treated.

The concept of Analog Well involves the probabilistic characterization of the behavior of the production of Wells in an analog field or reservoir to the prospectus to be drilled.

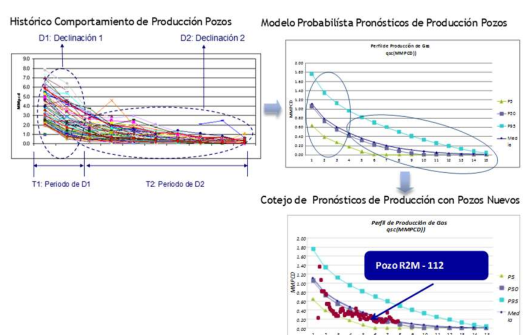

Figure 11- Analog Well: A production model of an Analog Well must reproduce the historical (past) behavior of the production of the analog field, and collate with the production forecast made for the new wells.

✓ Optimized and Scheduled Activity of Exploratory Locations.

✓ Probability Tree based on the geological success determined for each exploratory location, taking into account the effect of dependence between exploration opportunities as well as the dependence between different geological targets.

All this information feeds a probabilistic model created and that resides in a computational tool which generates:

• The probabilistic production profile or the production forecast band.

• The Comparison of the Probabilistic Cumulative Production Profile and the Curve of Resources (IR) to be Incorporated Estimated by Exploration.

• The Investments Probabilistic Profile, signaling:

✓ Investment in Exploration Wells

✓ Investments in Development Wells, in case that the exploratory location will turn out successful.

Figure 12 shows a diagram of the process followed by the previously mentioned computational tool.

It is important to note that the probabilistic tool works with double probability of success in the simulation (trees of probabilities and events). One probability corresponds to the Exploratory Well and the other probability to each Development Well of the area if the exploratory location turns out successful.

Figure 13 shows the Probability Tree for the Development of Exploration Opportunities.

The center of this tree is the Probability Tree of Geological Success, which will enable or disable the Probability Trees of the Drilling Activity for Development Wells.

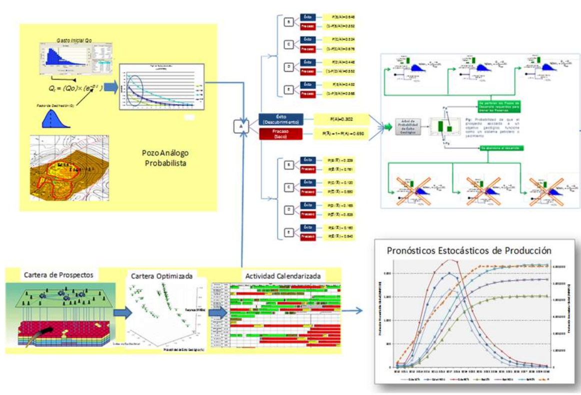

Figure 12 - Diagram of the Methodology for Generation of Stochastic Production Forecasts.

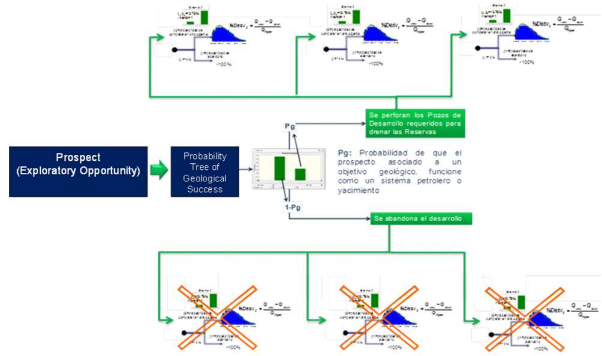

Figure 13 - Probability Tree of Development of exploration opportunities. In a simulation, each time a "one" (1) is generated from the binomial distribution of Geological Success, the binomials from the Probability Trees of the Drilling Activity for Development Wells will be enabled; since it implies that the prospect is a reservoir. And each time it generates a "zero" (0) will disable the binomial distribution of the Development Wells mentioned; as this implies that the exploratory opportunity is not an exploitable reservoir.

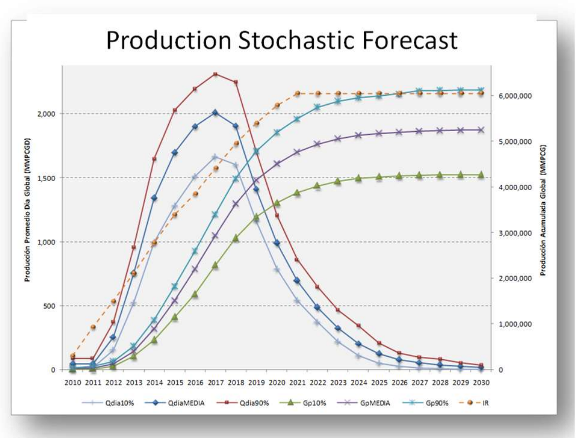

Figure 14 - Extended Production Stochastic Forecast, in which can be distinguished the probabilistic band (P10, P90 and Mean) Day Average Production, the cumulative production and the traditional IR Curve estimated by exploration.

Stage 2.5: Probabilistic Economic Evaluation.

Based on the production profile created (see Figure 14), in parallel, theses other profiles are generated: Investments and Income Probabilistic Profiles, corresponding to:

• Probabilistic Profiles of Incomes of Global Exploration.

• Probabilistic Profiles of Investment of Global Exploration.

• Probabilistic Profiles of Investments for Development Drilling.

• Probabilistic Profiles of Exploratory Investments.

• Probabilistic Profiles of Seismic Investment.

Figure 15 shows the process of the Probabilistic Economic Evaluation that takes as inputs the above mentioned stochastic profiles.

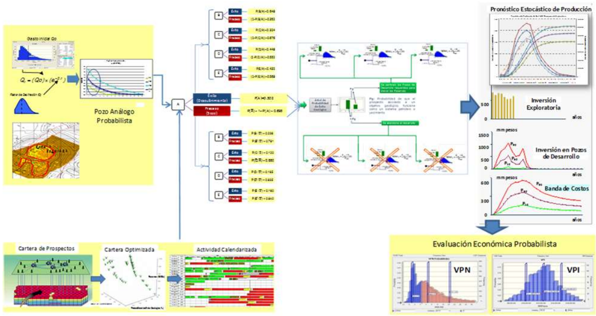

Figure 15 – Process of the Probabilistic Economic Evaluation

Stage 3: Rank among the evaluated scenarios, and selection of the optimal resource incorporation scenario.

Based on the analysis of the results for each evaluated Scenario of Resource Incorporation, these are ranked, and then the one that generates the best combination between the value generated and risk involved is selected.

The ranking process is based on extracting from the NPV and the IPV probability distributions obtained for each scenario (see Figure 15), three parameters: the profitability factor, the risk factor and the investment efficiency.

- ✓ The Profitability Factor is represented by the mean or expected value of the distribution of NPV and translates as the expected profit of the scenario evaluated in a time horizon.
- ✓ The Risk factor is represented by the standard deviation of the distribution of NPV, and reports how far from the expected profitability value may be the actual value of the NPV, because the influence of multiple uncertainties affecting the process of production.
- ✓ The investment efficiency is obtained by dividing the mean or expected value of the NPV between the mean or expected value of the IPV and translates to the amount of dollars to be gained, for every dollar invested in the exploitation plan.

Table 2 summarizes the most important results of the technical-economic evaluation carried out at 5 scenarios of incorporation of resources, and Figure 16 shows the three-dimensional matrix that supports hierarchy.

Escenarios de Incorporación de Recursos	Valor Presente de la Inversión	Eficiencia de la Inversión	Factor de Riesgo	Factor de Rentabilidad después de Impuestos
	Media VPI (MM Pesos)	Media (VPN / VPI)	DS VPN Despues Impuesto (MM Pesos)	Media VPN Despues Impuesto (MM Pesos)
Escenario 1	207,061.79	0.648	14,772.82	134,124.11
Escenario 2	206,988.46	0.645	14,645.11	133,581.50
Escenario 3	206,944.45	0.647	14,724.73	133,989.66
Escenario 4	206,544.78	0.638	14,701.23	131,877.37
Escenario 5	206,914.25	0.648	14,730.09	134,054.15

Table 2 – Results of the technical-economic evaluation carried out at 5 scenarios of incorporation of resources.

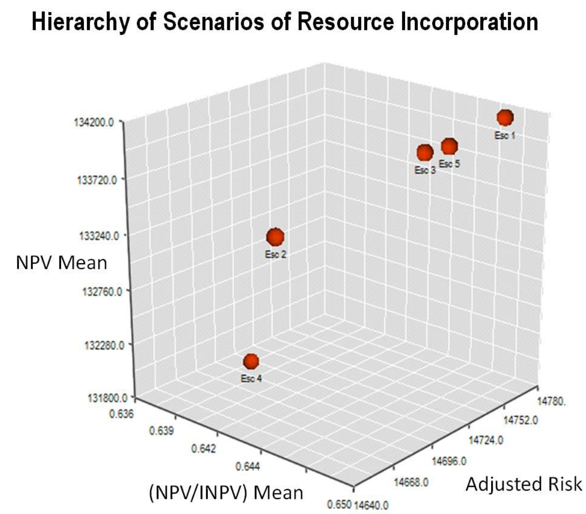

Figure 16 - Three-dimensional Ranking Matrix of Resources Incorporation Scenarios

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