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Editorial

Risk analysis applied to petroleum exploration and production: an overview

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Abstract

During the past decades, there have been some significant improvements in risk analysis applied to petroleum exploration and production. This special issue is dedicated to show some contributions and developments of risk analysis applied to petroleum exploration, field appraisal and development, production forecast under uncertainty, decision-making process, portfolio management, and real options approach. A brief overview is presented in this paper in order to introduce the universe of risk analysis, followed by a summary of the main contributions for this special edition and discussion and implication of the main trends in risk analysis.

Keywords: Uncertainty; Risk analysis; Decision analysis; Portfolio

1. Introduction

Exploration and production of hydrocarbons is a high-risk venture. Geologic concepts are uncertain with respect to structure, reservoir seal, and hydrocarbon charge. On the other hand, economic evaluations contain uncertainties related to costs, probability of finding and producing economically viable reservoirs, and oil price. Even at the development and production stage the engineering parameters embody a high level of uncertainties in relation to their critical variables (infrastructure, production schedule, quality of oil, operational costs, reservoir characteristics, etc.). These uncertainties originated from geological models and coupled with economic and engineering models involve high-risk decision scenarios, with no guarantee of successfully discovering and developing hydrocarbons.

Corporate managers continuously face important decisions regarding the allocation of scarce resources among investments that are characterized by substantial geological and financial risk and uncertainty. For instance, in the petroleum industry, managers are increasingly using decision-analytic techniques to aid in making these decisions. In this sense, the petroleum industry is a classic case of decision making under uncertainty; it provides an ideal setting for the investigation of risk corporate behavior and its effects on the firm's performance. The wildcat drilling decision has long been a typical example for the application of decision analysis in classical textbooks.

The future trends in oil resources availability will depend largely on the balance between the outcome of

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the cost-increasing effects of depletion and the cost-reducing effects of the new technology. Based upon that scenario new forms of reservoirs exploitation and managing will appear where the contributions of risk and decisions models are one of important ingredients. This trend can be seen in the last two decades. The new internationally focused exploration and production strategies were driven in part by rapidly evolving new technologies. Technological advances allowed the exploration in well-established basins as well as in new frontier zones such as ultra-deep waters. Those technology-driven international exploration and production strategies combined with new and unique strategic elements where risk analysis and decision models represent important components of a series of investment decisions.

This paper presents an overview of the main contributions in risk analysis for petroleum exploration and production. In this sense, this paper covers a brief review of previous applications involving the following topics: (1) Risk and Decision Analysis in Petroleum Exploration; (2) Field Appraisal and Development, and Production Forecast under Uncertainty, (3) Decision-Making Process and Value of Information and (4) Portfolio Management and Valuations Options Approach. This paper describes some of the main trends and challenges and presents a discussion of methodologies that affect the present level of risk applications in the petroleum industry aimed at improving the decision-making process.

2. Risk analysis: exploration

The historical origins of decision analysis can be partially traced to mathematical studies of probabilities in the 17th and 18th centuries by Pascal, Laplace, and Bernoulli. However, the applications of these concepts in business and general management appeared only after the Second World War (Covello and Mumpower, 1985; Bernstein, 1996). The problem involving decision making under conditions of risk and uncertainty has been notorious from the beginnings of the oil industry. Early attempts to define risk were informal.

The study by Allais (1956) on the economic feasibility of exploring the Algerian Sahara is a classic example because it is the first study in which the economics and risk of exploration were formally analyzed through the use of the probability theory and an the explicit modeling of the sequential stages of exploration. Allais was a French economist who was awarded the Nobel Prize in Economics in 1988 for his development of principles to guide efficient pricing and resource allocation in large monopolistic enterprises. Allais's work was a useful mean to demonstrate Monte Carlo methods of computer simulation and how they might have been used to perform complex probability analysis had they been available at that time instead of the simplifications for risk estimation of large areas.

During this period, there were several attempts to define resource level probabilities at various stages of exploration in a basin using resources distribution and risk analysis (Kaufman, 1963; Krumbein and Graybill, 1965; Drew, 1967; Harbaugh et al., 1977; Harris, 1984; Harbaugh, 1984; Harris, 1990). At that time governmental agencies (U.S. Geological Survey, Institut Francais du Petrole, etc.) were also beginning to employ risk analysis in periodic appraisals of the oil and gas resources.

During the 1980s and 1990s, new statistical methods were applied using several risk estimation techniques such as: (1) lognormal risk resources distribution (Attanasi and Drew, 1985), (2) Pareto distribution applied to petroleum field-size data in a play (Crovelli, 1995) and (3) fractal normal percentage (Crovelli et al., 1997).

During the 1960s, the concepts of risk analysis methods were more restricted to the academia and were quite new to the petroleum industry when they appear on the contributions of Grayson (1960), Arps and Arps (1974), Newendorp (1975, edited as Newendorp and Schuyler, 2000) and Megill (1977). During this period Newendorp (op.cit.) emphasized that decision analysis does not eliminate or reduce risk and will not replace professional judgment of geoscientists, engineers, and managers. Thus, one objective of the decision analysis methods, as it will be discussed later in this paper, is to provide a strategy to minimize the exposure of petroleum projects to risk and uncertainty in petroleum exploration ventures.

The Utility Theory provides a basis for constructing a utility function that can be employed to model risk preferences of the decision maker. If companies make their decisions rationally and consistently, then their implied risk behaviors can be described by the parameters of a utility function. Despite Bernoulli's attempt in the 18th century to quantify an individual's financial preferences, the parameters of the utility function were formalized only 300 hundred years later by Von Neumann and Morgenstern (1953) in modern utility theory. This seminal work resulted in a theory specifying how rational individuals should make decisions under uncertainty. The theory includes a set of axioms of rationality that form the theoretical basis of decision analysis and descriptions of this full set of axioms and detailed explications of decision theory are found in Savage (1954), Pratt (1964), and Schailfer (1969). Cozzolino (1977) used an exponential utility function in petroleum exploration to express the certainty equivalent that is equal to the expected value less a risk discount, known as the risk premium. Acceptance of the exponential form of risk aversion leads to the characterization of risk preference (risk aversion coefficient), which measures the curvature of the utility function. Lerche and MacKay (1999) showed a more comprehensible form of risk tolerance that could intuitively be seen as the threshold value whose anticipated loss is unacceptable to the decision maker or to the corporation.

An important contribution that provides rich insight into the effects of integrating corporate objectives and risk policy into the investment choices was made by Walls (1995) for large oil and gas companies using the multi-attribute utility methodology (MAUT). Walls and Dyer (1996) employed the MAUT approach to investigate changes in corporate risk propensity with respect to changes in firm size in the petroleum industry. Nepomuceno et al. (1999) and Suslick and Furtado (2001) applied the MAUT models to measure technological progress, environmental constraints as well as the financial performance associated with exploration and production projects located in deep waters.

More recently, several contributions devise petroleum explorations consisting of a series of investment decisions on whether to acquire additional technical data or additional petroleum assets (Rose, 1987). Based upon these premises the exploration could be seen as a series of investment decisions made under decreasing uncertainty where every exploration decision involves considerations of both risk and uncertainty (Rose, 1992). These aspects lead to a substantial variation in what is meant by risk and uncertainty. For example, Megill (1977) considered risk an opportunity for loss. Risk considerations involve size of investment with regard to budget, potential gain or loss, and probability of outcome. Uncertainty refers to the range of probabilities that some conditions may exist or occur.

Rose (2001) pointed out that each decision should allow a progressively clearer perception of project risk and exploration performance that can be improved through a constructive analysis of geotechnical predictions, review of exploration tactics versus declared strategy, and year–year comparison of exploration performance parameters. These findings showed the importance of assessing the risk behavior among firms and managerial risk attitudes. Continued monitoring of the firm's level of risk aversion is necessary due to a changing corporate and industry environment as well as the enormous contribution generated by the technological development in E&P. Over any given budgetary period, utilization of an established risk aversion level will result in consistent and improved decision making with respect to risk.

3. Risk analysis: field appraisal and development

During the exploration phase, major uncertainties are related to volumes in place and economics. As the level of information increases, these uncertainties are mitigated and consequently the importance of the uncertainties related to the recovery factor increases. The situation is more critical in offshore fields and for heavy-oil reservoirs (Pinto et al., 2001).

In the preparation of development plans, field management decisions are complex issues because of (1) number and type of decisions, (2) great effort required to predict production with the necessary accuracy and (3) dependency of the production strategy definition with the several types of uncertainty with significant impact on risk quantification.

In order to avoid excessive computation effort, some simplifications are always necessary. The key point is to define the simplifications and assumptions that can be made to improve performance without significant precision loss. Simplifications are possible, for instance, in the modeling tool, treatment of attributes and in the way several types of uncertainties are integrated.

One of the simplest approaches is to work with the recovery factor (RF) that can be obtained from analytical procedures, empirical correlations or previous simulation runs, as presented by Salomão and Grell (2001). When higher precision is necessary, or when the rate of recovery affects the economic evaluation of the field, using just the recovery factor may not be sufficient.

Techniques such as experimental design, response surface methods and proxy models were used by several authors (Damsleth et al., 1991; Dejean, 1999) in order to accelerate the process. Another possible approach is to use faster models such as streamline simulation as proposed by Hastings et al. (2001), Ballin et al. (1993), Subbey and Christie (2003) and Ligero et al. (2003).

The integration of risk analysis with production strategy definition is one of the most time consuming tasks because several alternatives are possible and restrictions have to be considered. Alternatives may vary significantly according to the possible scenarios. Schiozer et al. (2003)[1] proposed an approach to integrate geological and economic uncertainties with production strategy using geologic representative models to avoid large computational effort.

The integration is necessary in order to (1) quantify the impact of decisions on the risk of the projects, (2) calculate the value of information, as proposed by Demirmen (2001) and (3) quantify the value of flexibility (Begg and Bratvold, 2002). The understanding of these concepts is important to correctly investigate the best way to perform risk mitigation and to add value to E&P projects.

Therefore, risk analysis applied to the appraisal and development phase is a complex issue and it is no longer sufficient to quantify risk. Techniques today are pointing to (1) quantification of value of information and flexibility, (2) optimization of production under uncertainty, (3) mitigation of risk and (4) treatment of risk as opportunity. All these issues are becoming possible due to hardware and software advances, allowing an increasing number of simulation runs of reservoir models with higher complexity (Gorell and Bassett, 2001).

[1] Paper included in the special issue “Risk Analysis Applied to Petroleum Exploration and Production”, Journal of Petroleum Science and Engineering (in press, 2003).

4. Decision-making process, value of information and flexibility

Making important decisions in the petroleum industry requires incorporation of major uncertainties, long time horizons, multiple alternatives, and complex value issues into the decision model. Decision analysis can be defined on different and embedded levels in petroleum exploration and production stages. Decision analysis is a philosophy, articulated by a set of logical axioms, and a methodology and collection of systematic procedures, based upon those axioms, for responsibly analyzing the complexities inherent in decision problems (Keeney, 1982; Raiffa, 1968; Keeney and Raiffa, 1976; Howard, 1988; Kirkwood, 1996). In the last two decades, the theoretical and methodological literature on various aspects of decision analysis has grown substantially in many areas in the petroleum sector, especially in applications involving health, safety, and environmental risk.

Many complex decision problems in petroleum exploration and production involve multiple conflicting objectives. Under these circumstances, managers have a growing need to employ improved and systematic decision processes that explicitly embody the firm’s objectives, desired goals, and resource constraints. Over the last two decades, the advances in computer-aided decision-making processes have provided a mechanism to improve the quality of decision making in modern petroleum industry. Walls (1996) developed a decision support model that combines the toolbox systems components to provide a comprehensive approach to exploration petroleum planning from geological development through the capital allocation process.

An effective way to express uncertainty is to formulate a range of values, with confidence levels assigned to numbers comprising the range. Although geoscientists and engineers may be willing to make predictions about unknown situations in petroleum exploration and production, there is a need to assess the level of uncertainty of the projects. So, it is necessary to define the value of information associated with important decisions such as deferring drilling of a geologic prospect or seismic survey. Information only has value in a decision problem if it results in a change in some action to be taken by a decision maker. The information is seldom perfectly reliable and generally it does not eliminate uncertainty, so the value of information depends on both the amount of uncertainty (or the prior knowledge available) and payoffs involved in the petroleum exploration and production projects. The value of information can be determined and compared to its actual cost and the natural path to evaluate the incorporation of this new data is by Bayesian analysis.

As the level of information increases, the decision-making process becomes more complex because of the necessity of (1) more accurate prediction of field performance and (2) integration with production strategy. At this point, the concept of Value of Information (VoI) must be integrated with the Value of Flexibility (VoF). Therefore, risk may be mitigated by more information or flexibility in the production strategy definition. Reservoir development in stages and smart wells are good examples of investments in flexibility. The decision to invest in information or flexibility is becoming easier as more robust methodologies to quantify VoI and VoF are developed.

5. Portfolio management and the real options valuations

Asset managers in the oil and gas industry are looking to new techniques such as portfolio management to determine the optimum diversified portfolio that will increase company value and reduce risk. Under this approach employed extensively in financial markets, projects are selected based upon quantitative information on their contribution to the company long-term strategy and how they interact with the other projects in the portfolio. This theory of financial market and efficient portfolio was proposed by Markowitz (1952), winner of the 1990 Nobel Prize in Economics. This work has been adapted for the petroleum industry. A portfolio is said to be efficient if no other portfolio has more value while having less or equal risk, and if no other portfolio has less risk while having equal or greater value. The most important principle in portfolio analysis theory is that the emphasis must be placed on the interplay among the projects (Ball and Savage, 1999). The original idea states that a portfolio can be worth more or less than the sum of its component projects and there is not one best portfolio, but a family of optimal portfolios that achieve a balance between risk and value.

As the number of project opportunities grows, the petroleum industry is faced with an increasingly difficult task in selecting an ideal set of portfolios. Mathematical search and optimization algorithms can greatly simplify the planning process and a particularly well-suited class of algorithms has been developed recently for the oil and gas applications in portfolio management (Davidson and Davies, 1995; Chorn and Croft, 1998; Orman and Duggan, 1998; Fichter, 2000; Back, 2001; Erdogan and Mudford, 2001). Garcia and Holtz (2003) combined optimal portfolio management with probabilistic risk-analysis methodology, thus helping to guide managers in evaluating a portfolio of exploration prospects, not just according to their value, but also by their inherent risk.

For several decades in the petroleum industry, the most common form of asset valuation has been the standard discounted cash-flow (DCF) analysis. However, over the past few years, an increasing number of institutions and organizations have been experimenting with the use of other valuations approaches to overcome some limitations imposed by the DCF approach. The real options approach is appealing because exploration and production of hydrocarbons typically involve following several decision stages, each one with an investment schedule and with associated success and failure probabilities. For example, in exploration phase the project can be viewed as an infinitely compounded option that may be continuously exercised as the exploration investment is undertaken. Traditional methods based upon discounted cash flow (DCF) reported in the finance literature are always based upon static assumptions—no mention about the value of embodied managerial options. Kester (1984) was the first to recognize the value of this flexibility and Mason and Merton (1985), and Myers (1987), among others, suggested the use of option-based techniques to value implicit managerial flexibility in investment opportunities, such as those of abandonment reactivation, mothballing and timing.

Some important earlier real options models in natural resources include Tourinho (1979), first to evaluate oil reserves using option-pricing techniques. Brennan and Schwartz (1985) applied option techniques to evaluate irreversible natural resources assets and McDonald and Siegel (1985, 1986) developed similar concepts for managerial flexibility. After the real options theory became widely accepted in financial markets, applications in the oil industry followed rapidly. Paddock et al. (1988) evaluated offshore oil leases. By the mid-1990s, several textbooks had been published (Dixit and Pyndyck, 1994; Trigeorgis, 1993; Luenberger, 1997) and the range of applications had widened to include applications in several economic sectors. Bjerksund and Ekern (1990) showed that it is possible to ignore both temporary stopping and abandonment options in the presence of the option to delay the investment for initial oilfield development purposes. Galli et al. (1999) discussed real options, decision-tree and Monte Carlo simulation in petroleum applications. Laughton (1998) found that although oil prospect value increases with both oil price and reserve size uncertainties, oil price uncertainty delays all option exercises (from exploration to abandonment), whereas exploration and delineation occur sooner with reserve size uncertainty. Chorn and Croft (2000) studied the value of reservoir information.

6. This special issue

This special edition is an attempt to give the readers an opportunity to view some applications of risk analysis in petroleum exploration and discussion mentioned previously. Zabalza-Mezghani et al. (2003)[2] employed several statistical methods such as experimental design theory and response surface to deal with uncertainties in reservoir engineering. This approach has been validated both on realistic and synthetic cases and on a real producing field with specific uncertain parameters. An attempt to understand the uncertainty in assigning scaled-up values to finite regions of space in reservoir properties was proposed by Lake and Srinivasan (2004)[2]. The authors used the variance of the mean to investigate the definition of a representative elementary volume and of the behavior of lateral and vertical permeabilities with scale and the resultant impact on uncertainty distribution for reservoir properties.

Ross (2004)[2] provided a better characterization of a portfolio of oil and gas assets using a consistent definition of risk and uncertainty, combined with a resource classification based on clear distinction between project maturity and volumetric uncertainties. Using an integration of several tools of portfolio management and preference analysis, Walls (2004)[2] developed interesting results that make it possible to incorporate a company's financial risk tolerance into the portfolio selection process. According to the author, this approach enables the manager to evaluate and understand the explicit tradeoffs between risk and return and the impact of the firm's behavior.

Armstrong (2004)[2] developed a type of Bayesian analysis and coupled it with real options theory to address the question of how to evaluate the option to acquire more information. The results applied in the case of an oil company that has the option to gather information from production logging tool before carrying out a workover showed that the value of the option was less under conditions of high oil prices than for lower oil prices. Similarly, Accioly and Chiyoshi (2004)[2] presented a technique to model the dependence between random variables and construction of a bivariate distribution by using copulas models. These bivariate distributions were applied in simulation studies to improve uncertainty analysis for field development using a sample of 188 exploratory offshore wells, drilled in the Gulf of Mexico.

Dias (2004)[2] presented a set of selected real options models to evaluate investments in oil exploration and production under market and technical uncertainties. In this paper, the author summarized the classical model of Paddock et al. (1988) that exploits a simple analogy between American call options and real options model for an oilfield development. Journel (2004)[2] developed a general methodology to deal with early uncertainties in global reservoir parameters. Using net-to-gross ratio, the author approaches the problem by modeling uncertainty based on the concept of bootstrap or spatial resampling from stochastic simulation.

Schiozer et al. (2004)[2] proposed a methodology to integrate risk analysis and production strategy definition considering a special treatment of attributes and use of representative models that are selected to

[2] Paper included in the special issue "Risk Analysis Applied to Petroleum Exploration and Production", Journal of Petroleum Science and Engineering (in press, 2004).

characterize geological uncertainties. The authors employed this methodology in a typical offshore field in Brazil where several alternatives to reduce the level of information and to speedup the process were evaluated in forecasting the reservoir performance. Subbey and Christie (2004)[2] provided an interesting approach for generating uncertain history matching models and quantifying uncertainty in model performance predictions using a sampling space algorithm. Van der Poel and Jansen (2004)[2] developed a probabilistic analysis of the impact of the NPV from a smart well for sequential production of a stacked reservoir. Using smart wells deployment, Yeten et al. (2004)[2] employed a method for determining the optimal performance of wells containing downhole inflow control devices. The optimization accounts for geological uncertainties and the risk of failure of the control devices.

7. Discussion and implications

Decisions related to petroleum exploration and production are still very complex because of the high number of issues involved in the process. However, concepts of risk analysis applied to exploration, appraisal and development phases are becoming more popular as new hardware and software advances appear. New methodologies are being developed to help to mitigate risk, and this special issue is dedicated to contribute to this process.

Most organizations have settled on using consistent risk analysis procedures to assess all exploration and production of petroleum projects. Some oil companies have developed their own risk analysis software and algorithms. Other companies have licensed customized software from several different vendors or consulting firms. An important output of this trend is that geological, technical and economic parameters can be preserved, thus facilitating subsequent project review for purposes of performance analysis. According to Rose (2001) this provokes some inevitable changes in the corporate culture, operating values and tactics, and reward system.

Risk analysis has several limitations, pitfalls, and practical difficulties that affect its value as a decision aid. In some cases, these limitations are due less to inherent limitations in decision analysis than to deficiencies in specific applications of the approach in petroleum upstream projects. There is a need to understand how most effectively to model project level risks, whether they are those that affect output possibilities or those that directly influence costs. At the same time, this trend generates a need to fine-tune the risk analysis methods by finding out how to use more discretisation without intolerable loss of accuracy yielding a search for a next generation of tools for more complex simulation models. These developments will stimulate new progress as better models and methods make the analytical tools more flexible and accurate, and thus more attractive. This will increase the demand for the development of better risk and decision analysis software and training tools, the development of which will make the analyses more attractive and encourage the development of better models and methods.

Despite these limitations and difficulties, risk analysis has several major strengths and achievements in petroleum exploration and production, as it has been shown in this paper. First, risk analysis provides a means for handling highly complex decisions characterized by multiple objectives and high degrees of uncertainty in diverse stages of petroleum upstream. Second, risk analysis provides an approach for dealing with complex value tradeoff and preferences of the stakeholders in the decision process in oil exploration and production. Third, risk analysis provides a systematic and comprehensive way for considering all relevant factors in a decision in the E&P process.

Currently, unknown technologies can be expected to be available for future exploitation of oil resources in the new frontiers (especially ultra-deep waters, heavy-oil) with important impacts on risk mitigation. While the timing and frequency of these yet unknown technologies are speculative, longer trends cycles favor the use of technological risk models. Recent obtained results indicate that the technological progress for these new environments can be used to measure the firm’s strategic decision for technological risk aversion as well as ranking projects with several technological characteristics.

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