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A hybrid fuzzy-probabilistic system for risk analysis in petroleum exploration prospects

Mauro Roisenberg [a,*], Cíntia Schoeninger [a], Reneu Rodrigues da Silva [b]

[a] Department of Informatics and Statistics, Federal University of Santa Catarina, P.O. Box 476, INE-CTC-UFSC Campus Trindade, 88040-900 Florianópolis, Brazil
[b] Petróleo Brasileiro S.A., Petrobras, E&P, Rio de Janeiro, Brazil

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ABSTRACT

Petroleum exploration is an economical activity where many billions of dollars are invested every year. Despite these enormous investments, it is still considered a classical example of decision-making under uncertainty. In this paper, a new hybrid fuzzy-probabilistic methodology is proposed and the implementation of a software tool for assessing the risk of petroleum prospects is described. The methodology is based in a fuzzy-probabilistic representation of uncertain geological knowledge where the risk can be seen as a stochastic variable whose probability distribution counts on a codified geological argumentation. The risk of each geological factor is calculated as a fuzzy set through a fuzzy system and then associated with a probability interval. Then the risk of the whole prospect is calculated using simulation and fitted to a beta probability distribution. Finally, historical and direct hydrocarbon indicators data are incorporated in the model. The methodology is implemented in a prototype software tool called RCSUEX ("Certainty Representation of the Exploratory Success"). The results show that the method can be applied in systematizing the arguing and measuring the probability of success of a petroleum accumulation discovery.

1. Introduction

Petroleum exploration is an economic activity plenty of decision problems involving risk and uncertainty. As economical and technological resources are limited, managers of petroleum companies frequently face important decisions regarding the best allocation these scarce resources among exploratory ventures that are characterized by substantial financial risk and geological uncertainty. Few years ago, many petroleum companies improved their exploration performance by using principles of risk analysis and portfolio management. According to Rose (2001), in present days, the adoption of standardized risk analysis methods are essential to portfolio management, in order to optimize the allocation of exploration capital.

There are a lot of activities involved in modern petroleum exploration business. Tasks range from modeling geologic theories and data acquisition to econometrics simulations and selection of reservoir, drilling and completion technologies. In this work, we focus our attention to the problem of estimating the chance of success of finding hydrocarbon on a given prospect. That is once an appropriate geological model has been established and an exploration area has been selected, the next step in petroleum exploration is the identification of drilling prospect by geoscientists. This process is critical and requires geotechnical expertise and creativity. After the prospect has been identified, estimating the chance that a producible hydrocarbon accumulation is present, is one of the most important tasks in order to determine the prospect's value.

For many decades of petroleum exploration ventures has been dealt with probability theory as the formal tool to handle and represent uncertainty quantities (da Silva, 2000). Such representation are usually expressed as a probability value, known as "probability of success" (geological or economical), found by the combination of other probabilities that represent, the assessment of geological factors as source rock, trap, reservoir and seal, considered individually and combined by traditional and numerical methods as Monte Carlo Simulation (Behrenbruch, Turner, & Backhouse, 1985; Newendorp & Schuyler, 2000; Rose, 1992).

Despite the great progress in economical risk analysis and portfolio management, the "probability of geological success", i.e., the discovery of a hydrocarbon accumulation in a given exploratory prospect, is still a new and very hard area of research.

Uncertainty is intrinsically involved in all petroleum venture predictions, and particularly in chance of discovery (Rose, 2001). The problem is how to express the technical uncertainties realistically, and in a form that can be used in economic equations in order to estimate the economical risk (Rose, 2001). Geologist suffer in trying to reduce very complex and uncertain knowledge in just a single few numbers that represent the exploratory chance of success.

* Corresponding author. Tel.: +55 48 37217515; fax: +55 48 37219566.
E-mail address: mauro@inf.ufsc.br (M. Roisenberg).

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There are extensive attempts in systematizing the process of correctly estimate chance of success of finding hydrocarbon on a given prospect (MacKay, 1996; Newendorp & Schuyler, 2000; Otis & Schneidermann, 1997; Rose, 2001). But, as this process is done by different geoscientists, in different geologic areas and under a very competitive scenario, it frequently leads to optimistic or pessimistic bias in the prospectors estimative (Rose, 2001).

The bias is a very important problem in prospect risk assessment. If the prospect chance of discovery or economic value are contaminated with biased estimates, the exploration company's decision investments will lead to suboptimal economic performance (Rose, 2001). The more relevant type of bias that affect judgment under uncertainty are Overconfidence – predictive ranges are too narrow, indicating that estimators are much less accurate than they think they are; Overoptimism – prospectors exaggerate magnitude of reserves or chance of success in order to sell the deal; and Representativeness – analog based on small sample size may not be statistically significant (Rose, 2001).

The fuzzy set theory has been used to represent and solve problems of petroleum evaluation. Chen and Fang (1993), Chen, Osadetz, Embry, and Hannigan (2002) and Tounsi (2005) use fuzzy logic and approximate reasoning to asses petroleum field in different regions. In most of these studies, the geological factors are coupled with multiple-criteria decision-making theory. However, this approach has some inconveniences: the incorporation of *a posteriori* knowledge as historical and direct hydrocarbon indicators data cannot be easily incorporated in the system, and the difficulty to incorporate qualitative expressions like "excellent", "fair" or "poor" in the economical evaluation formulas.

In this paper, we present a new fuzzy-probabilistic methodology capable to represent uncertain geological knowledge and the prototype software tool called RCSUEX ("Certainty Representation of the Exploratory Success") that implements the methodology (Schoeninger, 2003). The main purpose of this work is to provide a method to deal with the problem of systematizing the process of correctly estimate chance of success of find hydrocarbon on a given prospect and to facilitate and to standardize the geologist argumentation task. This fuzzy-probabilistic methodology is founded in the following assumptions: risk can be qualified by set of questions and answers concerning the decision problem (Hardman & Ayton, 1997); when expressions like "moderate" and "severe" are significant for the domain expert, then fuzzy sets are more suitable for knowledge representation than "classical" or crisp sets (Terano, Asai, & Sugeno, 1994); fuzzy logic is adequate to represent uncertainty in petroleum geology (Chen & Fang, 1993; Fang & Chen, 1990); the beta probability distribution is pertinent to represent the certainty of success of a random variable in a Bayesian approach (Groot, 1970).

The paper is organized as follows: in Section 2, describes how risk analysis can be applied in the petroleum exploration process focusing in the elements of the hydrocarbon system and estimating the chance that a subsurface trap exist and if it is capable to store and accumulate hydrocarbons. Section 3 presents how fuzzy reasoning can be used as a very efficient mechanism to deal with incomplete and imprecise data, and knowledge expressed in vague and linguistic terms that characterize the petroleum risk evaluation problem. In this section, fuzzification, rule evaluation and defuzzification are described separately and particularities specific for the problem are discussed. Section 4 describes the process performed in our system (RCSUEX) to map from a subjective fuzzy domain to a objective probabilistic domain. Section 5 explains the importance and the methodology to incorporate historical data and Direct Hydrocarbon indicators in order to improve risk assessment. This section proposes a mathematical model that put together the objective perspective with the subjective one. Section 6 shows the application of the proposed method for a simple prospect risk assessment. Section 7 gives conclusions and brief discussion on the proposed methodology.

2. Risk analysis in the petroleum exploration process

The petroleum exploration process is highly coupled with geological models that explain the occurrence of hydrocarbon accumulations. Geologists, geophysicists and seismologists apply high levels of expertise to answers questions such as: what is the chance of finding an accumulation in the prospect? What is the volume of the accumulation? Which method should be used to recover the petroleum from the field? Capturing this knowledge and representing it in a formal model is a permanent aim for knowledge management in petroleum companies (Tounsi, 2005).

For many decades petroleum companies have assessed risky projects involving uncertainties about positive monetary results – predicting the distribution of financial gains or losses that may result from the drilling of an exploration well through objective procedures and principles of statistics, probability and utility theories (Harbaugh, Davis, & Wendebourg, 1995). In this study, we focus our attention, evaluating geological factors (subjective data) incorporated with statistical information (objective data). The information used in this evaluation came from usual seismic data, analogies and geological theories. Probability-analysis methods have been developed which make use of widely available forms of exploration information. Geophysical data, subsurface information derived from well logs, and production data can be analyzed by statistical methods to yield objective forecasts expressed as probabilities (Harbaugh, Doveton, & Davis, 1977).

According to Otis and Schneidermann (1997) in 1989, Chevron Overseas Petroleum Inc. developed a process to allow management to compare a wide variety of global exploration opportunities on a uniform and consistent basis. The final product was a continuous process that integrates geologic risk assessment, probabilistic distribution of prospect hydrocarbon volumes, engineering development planning, and prospect economics. The process was based on the concepts of the play and hydrocarbon system. Our work is also based in the play and hydrocarbon system concepts, but we focus mainly in obtaining the probability of geologic success i.e., if a stabilized flow of hydrocarbons is obtained on test of a exploratory well.

The hydrocarbon system concept can be used as an investigating model for hydrocarbon discoveries as it describes the geologic relationship between elements and processes since the play source rocks, reservoir, and seal until the result as oil or gas accumulations. Essential geologic elements of the hydrocarbon system are

- play source rock;
- reservoir rock and
- seal rock.

While the geologic processes of the hydrocarbon system are

- trap formation;
- genesis-migration and
- timing-synchronicity.

Information and data from each of these factors are collected and analyzed by geoscientist and engineers that then consider the "*favorability*" or the probability of success of each of these six elements of the play concept. Multiplication of these probabilities yields the probability of geologic success of the prospect (Otis & Schneidermann, 1997). Obviously, this mapping from the qualitative thought into a probabilistic number is a very hard task to geoscientists since all argumentation is subjective.