VALUE OF INFORMATION DURING APPRAISAL AND DEVELOPMENT OF PETROLEUM FIELDS

Eliana Luci Ligero
Departamento de Petróleo – Faculdade de Engenharia Mecânica – UNICAMP
Caixa Postal 6122 – CEP 13081-970 – Campinas – SP - Brasil
eligero@dep.fem.unicamp.br

Alexandre Monticuco Xavier
Departamento de Petróleo – Faculdade de Engenharia Mecânica – UNICAMP
Caixa Postal 6122 – CEP 13081-970 – Campinas – SP - Brasil
amxmec@yahoo.com

Denis José Schiozer
Departamento de Petróleo – Faculdade de Engenharia Mecânica – UNICAMP
Caixa Postal 6122 – CEP 13081-970 – Campinas – SP - Brasil
denis@dep.fem.unicamp.br

Abstract. *The Value of Information (VOI) during appraisal and development of petroleum fields is an economic criterion used in decision-making process, which involves the quantification of uncertainties and economic evaluation of several scenarios. Some methodologies have been proposed to evaluate the VOI, however they consider only one or just a few possible production strategies, oversimplifying the problem and underestimating the VOI. A new methodology has been proposed to evaluate the VOI based on the simulation of several reservoir models considering the uncertain attributes and some models (Geological Representative Models – GRM) are selected to represent the geological uncertainties. The production strategy of each GRM is optimized and the possible scenarios from the additional information are considered and the VOI is obtained through the Expected Monetary Value with and without information. A case study is presented showing the influence of the number of strategies used in the process and a comparison is made with current techniques. This paper shows the complexity to assess the VOI in the appraisal and development phases and the importance of this concept in decision-making in field projects. A new and more reliable methodology to assess the VOI using the concept of GRM is proposed.*

Keywords*: Value of Information, Risk Analysis, Geological Representative Models, Petroleum Reservoir Simulation*

1. Introduction

The development of petroleum fields is made under uncertain conditions associated to geological characterization of the reservoir and to economic and technological parameters; these uncertainties influence the value of the project. The low performance of petroleum industries is a result of the low investment applied in decision-making and the absence of sufficient investments to estimate the return of the project, which implies in overestimating the return or underestimating the possibility of loss (Begg *et al*., 2002). Three types of risks in development of petroleum fields have to be considered in the decision-making process (Demirmen, 2001): opportunity loss (a prospect is considered uneconomical and abandoned, but in fact it is economically viable), uncommercial development (an uneconomic field is developed because it is wrongly considered economical) and suboptimal development (a developed field yields less than the maximum economic return that could be obtained if the correct reservoir model were considered).

The involved risk in the development phase can be reduced if additional information is obtained in order to diminish or eliminate completely a specific uncertainty. However, the information acquisition is directly associated to costs. Therefore, before deciding on obtaining information, Mian (2002) suggests that two aspects can be analyzed: if it is worth to obtain additional information and if there is information capable of improving the decision-process.

A consistent decision tool that can be employed as criterion for decision-making is the Value of Information (VOI) that combines reservoir uncertainty to potential economic consequences. Nowadays, the concept of VOI is sufficiently divulged and for simple cases, the VOI analysis is an easy comprehension technique. However, the VOI calculation is complex when the number of uncertain attributes is elevated, the information affects different geological attributes and the information is incomplete or not reliable. Application of the VOI concept is common in the exploration phase, however there is not a well-defined methodology to apply the VOI concept in appraisal and development phases, mainly when the problem is modeled through numerical simulation demanding a high computational effort.

Works available in literature show the relevance and applicability of VOI analysis in the decision process and risk analysis of E&P projects (Clemen, 1995, Koninx, 2000, Coopersmith and Cunninghan, 2002). However, a systematic approach was not yet developed to explore the potential of VOI methodology exclusively in the appraisal and development phases. Some methodologies to evaluate the VOI consider only one or just a few possible production strategies. It is common in petroleum industries to consider only three representative models, oversimplifying the problem and underestimating the VOI due to the complexity of the problem. The VOI quantification has to take into account the benefits that can be extracted of the process: the possibility to have a specific production strategy applied for each of the several possible scenarios after the acquisition of the information.

Demirmen (1996) applied the VOI concept to subsurface appraisal in petroleum exploration and production to provide a consistent criterion to justify this activity. By the extension, VOI could also to be used for ranking purposes. Although, the immediate purpose of appraisal was to reduce the uncertainty, the ultimate goal was to impact development decision and to reduce the risk associated to development. Demirmen (2001) concluded that the apparent complexity of VOI approach and the effort to implement the technique should not deter its application. Despite the difficulty, it is well worth performing this task.

According to Floris and Peersmann (2000), an E&P Decision Support System (DSS) was developed and its function was to help the E&P manager to make more informed decisions considering exploration and development of hydrocarbon assets. The scenarios representing the key decision and uncertainties were defined and from them a scenario tree was built. The decision tree was used as a criterion to invest or not in the end of the branches of the tree. If information was acquired and one of the tree branches had a negative NPV, the option was not to invest in the project. However, this criterion just eliminated the scenarios with negative NPV and did not consider the advantages of the information in order to modify the production strategy of the field. For example, if all scenarios had positive NPV, the VOI would be equal to zero. Consequently, the DSS methodology underestimates the VOI.

Although the concept of VOI is relatively clear, the VOI calculation in the appraisal and development phases can be complex due to the interdependence among uncertainties, oil recovery and production strategy and the excessive time consumption in the modeling process. In addition, there is no publication in the literature with a clear methodology to calculate the VOI for cases with several uncertain attributes.

2. Objectives

A new and reliable methodology to assess the VOI during the appraisal and development phases using the concept of Geological Representative Models (GRM) is proposed. The number of GRM, each one with a different production strategy, is higher than three and although it is a simplification, the trustworthiness of the process is kept yet. This work also shows that some of the procedures used by petroleum industries and proposed in the literature yield underestimated values due to the oversimplification of the problem.

3. Methodology for VOI Calculation

The proposed methodology for VOI calculation is applicable either to simple or complex reservoir scenarios, with a few or many uncertain attributes. Its initial steps correspond to the steps of the risk analysis methodology based on derivative tree technique proposed by Steagall and Schiozer (2001) and implemented by Schiozer *et al.* (2004). The steps of the methodology are described as follows (steps 1 to 6 are the same of the risk analysis methodology):

1. Selection of all uncertain attributes, definition of their uncertainties and occurrence probabilities. This step must be conducted by a group of specialists in order to guarantee the best initial data. The usual approach is to start with three levels for each attribute: a medium, an optimistic and a pessimistic. The number of levels should be increased or reduced according to the type and importance of the attributes.
2. Constrution of a deterministic geological model composed by the most probable values of all input variables, which is called base model. The production strategy of this model is optimized in terms of NPV (Net Present Value).
3. Execution of a sensitivity analysis in order to select the most critical attributes and to disregard the uncertain attributes which do not present significant influence on the objective functions, reducing the number of possible simulation models. The sensitivity analysis consists in changing one uncertain attribute by one in the base model.
4. Automatic construction of the simulation models according to the derivative tree and gradual addition of attributes and levels according to the variation of objective functions for percentiles P10 (optimistic), P50 (probable) and P90 (pessimistic) and desired accuracy. This procedure allows the selection of important atributes and guarantees an acceptable performance without excessive computational time (Costa and Schiozer, 2003).
5. Running the simulations through comercial reservoir simulator and use of parallel (distributed) computing in order to speed up the process.
6. Statistical treatment of the results (NPV for each derivative tree model) in order to evaluate the risk curve and the risk associated to the project.
7. Verification of the possibility to reduce the uncertainty of some attributes by acquisition of information.
8. Transformation of the derivative tree in the decision tree due to information acquisition. Figure 1 shows that a chance event node (circle) is transformed in a decision node (square). Chance event nodes are events that cannot be controlled by the decision maker, while decision nodes are controlled by decision maker (Schuyler, 2001). In the proposed methodology, a group is defined as a branch that derives from a decision. The derivative tree in Fig. 1 possess only one group and a fixed production strategy, however the decision tree is composed for three groups and it should be considered one strategy for each group. The definition of group is important to quantify the VOI, that depends on the choice of an appropriate production strategy for each group.

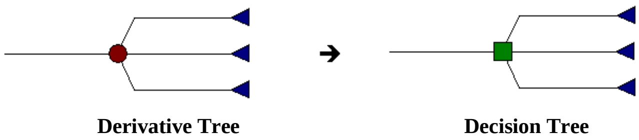


Figure 1. Transformation of a derivative tree in a decision tree.

9. Selection of the geological representative models (GRM) in order to represent the geological uncertainties and the variations of production strategies. The choice of GRM to be used in the calculation of VOI is different from the criterion used by Ligero *et al*. (2003) and Schiozer *et al*. (2004) to integrate geological uncertainties to other types of uncertainties. The proposed criterion to select GRM depends on the number of variables that can have their uncertainty reduced (the higher the number of these variables, the higher the number of GRM), the dispersion of the points in the plot Net Present Value "versus" Recovery Factor (the closer the points, the smaller the difference of production strategies, otherwise the difference is significant), the occurrence probability of each GRM, the level of confidence desired by the company that develops the project (as higher the number of GRM, the more reliable and accurate the results) and the avaliable time to calculate and analyse the VOI. It is important to emphasize that the base model is also considered as a GRM.
10. Optimization of the production strategies of GRM according to the procedure presented by Santos and Schiozer (2003). The optimized strategies are substituted in each GRM. If the strategies of the base model or the GRM are not optimized, they must be. This procedure should be iteractive as shown by Xavier (2004).
11. Calculation of the Expected Monetary Value without information (EMV_{SI}) according to Eq. (1). All models of the derivative tree are simulated considering each one of the optimized strategies in order to select the prodution strategy that has the highest EMV to represent the case without information. As consequence, the number of simulation runs is the number of optimized strategies multiplied by the number of branches of the derivative tree.

$$EMV_{SI} = \max_{w=1}^{n_{EST}} \left\{ \sum_{j=1}^{N} \left[\left(NPV_{strategy(w),\, model_j} \right) . P_{model_j} \right] \right\} \tag{1}$$

12. Calculation of the Expected Monetary Value with information (EMV_{CI}):

$$EMV_{CI} = \sum_{k=1}^{G} \left\{ \max_{w=1}^{n_{EST}} \left[\sum_{\ell=1}^{N_G} \left(NPV_{strategy(w),\, model_\ell} \right) . P_\ell \right] \right\}_{(k)} \tag{2}$$

13. Calculation of the value of information, which is the difference between EMV_{SI} and EMV_{CI}:

$$VOI = EMV_{SI} - EMV_{CI} \tag{3}$$

4. Application

In order to apply the methodology for VOI calculation, a modified reservoir based on a real offshore field in Brazil was studied. The main drive mechanism is solution gas and the injection fluid is water. It is a mature reservoir with a long production history but the data used here refers to the appraisal and development phase. Table 1 summarizes the uncertain attributes, the levels of uncertainty and associated probabilities. The most probable levels are indicated as "base". The three levels of uncertainty of the structural model are in Fig. 2.

A regular Cartesian grid with 51x28x6 cells represented the reservoir. A commercial *Black-Oil* simulator was used to run the flow simulations. The simulation time for all models was 20 years. The initial optimized production strategy of the base model consisted of 6 producer wells (1 vertical and 5 horizontal) and 4 horizontal injector wells.

It was assumed that the perforation of one well was possible to reduce the uncertainty of structural model and water-oil contact. The information was perfect and capable of totally eliminating the uncertainty of these attributes.

The steps of the VOI calculation that are coincident to the steps of the risk analysis methodology were executed automatically and parallel computing were used to run the simulations (Ligero and Schiozer, 2002).

5. Results

The results referring to the application of the proposed methodology for VOI calculation are presented according to the sequence of steps that must always be followed. During the result analysis, some aspects of the methodology are better explained and some steps are described in greater detail.

5.1. Sensitivity Analysis

The sensitivity analysis is an important simplification to select the critical attributes and consequently to reduce the number of simulation runs. The main objective function considered in the sensitivity analysis was the Net Present Value (NPV), as shown in Fig. 3(a). However, the sensitivity analysis based on Cumulative Oil Production (Np) was also considered, Fig. 3(b). The selected critical attributes were water-oil contact, porosity, horizontal permeability and structural model. The three levels of the critical attributes were important, except for structural model, which had only two significant levels.

Table 1. Uncertain Attributes for the Studied Case

Attributes	Levels	Probabilities
Structural Model	areas0 (base)	0.6
	areas1	0.2
	areas2	0.2
Porosity	por0 (base)	0.6
	por1 = por0 * 0.7	0.2
	por2 = por0 * 1.4	0.2
Horizontal Permeability	permx0 (base)	0.6
	permx1 = permx0 * 0.5	0.2
	permx2 = permx0 * 2.0	0.2
Vertical Permeability	permz0 (base)	0.6
	permz1 = permz0 * 2.5	0.2
	permz2 = permz0 * 0.4	0.2
PVT	pvt0 (base)	0.6
	pvt1	0.2
	pvt2	0.2
Relative Permeability	kro0 (base)	0.6
	kro1	0.2
	kro2	0.2
Water-oil contact	dwoc0 = 3100 m (base)	0.6
	dwoc1 = 3075 m	0.2
	dwoc2 = 3210 m	0.2

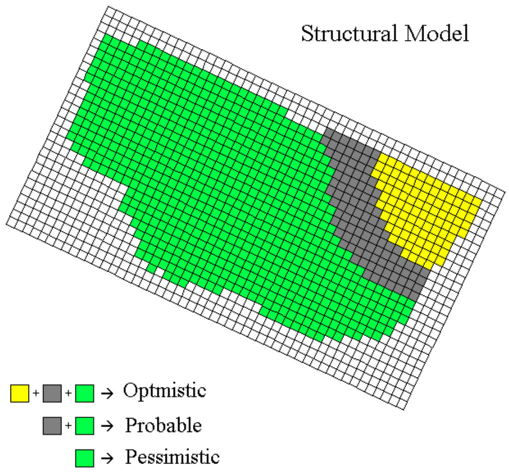
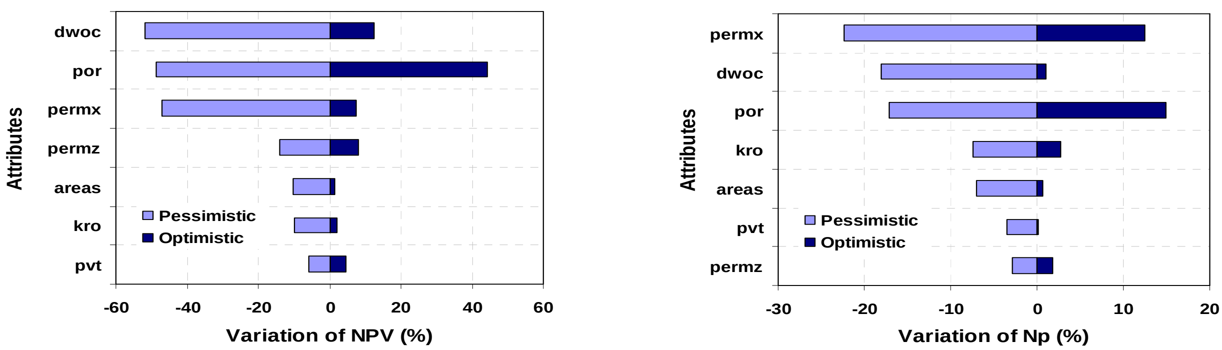


Figure 2. Structural model - Levels of uncertainty (Probable = areas0; Pessimistic = areas1; Optimistic = areas2).



(a) (b)

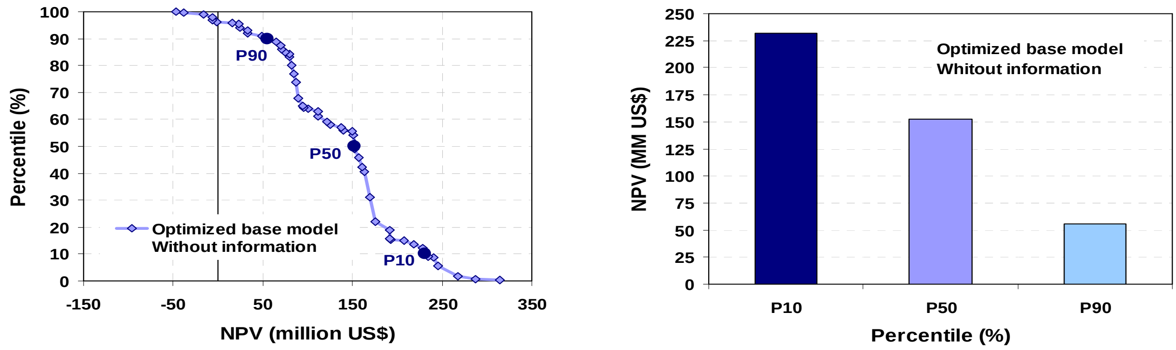
Figure 3. Sensitivity analysis for 20 years: (a) Net Present Value and (b) Cumulative Oil Production.

5.2. Risk Quantification

The critical attributes were employed to generate the reservoir simulation models through the derivative tree technique. A total of 54 models ($3^3 \cdot 2^1$) were simulated and the NPV risk curve for a period of 20 years was elaborated (Fig. 4(a)). The percentile values, P10 (optimistic), P50 (probable) and P90 (pessimistic), are shown in Fig. 4(b). The difference between P10 and P90 represents the risk of project. The derivative tree is shown in Fig. 5.

5.3. Transformation of the Derivative Tree in the Decision Tree

The transformation of the derivative tree in the decision tree depends on the uncertain attributes that can have their uncertainty reduced by information acquisition. The perforation of one well reduced the uncertainty of the structural model with two levels of uncertainty and water-oil contact with three levels. The information was perfect and consequently capable of totally eliminating the uncertainty of these attributes. The information allowed the derivative tree (Fig. 5) was transformed in the decision tree (Fig. 6).



(a) (b)

Figure 4. Project without information: (a) risk curve and (b) Percentiles P10, P50 e P90.

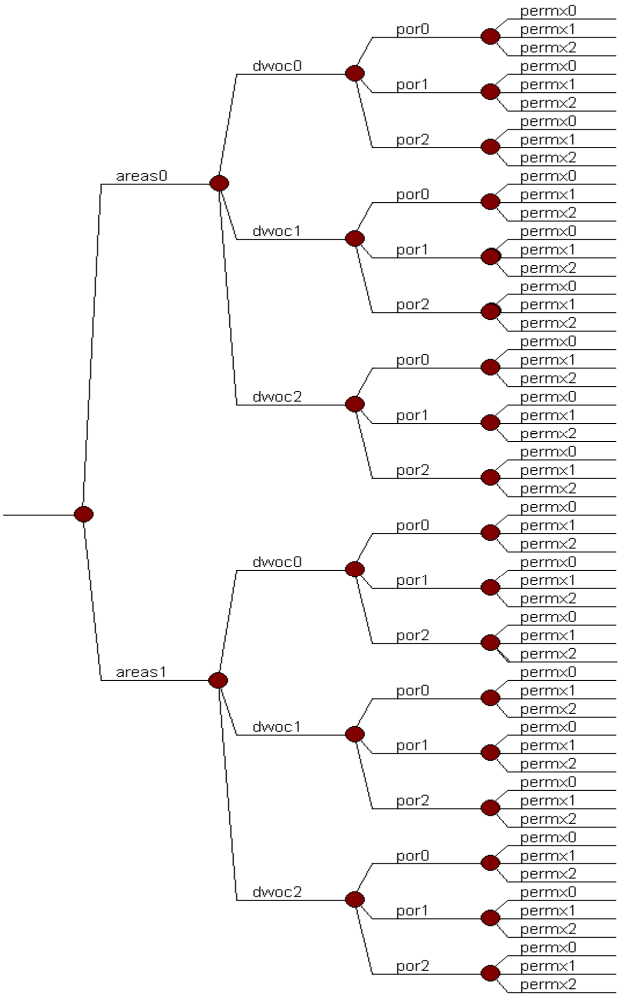


Figure 5. Derivative tree with 4 uncertain attributes.

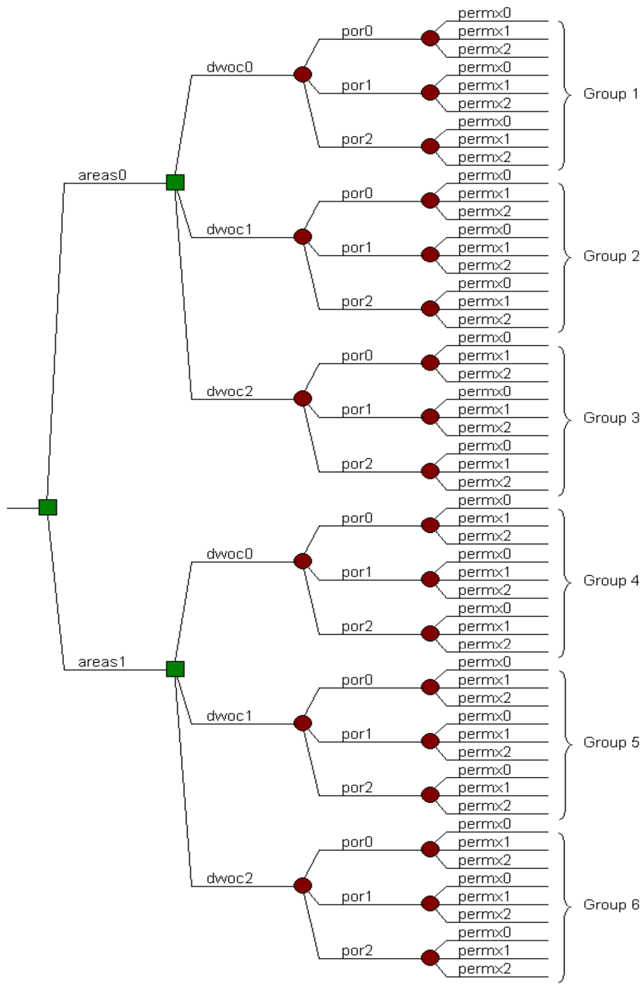


Figure 6. Decision tree - Complete information of structural model (areas) and water-oil contact (dwoc)

5.4. Geological Representative Models

The choice of the Geological Representative Models is one of the most important steps of the methodology for VOI calculation. The production strategy of each GRM is fundamental in the process: the higher the number of optimized strategies arising from the decision tree, the stronger the influence on VOI.

The decision tree, Fig. 6, was divided in six different groups to include the uncertainty of structural model and water-oil contact. The effect of increasing gradually the number of GRM was analyzed (starting from one model for each group), in order to verify the reliability of the VOI calculation. The increase of GRM required that more than one model was selected for group. A greater number of GRM were concentrated to represent the models with higher occurrence probability. The model probabilities were represented by circles, Fig. 7, whose diameters were proportional to the their values. The groups 1, 2 and 3 contained the models with highest probabilities of all decision tree models. Consequently, a greater number of GRM were considered in these 3 groups.

The selection of GRM must consider models with distinct characteristics: low RF and low and high NPV, high RF and low and high NPV and intermediate RF and NPV. The selected GRM, total of twelve, are in Fig. 8.

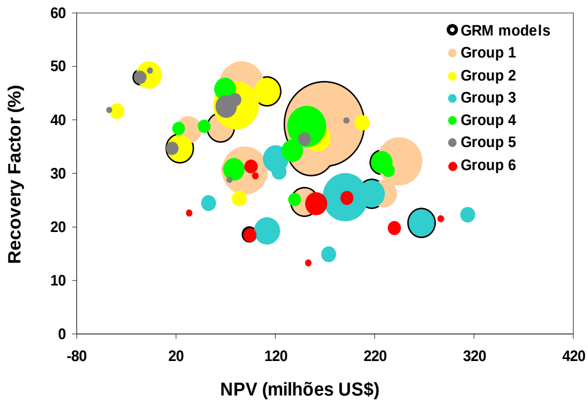


Figure 7. Probability of the models in the decision tree.

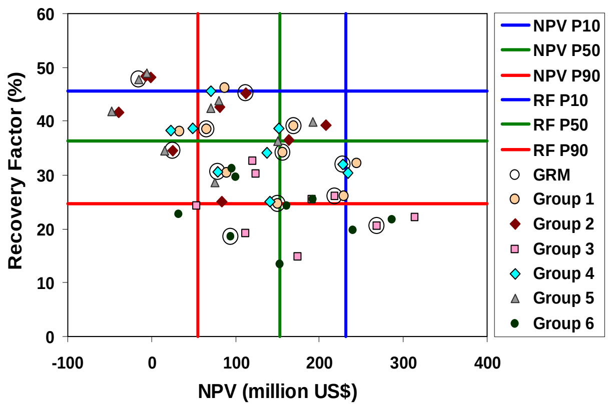


Figure 8. Selected GRM (Total of Twelve).

5.5. Optimization of the Production Strategies of GRM

The production strategies of the GRM were optimized in terms of NPV. As the base model was also a GRM, it was necessary to re-optimize its production strategy. The VOI calculation were strongly dependent on the optimization process, since the better the optimization of the strategy of each model, the better the NPV values, the more accurate the production strategy of each model and the more reliable the calculated VOI. The maximal variation of the number of wells of the optimized strategy for the GRM was equal to 9 horizontal wells. Variations in the number of wells implicate in different production systems, injection capacities and fluid productions. Some significant differences on fluid production were observed, what implies in a diversity of definition of platform, a varied oil processing capacity and a varied water treatment and injection.

5.6. Expected Monetary Values

The EMV_{SI} does not depend on the number of branches or groups that can have their uncertainty reduced and its calculation was based on the best production strategy of all branches of the derivative tree (Fig. 5) and Eq. (1). Otherwise, the calculation of EMV_{CI}, by Eq. (2), required only one and the best production strategy for each branch or group that could have their uncertainty reduced. As structural model and water-oil contact were susceptible to reduction of uncertainty, the strategy that maximized the partial EMV of each group was selected

The values of EMV (Fig. 9), in general, increased when the number of strategies in the process also increased. The addition of 5^{th} strategy increased more the EMV_{SI} than the EMV_{CI}. The opposite was observed when the 8^{th} strategy was added. The relative increase between EMV without and with information determined if the VOI increased or not, affecting significantly the VOI that stabilized in 8 millions US$.

The comparison between the risk curve without and with information is in Fig. 10. The risk of the project (measured here as P10-P90) was reduced from 198.59 to 186.05 millions US$ as consequence of information acquisition.

5.7. Comparison with Other Methodologies

The VOI and the number of simulation runs obtained through the proposed methodology with twelve GRM were compared with the results generated by the application of two other methodologies: the DSS method described by Floris and Peersmann (2000) and the common method used in petroleum industries that considers only three representative models (optimistic, pessimistic and probable). Table 2 illustrates the obtained results. The VOI calculated by DSS method was underestimated because this approach eliminates the scenarios with negative NPV and does not consider the information to alter the field production strategy. In addition, scenarios with positive NPV results in null VOI and whereas if adequate strategies should apply to the possible scenarios, the information would give value to the process.

The practice of adopting only three representative models oversimplified the VOI calculation and consequently also underestimated it. The VOI obtained by the proposed methodology is the most reliable and accurate. In the ideal case, an appropriate production strategy for each possible scenario should be optimized, although in general, this is not viable in practice due to the excessive computational effort. The simplification represented by the GRM becomes the VOI calculation possible and maintains the reliability of the process. As consequence, the proposed methodology requires higher number of simulation runs than the other approaches.

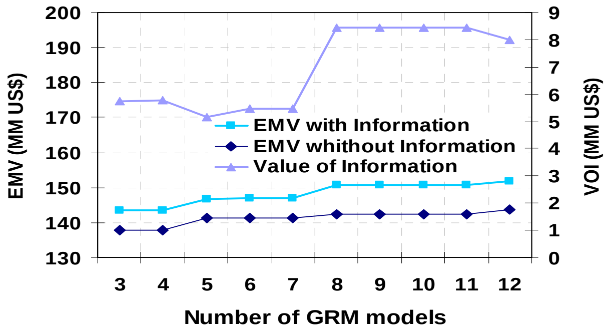


Figure 9. Influence of the number of GRM in VOI and EMV.

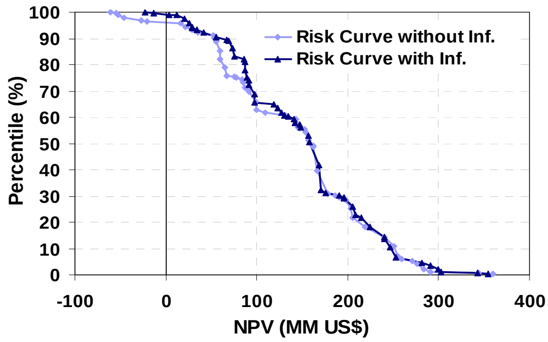


Figure 10. Risk curve without and with information.

Table 2. Comparison among methods to VOI calculation

Method to VOI Calculation	VOI (million dollars)	Simulation Runs
DSS	0.00	54 + (~25) = 81
3 Representative Models	5.74	84
Proposed Methodology (12 GRM)	8.00	948

5.8. Number of GRM "versus" Number of Simulation Runs

If the information eliminates a higher number of attributes in the tree, the number of groups that subdivides the tree is higher and the number of models in each group is smaller. The increase in the number of groups requires a high number of GRM, whose production strategies must be optimized.

As it is not feasible to optimize all models of the decision tree ideal, there is a limit to the number of GRM that make the VOI calculation viable. For the studied case, if a more precise VOI is required, an alternative is to choose a number of GRM comprehended between 12 and 54 (total number of models in the tree). The consideration of 12 GRM to calculate the VOI resulted in 948 simulations and if all models of the tree were considered, the number of simulations would be higher than 4,000, what is unavailable in practice.

6. Conclusions

The available methodologies to evaluate the VOI in appraisal and development phases do not detail sufficiently the procedure or simplify the process, resulting in underestimation of the VOI. A new methodology to quantify the VOI in these phases was developed and its complexity was observed due to the high number of variables and uncertainties, the necessity to model the reservoir accurately and the optimization of production strategy. A complete process to VOI calculation, where the production strategy of all decision tree models should be optimized, is not feasible in practice. For this reason, the proposed methodology speeded up the process and made it feasible through the GRM, which were used to choose adequate production strategy for each scenario that was susceptible to obtain information. In addition to being useful to generate strategies, the GRM were reliable to produce a risk curve, to calculate the EMV of the project and to calculate the percentiles P10, P50 and P90. However, a low number of GRM should produce errors due to different and possible production strategies.

The precision and reliability of VOI depended on the number of GRM, the optimization of their strategies and the precision considered in the optimization. The process to evaluate the VOI must be dynamic and gradual in the selection of GRM until the stabilization is reached. The VOI quantification process can yield significant errors when only three models are selected according to a common practice in petroleum industry or when the DSS method is employed. The proposed methodology is applicable to simple or complex models and with high number of variables. The proposed methodology is useful in decision-making process and represents a more reliable process, even if the time of process is elevate.

7. Nomenclature

areas	Strututral model	Np	Cumulative oil production
DSS	Decision Suport System	N_G	Total models or scenarios for groups
dwoc	Water-oil contact	NPV	Net present value
EMV	Expected monetary value	P	Probablility (Eq. 1 and Eq. 2)
EMV_{SI}	Expected monetary value whithout information	P10	Optimistic percentile
EMV_{CI}	Expected monetary value whith information	P50/P90	Probable and pessimistic percentile, repectively
E&P	Exploration and production	permx	Horizontal permeability
G	Number of gropus in the tree	permz	Vertical permeability
GRM	Geological representative models	por	Porosity
kro	Oil-water relative permeability	PVT	PVT table
N	Total number of models or scenarios	RF	Recovery factor
n_{EST}	Number of optimized strategies	VOI	Value of information

8. Acknowledgements

The authors wish to thank CNPq (Proset), ANP, Finep (CTPETRO), CEPETRO and Petrobras.

9. References

Begg, S, Bratvold, R and Campbell, J., 2002, “The Value of Flexibility in Managing Uncertainty in Oil and Gas Investments”, SPE Annual Techinical Conference & Exhibition, Texas, SPE 77586, USA, October.

Clemen, R. T., 1995, “Making Hard Decisions – An Introduction to Decision Analysis”, Belmont, pp 664.

Coopersmith, E.M. and Cunningham, P. C., 2002, “A Practical Approach to Evaluating the Value of Information and Real Option Decisions in the Upstream Petroleum Industry”, SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA., SPE 77582, September/October.

Costa A.P.A. and Schiozer, D.J., 2003, “Treatment of Geological Attributes in Risk Analysis Applied to the Appraisal Phase of Petroleum Fields”, Petroleum Society’s Canadian International Petroleum Conference, Calgary, Alberta, Canada, Paper 2003-098, June.

Demirmen, F., 2001, “Subsurface Appraisal: The Road from Reservoir Uncertainty to Better Economics”, SPE Hydrocarbon Economics and Evaluation Symposium, Dallas, USA, SPE 68603, April.

Demirmen, F., 1996, “Use of Value of Information Concept in Justification and Ranking of Subsurface Appraisal”, SPE Annual Technical Conference & Exhibition, Denver, USA, SPE 36631, October.

Floris, F. J. T. and Peersmann, M. R. H. E., 2000, “E&P Decision System for Asset Management – A case study”, SPE European Petroleum Conference, Paris, France, SPE 65146, October.

Koninx, J.P.M., 2000, “Value of Information: From Cost Cutting to Value Creation”, SPE Asia Pacific Oil and Gas Conference and Exhibition, Brisbane, Australia, SPE 64390, October.

Ligero, E.L., Costa, A.P.A and Schiozer, D.J., 2003, “Improving the Performance of Risk Analysis Applied to Petroleum Field Development”, Latin American and Caribbean Petroleum Engineering Conference, Trinidad, West Indies, SPE 81162, April.

Ligero, E.L. and Schiozer, D.J., 2002, “Risk Analysis Applied to Petroleum Field Development: Automated Methodology and Parallel Computing to Speedup the Process”, Second Meeting on Reservoir Simulation, Buenos Aires, Argentina, November.

Mian, M.A., 2002, “Project Economics and Decision Analysis – Volume II: Probabilistic Models”, Penn Well Corporation, Tulsa, Oklahoma, pp. 411.

Santos, J.A.M. and Schiozer, D.J., 2003, “Quantifying Production Strategy Impact in Risk Analysis of an E&P Project Using Reservoir Simulation”, 17th Reservoir Simulation Symposium, Houston, USA, SPE 79679, Feb.

Schiozer, D.J., Ligero, E.L., Suslick, S.B., Costa, A.P.A. and Santos, J.A.M., 2004, “Use of Representative Models in the Integration of Risk Analysis and Production Strategy Definition, Journal of Petroleum Science and Engineering, Vol. 44, No 1-2, pp.131-141.

Schuyler, J, 2001, “Risk and Decision Analysis in Projects”, Project Management Institute Inc, Second Edition, USA, pp.259.

Steagall, D.E. and Schiozer, D.J., 2001, “Uncertainty Analysis in Reservoir Production Forecast during the Appraisal and Pilot Production Phases”, SPE Reservoir Simulation Symposium, USA, SPE 66399, February.

Xavier, A.M., 2004, “Análise do Valor da Informação na Avaliação e Desenvolvimento de Campos de Petróleo”, Dissertação de Mestrado em Ciências e Engenharia de Petróleo, Faculdade de Engenharia Mecânica e Instituto de Geociências, UNICAMP, Campinas, pp. 160.

10. Responsibility notice

The authors are the only responsible for the printed material included in this paper.