BRAZILIAN BUSINESS REVIEW
Vol. 3, No. 2
Vitória-ES, Brazil – Jul/ Dec2006 DOI: http://dx.doi.org/10.15728/bbr.2006.3.2.6
pp. 223-237

Risk Analysis of Offshore Oil Development Projects: A Case Study

Bruno Nogueira Silva ¥
FCAA-Petrobras

Leonardo Lima Gomes Θ
FUCAPE BUSINESS SHOOL

Rodrigo Loureiro Medeiros ♣
FUCAPE BUSINESS SHOOL

ABSTRACT: Development of offshore oil production projects entails a huge capital outlay. The various aspects of the project are filled with uncertainties. If these are not considered correctly, an initially attractive venture can become uneconomic. It is thus necessary to carry out analyses that can identify and quantify the inherent risks of the project so that they can be mitigated as much as possible. This work presents a method of quantitative risk analysis that can serve as a basis for decisions regarding projects of this nature. We use a case study to exemplify the proposed risk analysis methodology.

Key words: risk analysis, offshore oil, projects.

Received in 09/26/2006; revised in 11/19/2006; accept in 12/02/2006.

Corresponding authors:
¥ *Bruno Nogueira Silva*
E-mail: bruno@fcaa.com.br
Θ *Leonardo Lima Gomes*
E-mail:leonardolima@fucape.br
♣ *Rodrigo Loureiro Medeiros*
E-mail: rodrigo@fucape.br

Editor's note: *This paper was accepted by Alexsandro Broedel Lopes.*

1. INTRODUCTION

DDeciding on an investment when there is no uncertainty is relatively simple. One need only calculate the net present value (NPV) and internal rate of return (IRR) of the various alternatives and choose the one with the best return. However, in practice decisions nearly always are filled with uncertainties. Companies' success depends on economic feasibility studies before deciding to embark on a project. These studies must consider the risks and uncertainties present in the project.

The high degree of uncertainty in offshore petroleum projects heightens the importance of using various methods to help identify where the greatest uncertainties lie and what variables most influence the expected economic result. The impact of these uncertainties must be quantified and the risks fully assessed, under penalty of generating undesirable economic results for the firm.

In the case of oil exploration and development projects, the investment decisions are affected by both technical and economic uncertainties. The technical uncertainties are intrinsic to the project and are not correlated with general market movements, but the economic uncertainties are.

One of the most commonly used forms of risk analysis is numerical simulation by the Monte Carlo method, which according to Prado (2000) is a way to transform a set of random numbers into another set of numbers (random variables) with the same probability distribution as the original set.

There are some computer programs that can be used to carry out risk analysis, such as @Risk® and Crystal Ball®, among others. In the case study presented here, we use the @Risk® software.

We carried out 10,000 iterations and present here some of the main indicators to better identify the project risk, along with graphs to better illustrate these indicators.

2. RISK ANALYSIS

Before discussing the uncertainties and risks associated with these projects, it is necessary first to draw a theoretical distinction between the two words. According to Simonsem (1994), "risk is when the random variable considered has a known probability distribution, while uncertainty is when this distribution is unknown." Therefore, it is desirable, to the extent possible, to convert uncertainty into risk, calculated by determining the probability distributions for the uncertain variables.

There are various methods used to assess the risks to which offshore oil projects are subject: sensitivity analysis, analysis of scenarios, Monte Carlo simulation and decision trees.

Sensitivity analysis consists of changing the value of each of the variables individually to enable analysis of the effect of this alteration on the project's cash flow, identifying the variables that most influence its economic result.

Scenarios analysis permits correcting one of the errors of sensitivity analysis, by considering the interdependencies between the project's variables, for example: the optimistic, pessimistic and most probable (or expected) scenarios, considering different but consistent combinations of the variables.

Monte Carlo simulation involves the impact the variables have on the project's result. In summary, this method associates probabilities of the occurrence of these variables, considering all the possible combinations of the variables, making this method more robust that the other two.

Decision trees can be used to analyze projects that involve sequential decisions. Projects are not treated as black boxes, in which strict decisions such as acceptance or rejection are considered, ignoring the effect of earlier decisions on subsequent investment decisions.

2.1 – Monte Carlo simulation (MCS) to analyze projects

The Monte Carlo method utilizes random numbers to compute quantities that are not necessarily random. It seeks to generate random values in a model with the objective of producing hundreds or thousands of scenarios. Due to its simplicity of application, this method has proved to be an excellent tool to deal with financial problems, such as how to calculate options prices, measure market and credit risk, calculate value at risk (VaR), analyze investment projects and solve real options.

For project analysis, the Monte Carlo method, according to Brealey and Myers (1998), consists of three phases:

Phase 1: Construction of the project mode. – consists of supplying the computer with a precise model of the project;
Phase 2: Specification of the probabilities of forecasting errors;
Phase 3: Selection of the numbers for the forecasting errors, calculation of the resulting cash flows of reach period and their registration, as long as the model is precise.

These authors suggest that MCS not only be used for the NPV distributions, but also to raise the level of comprehension of the project, investigate its future cash flows and evaluate the risk. It can serve as a basis for calculating the NPV, discounting the expected cash flows by an appropriate discount rate.

Despite its ease of application, MCS has some disadvantages. Among them are, in complex problems, the high number of interactions to obtain a result. Various techniques to reduce the variance have been developed to increase the result's precision without unduly raising the computation time. Another way to hasten the simulation's conversion process is to modify the way the random numbers are generated. The Latin hypercube sampling method, which uses the Monte Carlo principle, generates random numbers in a more efficient way. In this article, we follow this methodology together with the @Risk program to resolve the problem of the case study proposed later.

Another point that should be considered in the Monte Carlo method is the extreme difficulty of estimating the relationships among the variables and the probability distributions on which the simulation is based. For this reason, a project's risk analysis team should be very diligent in generating the inputs.

3. METHODOLOGY

3.1 – Main uncertainties

The main uncertainties of offshore oil projects regard the production curve, investments, operating costs, project delays and prices of the products (oil and gas).

3.1.1 – Production curve

According to Ligero, Costa and Schiozer (2003), one of the main uncertainties in developing oilfields relates to the static variables (geological model) and dynamic variables (flow parameters) of the reservoir. These reflect directly on the production curve, and consequently on the project's net present value (NPV). Steagall and Schiozer (2001), in turn, propose a method to analyze and quantify the uncertainty and risk in production forecasts. Their method is based on the work of Loschiavo (2001), in which numerical simulation of the flow under different scenarios of a reservoir is used, combining the uncertainty attributes.

The production curve should represent the set of main existing uncertainties. For this, it is advisable to obtain as many production curves as possible, considering the parameters that cause the most impact on the reservoir. For each scenario – combination of parameters under analysis – a new production curve is generated, which consequently alters the projects expected economic result. All the curves generated should consider the same design concept (capacity of the stationary production unit - SPU) and the number and location of the wells, because the risk of the concept envisioned should be analyzed in relation to the uncertainty about the reservoir, according to the level of information available about it. The big obstacle in doing a risk analysis of the reservoir is that it generates a huge number of production curves, which are normally obtained using a numerical flow simulator. It should be stressed that the time to generate a curve is generally lengthy, making the generation of many curves expensive. For this reason, this topic is frequently discussed in industry forums and is an area of intensive research and advances to improve the desired analyses.

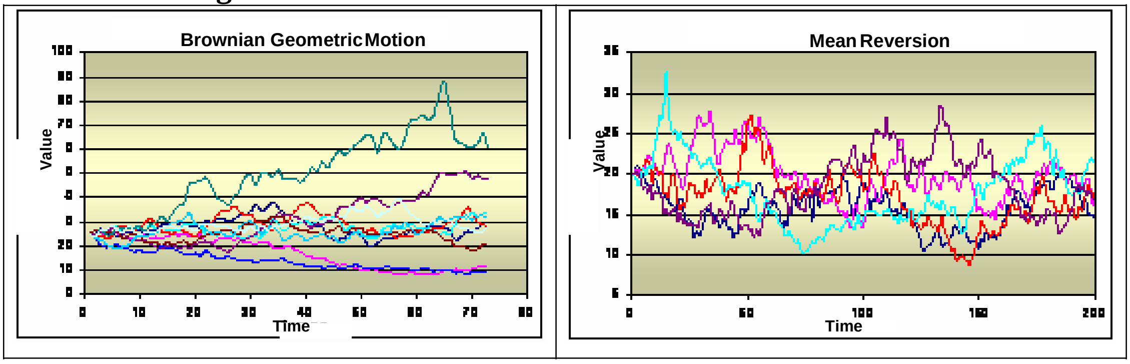
3.1.2 Investments

Regarding investments, there are both technical and market uncertainties.

The quantification of the technical uncertainties includes finding the probability distribution that best represents a determined investment item, through historical data. Some programs, such as BestFit®, can be used to find the best distribution from the data fed into the software. If such data are not available, a distribution for the investment costs can be used based on the experience of the technical staff in charge of budgeting.

The market uncertainties referring to the investments should be assessed by modeling market costs using stochastic processes, such as Brownian geometric motion (BGM), mean reversion (MR), etc. This is because these costs vary stochastically over time. For example, the rate for a pipe-laying boat can be higher or lower over time and its variance can increase in time. Figure 1 presents samples of random walks for BGM and MR.

Figure 1: Brownian Geometric Motion and Mean Reversion



3.1.3 Operating costs

Like investments, operating costs can have technical and market uncertainties. The technical uncertainties basically refer to the prices of the materials, services, time of use and frequency of workovers (well interventions). The market uncertainties refer mainly to the cost of the drilling rig that will carry out any workovers.

Further regarding technical uncertainties, operating costs have two parts: one that varies with output and another independent of output. Thus, equation 1 can be used for operating costs:

$$OC_{Fix}(t)=[OC_{Fix}(t)+OC_{Var}\times Q(t)] \qquad [1]$$

where,

OC_{Fix} = Fixed operating cost;
OC_{Var} = Variable operating cost;
Q = Oil flow of the project.

To consider the uncertainty in the fixed and variable costs, a probability distribution must be adopted for them based on historical data, when applicable, or if none are available, then on data obtained from the experience of technical staff in the area.

The consideration of the market uncertainties in the operating costs follows the same method described for investments, namely, considering stochastic processes.

3.1.4 Oil and gas prices

The uncertainties regarding oil and gas prices are market uncertainties and should be modeled using stochastic processes. Choosing the best stochastic process involves analyzing historical data and the project's proposed time horizon. The most popular stochastic process is BGM. However, Dias and Rocha (2001) use the mean reversion stochastic process combined with jumps to model the price of oil.

According to Dias (1996), econometric tests of the price of oil, over an interval of 30 years (or less) do not reject the hypothesis of BGM. However, when a longer interval is considered, of 117 years, the BGM model was rejected in favor of MR. So, it can be important to consider this latter model for long-duration projects.

3.1.5 Timetable for implementation

Another very important factor to consider in analyzing risk and uncertainty is the project's timetable. A way to consider this uncertainty is to carry out a risk analysis for the timetable, using probability distributions for starting and ending dates of the activities that cause uncertainty. To do this, specific programs can be used, such as @Risk for MS Project from Palisade Corporation. This analysis generates a probability distribution for the starting date of production. The probability of delayed or early start-up can considerably affect the project's NPV.

3.2 Analysis of the project

To carry out a risk analysis, we recommend first considering the technical uncertainties, because these are manageable. According to Dixit and Pyndick (1994), technical uncertainty encourages the investment step-by-step as the variance of this uncertainty is reduced. For example, the manager can invest in information to improve the understanding of the project, and consequently, mitigate its risks. The probability distribution of the NPV resulting from this analysis will show the project's degree of risk, and the manager can know the variables that most affect its economic outcome.

After conducting the analysis only considering the technical uncertainties, the two uncertainties – technical and market – are mixed to verify the impact they can cause on the project's NPV. The NPV probability distribution is thus generated. Since market uncertainties are not manageable, the project manager cannot take mitigating actions in this respect. According to Dias (1996), economic uncertainty is exogenous to a firm's decision-making process.

4. A CASE STUDY

To illustrate the risk analysis methodology presented, we carried out a case study of a deepwater offshore oilfield. The data are adapted from those presented by Suslick (2001).

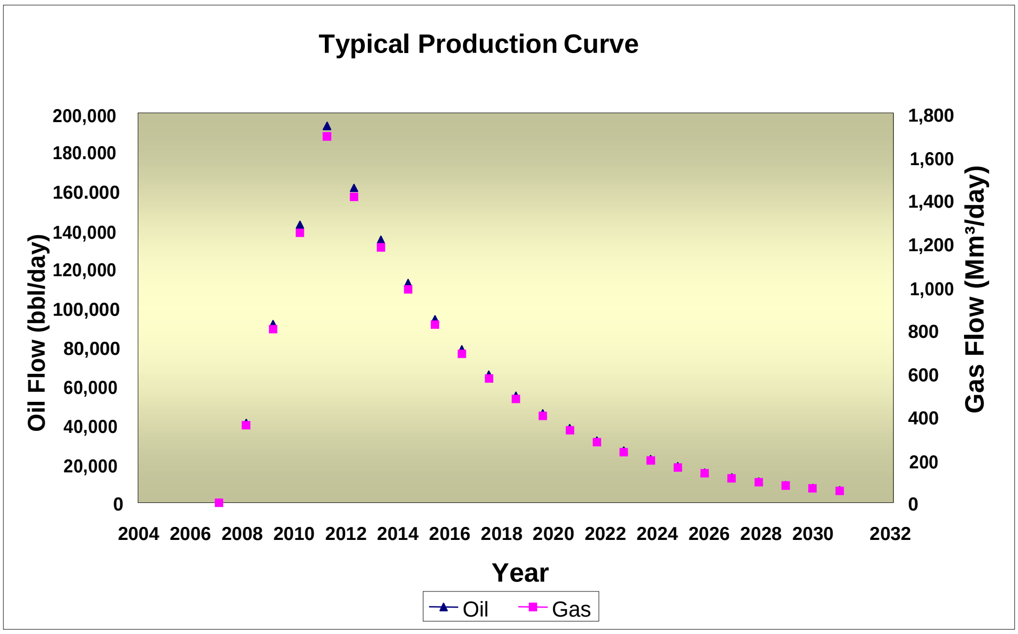
4.1 – The data considered

We considered a steeply rising production curve in the first years, until its peak, followed by an exponentially declining curve. This is the most commonly used curve and can be represented by the following equation:

$$Q = Q_i \times e^{-\alpha t} \qquad [2]$$

A typical production curve is shown in Figure 2.

Figure 2: Typical Oilfield Production Curve



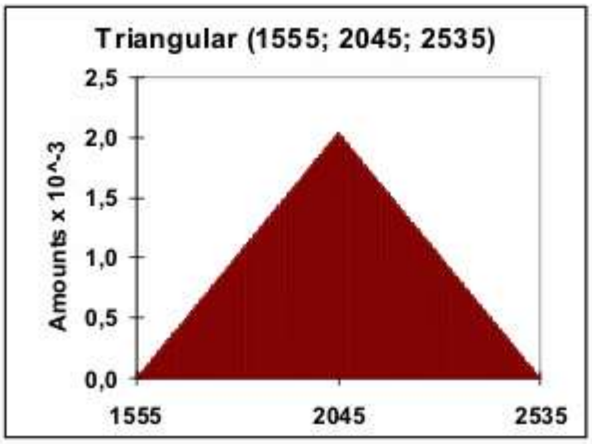
We considered the production peak as a variable following a triangular distribution with minimum, most likely and maximum parameters equal to 137, 200 and 247 thousand bbl/d, respectively. The SPU is limited to 200 thousand barrels of liquid per day, so it is not possible to surpass this level in case of simulating a curve with greater potential output.

To consider the uncertainty in the model presented in equation [2], we assumed a normally distributed exponential rate of decline, α, with mean 18% and standard deviation 0.9%. We considered the project length to be the concession period granted in Brazil by the National Petroleum Agency (ANP), 27 years. Therefore, the variation not only occurs in the production curve, but also in the field's total reserve (volume recovered), which for the most probable case would be approximately 500 MMbbl.

For investments to develop production, we assumed a minimum and maximum price of US$ 3.11 and 5.07/bbl for a field of around 500 MMbbl, as adopted by Suslick (2001). For giant fields, as is the case in this study, uncertainty is very significant, since normally they are complex projects and demand a high outlay. Therefore, to consider the technical uncertainty in this item we chose a triangular distribution with the minimum and maximum parameters cited just above, and for the most probable value we assumed the average of these two figures, namely US$ 4.09/bbl. The minimum, most probable and maximum parameters for this triangular distribution, converted into millions of dollars, works out to US$ 1555, 2045 and 2535 million, respectively, as shown in Figure 3.

The triangular distribution is widely used when there are no historical data available, and also because it is easy to understand. We did not consider market uncertainty referring to the investments.

Figure 3: Triangular Distribution for the Total Investment



We used equation [1] to consider the technical uncertainty in the operating costs. Again we used a triangular distribution for the fixed operating cost, with minimum, most probable and maximum parameters of US$50, 45 and 40 million, respectively. The most probable figure corresponds to approximately 57% of the total expected operating cost, as used in the case study of Suslick (2001). For variable operating cost, we adopted as fixed US$1.55/bbl, meaning the variation occurs due to the production curve. Again, we did not consider market uncertainty in variable operating costs.

The cost of abandonment must also be considered. Here we assumed a triangular distribution with minimum, most likely and maximum parameters or US$ 80, 100 and 140 million, respectively.

We considered that the oil price follows Brownian geometric motion (BGM), with a mean of US$ 20/bbl, volatility of 30% and growth rate of 1%.

The BGM equation is as follows:

$$P_t = P_{t-1} \times \exp\left[\left(\alpha - \frac{\sigma^2}{2}\right) \times \Delta t + \sigma \times Normal(0;1) \times \sqrt{\Delta t}\right] \qquad [3]$$

where,

P_t = Oil price at time t;
P_{t-1} = Oil price at time t-1;
α = Growth rate;
σ = Volatility;
Δt = Difference between time t and t-1.

We considered the price of gas to be proportional to the price of oil, as follows:

$$PG_t = z \times P_t \qquad [4]$$

where,

PG_t = Gas price at time t in US$/m³;
z = Coefficient of relation between the oil and gas prices;
P_t = Oil price at time t in US$/bbl.

The value of the parameter z in this study was 0.35%.

We used the @Risk for MS Project program to generate the probability distribution for the initial production date. We further considered the variation of the duration of activities with uncertainty, and carried out the risk analysis with 10,000 iterations.

The probability distribution of early or delayed start of output found was triangular, with minimum, most likely and maximum parameters of – 4,0 and 10 months respectively. With this distribution, delayed or early start-up of production directly affects the production curve, and consequently the associated operating cost and taxes. For the sake of simplification, we considered that delayed or early start-up does not affect the time distribution of the investments, which is a conservative hypothesis for this case study.

The variables in this risk analysis and the respective models to express their uncertainties are summarized in Table 1.

Table 1: Variables Considered in the Project's Risk Analysis

Variable	Model
Investment (US$ million)	Triangular dist. (1400;1555;1700)
Peak production (1000 bopd)	Triangular dist. (137;200;247)
Exponential rate of decline (%)	Normal dist. (18%;0.9%)
Fixed operating cost (US$ million)	Triangular dist. (40;45;50)
Oil price (US$/bbl)	Brownian geometric motion
Gas price (US$/m³)	F (oil price)
Delay in implementation timetable (months)	Triangular dist. (-4; 0;10)
Abandonment (US$ million)	Triangular dist. (80;100;140)

4.2 – Results of the simulation

For the risk analysis we used the @Risk, with the Latin hypercube sampling method and 10,000 iterations, a very reasonable number for the model of this study, due to its simplicity.

We ran three simulations, only varying the minimum attractiveness rate (MAT), with values of 10%, 15% and 20% for simulations 1, 2 and 3, respectively. We performed this analysis because the project's NPV is strongly influenced by this variable, which is hard to determine.

4.2.1 – Results considering technical uncertainties

First we carried out an analysis only considering the technical uncertainties, to better understand the effect of the manageable risks of the project under study and be able to take actions to mitigate them. Table 2 presents the main statistics related to the analysis considering only technical uncertainties.

Tabela 2: NPV Statistics for the Analysis Considering Technical Uncertainties

STATISTIC	Simulation 1 (MAT=10% p.a)	Simulation 2 (MAT=15% p.a)	Simulation 3 (MAT=20% p.a)
Minimum (MMUS$)	-98.90	-331.40	-443.10
Maximum (MMUS$)	1,697.60	921.20	474.60
Mean (MMUS$)	818.60	308.80	26.40
Standard Deviation (MMUS$)	304.90	210.60	153.70
Variance (MMUS$)	92,985.90	44,358.40	23,638.90
P10 (MMUS$)[1]	1.209.80	581.00	226.70
P50 (MMUS$)[2]	829.70	316.30	30.90
P90 (MMUS$)[3]	411.70	28.20	-177.10

[1] P10 = Optimistic, with only 10% probability of being surpassed.
[2] P50 = Most likely scenario, with 50% probability of being surpassed.
[3] P90 = Pessimistic, with 90% probability of being surpassed.

Another indicator of great importance is the probability of the project's NPV being negative. For the project studied here, the values found were 0.2%, 8.1% and 42.3% for simulations 1, 2 and 3, respectively, considering only technical uncertainties.

We should stress that the correct interpretation of this result fundamentally depends on the risk aversion of the decision-maker and the history of similar projects. It is not advisable to consider the figure obtained as an absolute decision parameter.

Figures 4, 5 and 6 represent the probability distributions of the NPVG found in the simulations. Note that the probability of the NPV being less than zero grows sharply with increasing minimum project attractiveness, especially when going from 15% to 20%. This shows the need to carefully define the rate adjusted to the risk to be considered in this type of study.

Figure 4: NPV Probability Distributions for Simulation 1 Considering only Technical Uncertainties

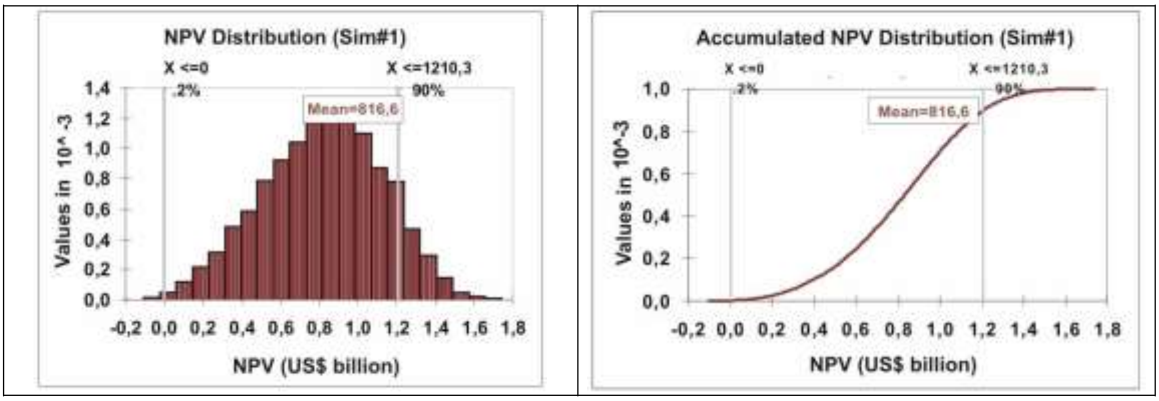


Figure 5: NPV Probability Distributions for Simulation 2 Considering only Technical Uncertainties

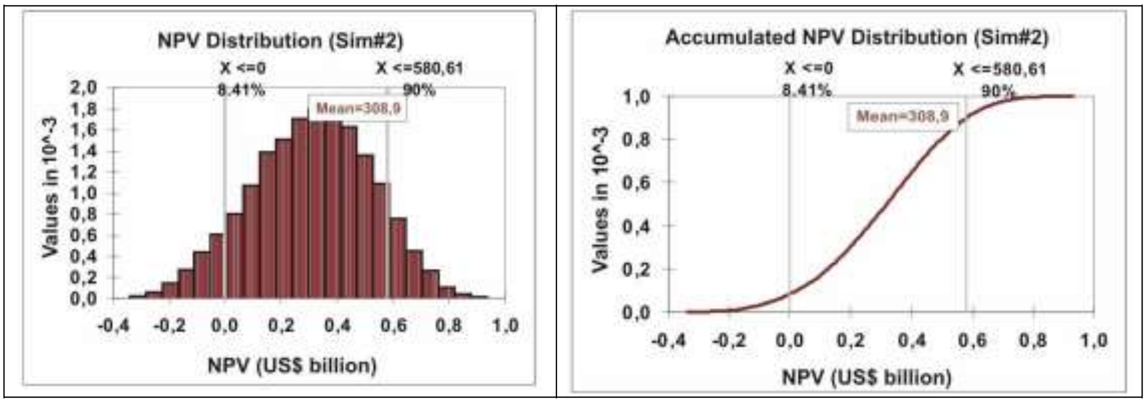
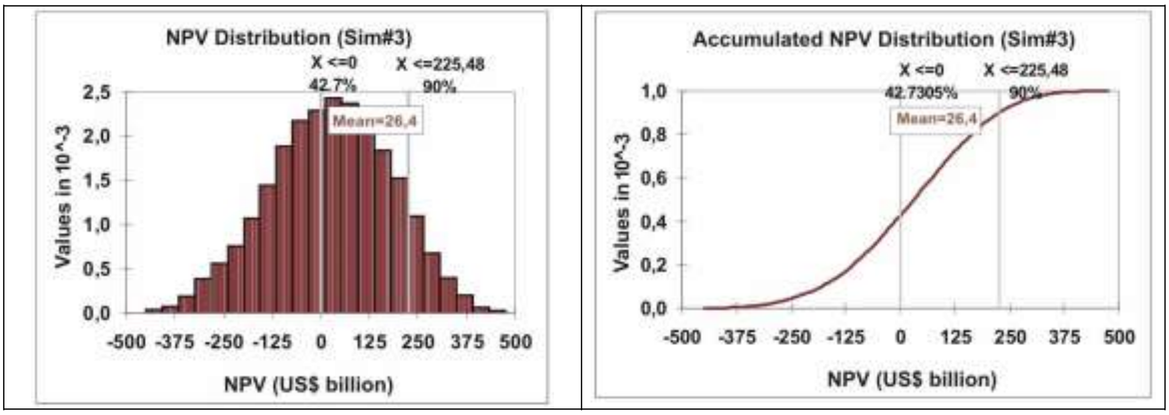


Figure 6: NPV Probability Distributions for Simulation 3 Considering only Technical Uncertainties



Another interesting aspect is to know which variables have the greatest impact on the project’s NPV. Figure 7 shows a sensitivity analysis of the NPV, considering simulation 3. For the other simulations, the ranking was the same.

Figure 7: Correlation Coefficient (Tornado) Graph for the NPV Considering only Technical Uncertainties

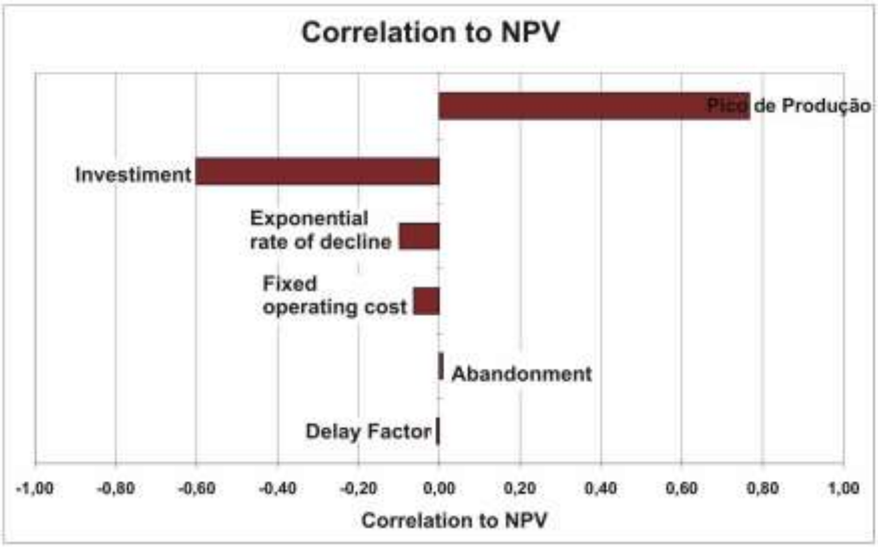


Figure 7 shows that the production curve and investments are the items that have the most impact on the NPV. Hence, it is advisable to evaluate the possibility of investing in additional information to mitigate these risks.

4.2.2 – Results considering technical and market uncertainties

We also conducted an analysis considering both technical and market uncertainties to assess how much these combined uncertainties can affect the result. The results presented do not permit affirming which measures can be taken to reduce the risks, because the technical and market uncertainties have very different characteristics.

Table 3 presents the results of the simulation carried out combining the technical and market uncertainties.

Table 3 – NPV Statistic for the Analysis Considering Technical and Market Uncertainties

STATISTIC	Simulation 1 (MAT=10% p.a)	Simulation 2 (MAT=15% p.a)	Simulation 3 (MAT=20% p.a)
Minimum (MMUS$)	-1,789.70	-1,479.40	-1,242.00
Maximum (MMUS$)	34,362.20	21,097.30	13,561.60
Mean (MMUS$)	1,095.10	475.80	133.20
Standard Deviation (MMUS$)	2,318.80	1,469.50	974.60
Variance (MMUS$)	5,376,972.00	2,159,522.00	949,927.90
P10 (MMUS$)[1]	-877.50	-803.00	-729.40
P50 (MMUS$)[2]	467.20	88.60	-118.80
P90 (MMUS$)[3]	3,737.40	2,164.30	1,272.30

[4] P10 = Optimistic, with only 10% probability of being surpassed.
[5] P50 = Most likely scenario, with 50% probability of being surpassed.
[6] P90 = Pessimistic, with 90% probability of being surpassed.

The probabilities of a negative NPV were 37.0%, 46.5% and 56.6% for simulations 1, 2 and 3, respectively, which shows that market uncertainties can mean large gains, but also large losses.

Figures 8, 9 and 10 show the NPV distributions for the project under study.

Figure 8: NPV Probability Distributions for Simulation 1 Considering Technical and Market Uncertainties

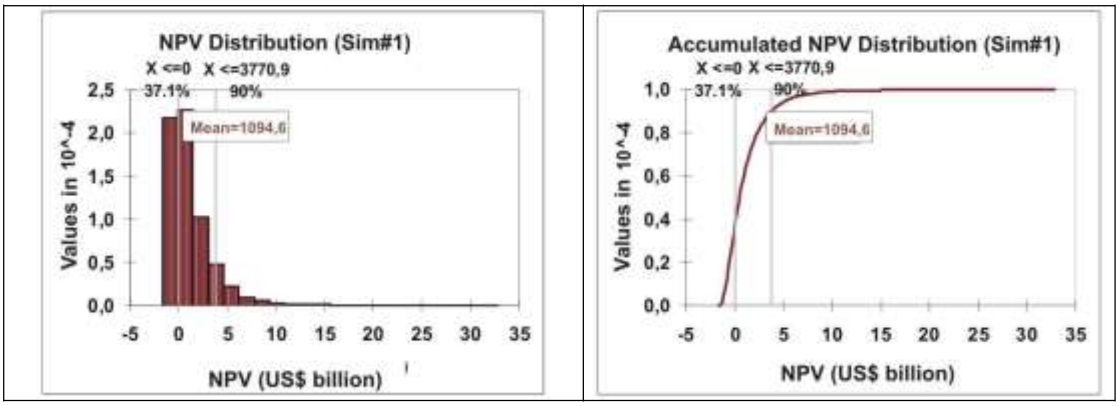


Figure 9: NPV Probability Distributions for Simulation 2 Considering Technical and Market Uncertainties

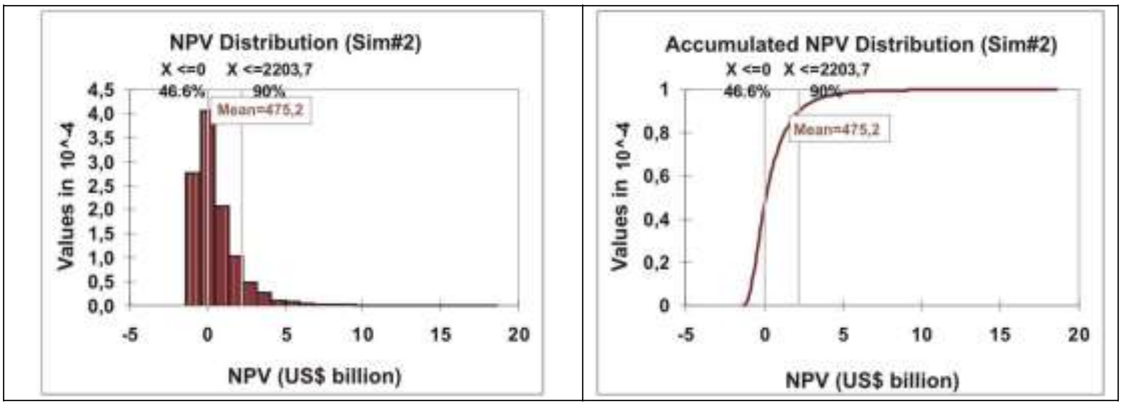
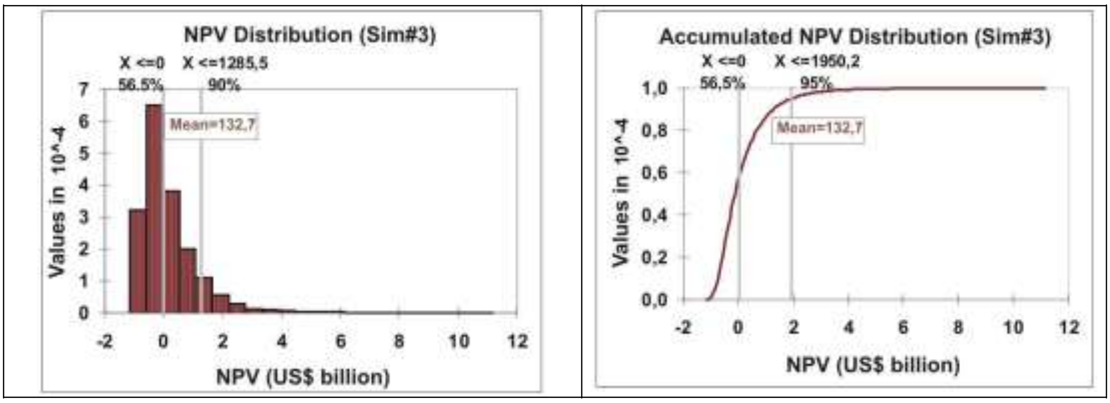
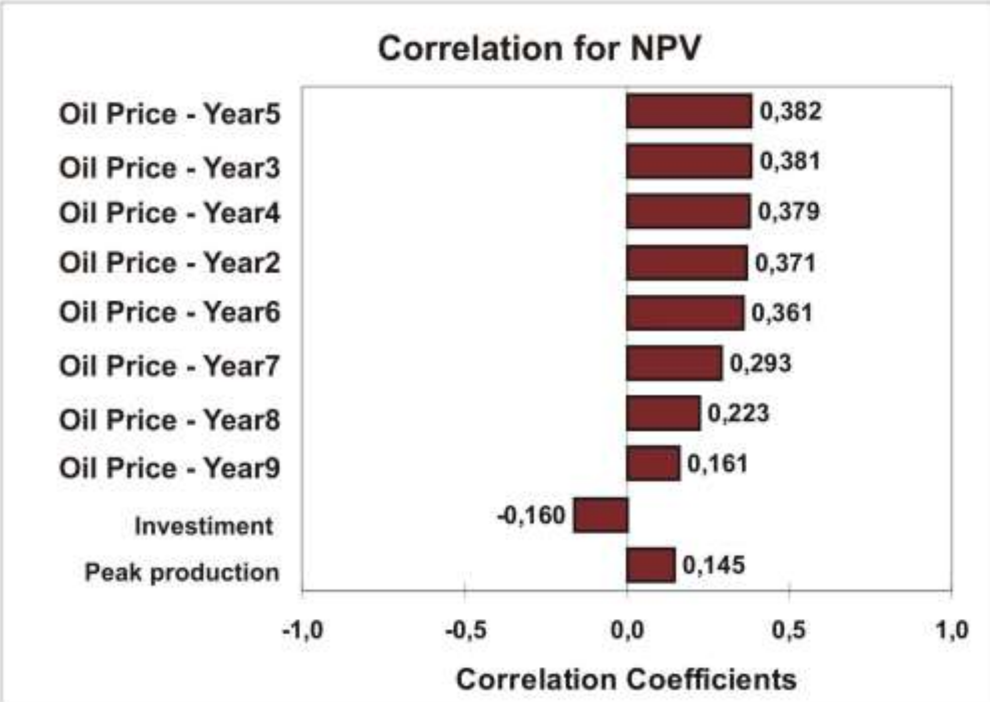


Figure 10: NPV Probability Distributions for Simulation 3 Considering Technical and Market Uncertainties



We also conducted a sensitivity analysis for the project's NPV. This analysis is depicted in Figure 11 and shows that the price of oil causes the greatest impact on NPV. This is due to the high oil price volatility in the world market.

Figure 11: Correlation Coefficient (Tornado) Graph for NPV Considering Technical and Market Uncertainties



5. CONCLUSION

Risk analysis of investment projects is a way to gain a better understanding of the risks involved, by identifying and quantifying the risk of the variables that most influence a project's economic outcome. This knowledge is extremely useful to assist decision-makers to choose projects to carry out. This is particularly important in large projects with high levels of uncertainty, such as development of oilfields.
Risk analysis permits knowing the risks involved in projects to enable more effective mitigation measures. Thus, technical and market uncertainties should not be mixed, because they demand distinct mitigation actions. An analysis should first be conducted considering these uncertainties separately, and then they can be combined to get an idea of their possible influence on the project's NPV.

Conducting risk analysis requires a high level of diligence by the whole team involved in the project, because the precariousness of the input data can cause doubtful results and thus reduced reliability of the analysis.

The results of the risk analysis carried out in the case study here show that the production curve and investments were the items that had greatest impact on the NPV, considering only technical uncertainties. The indicator of the probability of negative NPV showed that, depending on the MAT adopted for the project, it may or may not have a probability of being loss-producing. An increase in the MAT has a very large impact on the

NPV, particularly when increasing it from 15% to 20%. The project manager at this point has a fairly solid basis for deciding whether or not to go ahead with the project, or whether or not to take certain actions to mitigate the main inherent risks.

The analysis of risk combining the technical and market uncertainties showed that with the insertion of uncertainty about the price of inputs, the probability of a negative NPV grew considerably, mainly considering a lower MAT. The project had a high possibility of providing large gains regarding NPV, but also of generating large losses. The oil price was the item that had the greatest impact on the project's NPV, due to its high volatility.

REFERENCES

BREALEY, A R. & MYERS, C. S (1998). *Princípios de Finanças Empresariais*. Portugal: Ed. Mcgraw-hill.

DIAS, M. A. G. & ROCHA, K. M. C (2001). Petroleum Concessions With Extendible Options Using Mean Reversion With Jumps To Model Oil Prices. 3rd Annual International Conference on Real Options, Wassenaar/Leiden.

DIAS, M. A. G. (1996). Investimento Sob Incerteza em Exploração & Produção de Petróleo. Master's Dissertation, PUC-RIO, RJ.

LIGERO, L. E, COSTA, A.P.A & SCHIOZER, D.J (2003). SPE 81162, SPE Reservoir Simulation Symposium, Port-of-Spain, Trinidad, West Indies.

LOSCHIAVO, R. (2001). Estimativas de Incertezas na Previsão de Desempenho de Reservatórios. Master's Dissertation, UNICAMP, SP

MOTTA, R., CALOBA, G., ALMEIDA, L., MOREIRA, A., NOGUEIRA, M., CARDOSO, L. & BERLINK, L. (2000) Investment and Risk Analysis Applied to Petroleum Industry. SPE 64528, SPE Reservoir Simulation Symposium, Brisbane, Australia.

PRADO, D. (2000) *Teoria da Filas e Simulação*. Belo Horizonte: Ed. DG.

SIMONSEM, M. H (1994). *Dinâmica Macroeconômica*. São Paulo: Ed. Atlas.

STEAGALL, D. E & SCHIOZER, D. J (2001). Uncertainty Analysis in Reservoir Production Forecasts During Appraisal and Pilot Production Phases. SPE 66399, SPE Reservoir Simulation Symposium, Dallas, USA.

SUSLICK, B. S (2001) *Regulação em Petróleo e Gás Natural*. Campinas: Ed. Komedi.