



Valuation of a Real Options Portfolio

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Summary: This study aims to define a methodology supported in the concept of Real Options that will allow measuring the impact of variations in the execution of projects, on the value of the investment portfolio of the Production Vice-presidency of Ecopetrol S.A. (PRV). The proposed methodology involves the classification of the potential value of the Real Options and the valuation of the same using the Binomial method, the Montecarlo simulation, and the calculation of explicit volatility; while proposing the 3D graphic representation of the so called portfolio of Real Options.

The resulting methodology was validated using a real case of variation in two projects of the PRV portfolio in the year 2006 and it was possible to determine the way such change impacted the value of the same. This study aims to generate an important advance in management's way of thinking at Ecopetrol S.A., and the petroleum industry at large, basically in the recognition of the value that the sagacity of management decisions, regarding investment projects, has over the portfolio of the company.

Introduction

The totality of the variations of the projects led by Ecopetrol's PRV during the year 2006 were a consequence of decision making in reaction to the different causes and particularities of each project; this evidences a lack of formal and practical methodology to evaluate the impact of those causes and particularities, on the value of the portfolio.

The bibliography available on Real Options was analyzed in detail, in particular the way the investment portfolio of Ecopetrol S.A., is structured, approved controlled and monitored. Likewise, the uncertainty variables affecting petroleum companies were briefly analyzed; also the basic concepts of profitability, risk, diversification and the optimization of portfolios were reviewed, and the theory of Real Options and the formulation of the concept of a portfolio of Real Options were also analyzed to form the fundamental basis of this work.

The validation of the proposed methodology was based on the information obtained from the PRV portfolio for the year 2006, using a real case of

variation occurring in two projects of the PRV portfolio during such year and it was possible to determine the way in which such changes affected the value of the same.

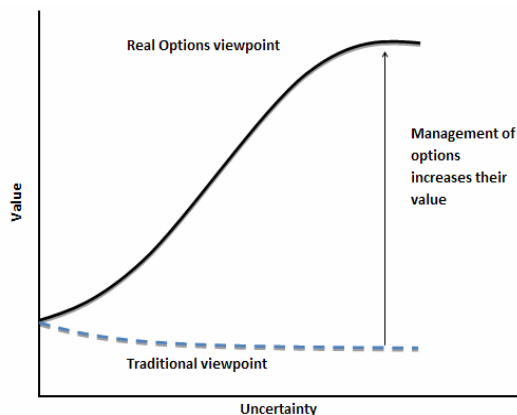
As a complement to the findings showing that the majority of the changes that took place within the PRV portfolio occurred due to planning and maturity faults, the authors propose a methodology of cost optimization and control for Ecopetrol's PRV projects, and which is set forth in the thesis presented by the authors.

Theoretical Background

The theory of Real Options (RO) constitutes one of the most important basis of modern financial theory and it is placed among the most innovative and complete decision-making methodologies, especially because it can be used in situations of high uncertainty and where the resources needed to carry out the project are high, as in the case of the petroleum sector.

Successive theoretical studies have demonstrated that the net value of investment projects is a function of its RO's, which define the acceptance or rejection of the same. One of the main

objectives behind the implementation of RO in petroleum companies is related to capturing the flexibility value available at the time of making strategic investments, which when shown schematically (graph 1) represents the additional value added in virtue of the capacity of management to react when faced with new information obtained, after decisions have been made and over which there is no flexibility, as in the case of Discounted Cash Flow (DCF).



Graph 1. Value of Real Options

The methodology of the RO assumes that the world is characterized by change, uncertainty and competitive interactions between projects and companies, and establishes that management can make future decisions in response to changing circumstances; the future is considered full of alternatives and options that add value in the majority of cases.

Endogenous or technical risks are relatively easy to evaluate with current valuation methodologies; exogenous risks are not easy to measure due to the volatility of markets, reason why RO's are a way of assessing projects with that sort of risks, as in the case of petroleum projects.

Likewise, in some companies where the projects are submitted to uncertainty levels, the tendency leans towards finding a "satisfying solution" which means finding quick solutions that even though not being the ones with the greatest profitability value; however, do fill the expectations of those having interest at stake in the company; all the above, brings about the acceptance of solutions that are below perfect, because there is not time for perfection. Without pretending to be perfect, the proposed methodology allows the valuation of the real impact on the company's portfolio.

Future opportunities, product of current investments, are seldom taken into account as part of the delimitation and budgeting schemes of the organizations, something that impedes both aggressive planning and more importantly having available action plans that assure and incorporate the information obtained and define a more robust decision-making scheme.

One important advantage of the RO's is that they help to protect the totality of investment profit, by decreasing potential losses. It is important to mention that when the RO's are used by the companies, these help reinforce the multidisciplinary vision of the teams, increase the value of the stockholders' options and emphasize the dynamics of the learning process in projects where execution by phases is viable.

Moszkowicz (2003) analyzed the results of "expost" evaluations of projects that could have been evaluated using RO's and which were sanctioned only with DCF, finding that for projects with a very high Net Present Value (NPV), the evaluation with RO's could have meant an increase of 16.6% of the accrued NPV with regard to the one obtained using only DCF; in projects with NPV slightly above zero, the results of the accrued NPV "expost" were significantly superior, evidencing the usefulness of the RO's.

Another important aspect seen in the PRV is that the enterprises tend to commit their investment resources early on, ignoring the possibility of differing payment through time (Kester, 1981). A detailed analysis inside the PRV demonstrates the competitive attitude of the different areas for the allocation of resources during the first month of the year, when on the contrary, the least amount of execution takes place. On the other hand, the urgency for production has generated the approval or commencement of "immature" projects, increasing the degree of uncertainty and worst yet; do not allow the gain of profit above that initially calculated. Such situations are common when the projects have a high NPV, the risk and the interests are low and there is strong competition in the business sector. For the specific case of Ecopetrol S.A., the risk and interest variables are not considered, but the influence of availability and opportunity of contracting services such as drilling rigs and the possibility of having additional or easily obtainable budgets, is presented.

In general terms, specialized literature coincides in stating that the classification of the RO's given by Amram Martha and Kulatilaka (1999) generally gathers the different types of RO's affecting real assets, but for the concrete effects of this study the investigations of Bravo & Sanchez (2003) and William Bailey et al (2004) were used, who reviewed within the petroleum company sector the possible RO's and that are commonly present in the natural cycle of decision-making as identified in figure 1.

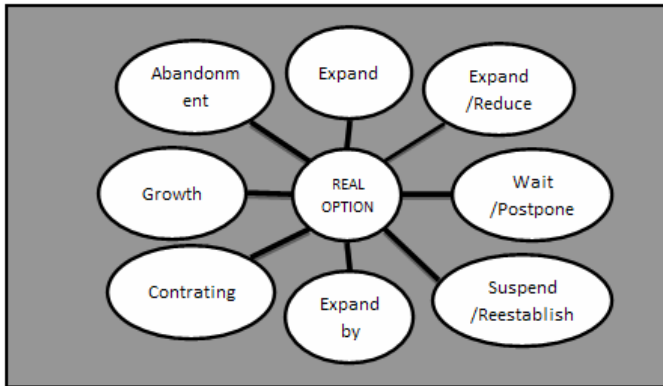


Figure 1. Types of Real Options in the petroleum sector

The RO Portfolio

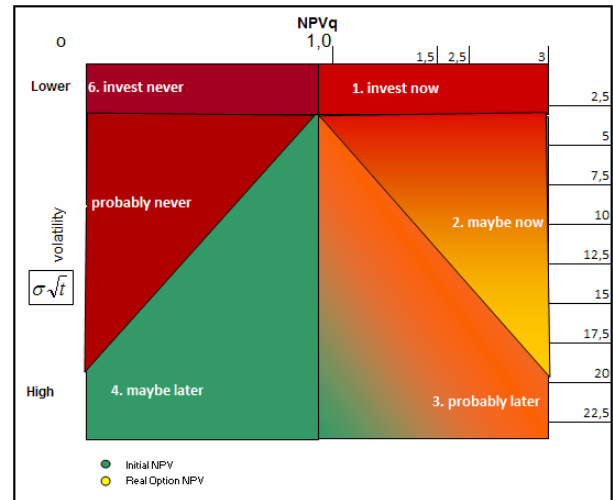
The concept of a Real Options portfolio, is a new financial concept, developed on the basis of the research conducted by Luerhman (1998) and the application of Bravo & Sanchez (2007).

An RO portfolio is defined as the graphic representation of the different projects of a company, each with NPV and different volatility, where different execution alternatives (options) are considered. Through such representation it is possible to associate the valuation of assets by DCF and the valuation by RO, using a simple graphic representation that allows the classification and location of projects according to their profitability, volatility, value and the time allocated to the expiration of the option.

According to Luerhman; initially, the NPV should not be considered as a difference (positive flow minus negative flow) but as a quotient, where the numerator is the expected positive cash flow and the denominator is the expected investment cost. In such case the acceptance rule is for this quotient (denoted by NPVq) to be greater than 1. NPVq is the variable graphed in the horizontal axis of the RO portfolio.

The definition of NPVq makes it possible to decide if the investment is made or not, and it is evaluated as a NPV project; such form of decision-making only conjugates the time of duration of the project and the discount rate (considered when bringing the flows to present value), the value of the project (equivalent to S) and the cost of investment (equivalent to X), but the reality of the majority of projects with RO is that additionally, the variability and the time available to differ the project should be considered

Based on the above, the model works with the accumulative variance, defined by multiplying the variance by the time unit and calculating its square root. Graph 2 shows a practical and integral way of representing the investment projects in an RO portfolio diagram.



Graph 2. Diagram of a Real Options portfolio

As can be observed, if volatility increases so does the price of the option, the same happens if S goes up or X goes down. Thus, the more volatility moves to the right and/or down, the more value the option would have, and so would the project. The diagonal line (a curve in reality) represents the NPV = 0, and it is formed by maintaining both the discount rate (r) and the standard deviation constant, but varying time; while the vertical line indicates that NPVq = 1.

When t = 0 (expiration) both NPV's have the same criteria and the projects located in this zone are accepted or rejected immediately, because there is no flexibility. But as more time is available and there is greater volatility these two lines separate and the valuation shall include other factors.

Here the main difference between NPV and NPVq is that if there is a t time for the expiration of the option, the investment flows (X) can be postponed until the time available for maturity. The reason (rate) in the case of NPVq is going to be greater when bringing the NPV of these negative flows (discounted through time), maintaining constant positive flows; the ratio now not being S/X but $S/X \cdot (e^{-rt})$.

The concept of NPVq is an indicator arbitrarily developed to allow greater analysis in the area where (in a previous analysis) a project is not positive. It is clear then that it may have a positive value while the normal NPV may yield a negative result (area under the curve). In such case the interpretation is that it is better not to implement the project now, but the project is very promising because these two variables (S and X) are very close (separated only by the value in time). If management waits for the value of the project to increase to a discount rate greater than r, and focuses on that, most likely there will be a viable project in the future. Likewise, it may be applied to project prospects than in spite of having positive NPV, also possess intrinsic options that as more information is obtained, mature more and their value increases.

Analysis of the 2006 VPR portfolio

Following the procedure described in figure 2, the PRV presented a firm request of operating investments for the year 2006 for US \$705 equivalent millions, 10% originated in Colombian pesos and 90% in American dollars (USD).

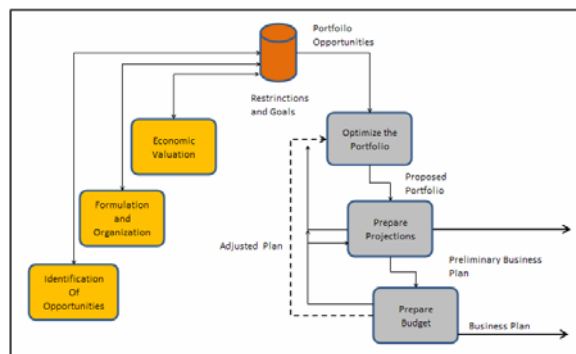


Figure 2. Portfolio process at Ecopetrol S.A.

After supplying the corresponding justifications to the organisms of the company and after submitting the budget request for the approval of the CONFIS and other state organisms (this authorization process now a days depends on the Board of

Directors and not the government anymore), the final approval of the investment budget for PRV for the year 2006 was US \$675 equivalent million, because some projects were postponed or fractioned into phases.

Project execution process at PRV

Once the respective Regional Production Management part of the PRV, obtains the approval and the resources for the investment projects, the execution planning process begins. In this phase the Technical management through the Project Engineering Department coordinates with the Regional Technical Leader the support for the preparation of the Detailed Work Program (DWP) and the base line of the project (appointment of the work team, detail of activities, resource allocation, logic relation and duration of activities), consolidates the Annual Purchasing and Contracting Plan of the project (APCP), provides support for the preparation of the risk analysis, execution strategies and the identification and definition of the phases of the project.

The Project Engineering Department updates and incorporates the real activity commencement dates and issues periodic execution programs on a weekly, fortnightly and monthly basis, in order to measure the progress in the determined periods of time. Likewise, it obtains completes the necessary resources for the execution and initiates the detail engineering processes to structure the required contracting and purchasing packages in accordance with the DWP and the APCP of the project. These packages together with the corresponding planning, which includes, specifications of the selection processes, evaluation criteria and required execution times are delivered to the contracting and purchasing department of the Corporation. The Project Engineering Department controls the physical advances and budget execution of the project, conducting the analysis of the progress through the Gained Value methodology, using the tools provided by the Corporation.

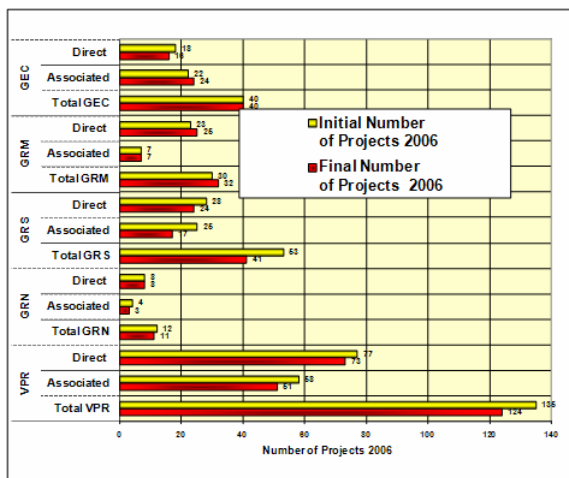
Deviations from the initial program are reported to the Regional Management in charge of the project, together with the corresponding reprogramming, the description of the new critical route (if it has varied) and the adjustments to resources required to complete the execution of the project. The conclusion of the project or of the activities of the project within a specific term is accompanied by a

final report issued by the Engineering Department Chief, and approved by the Technical Manager.

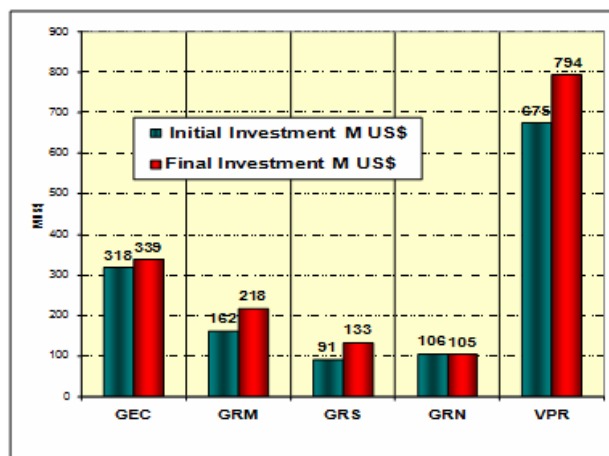
The changes that affect the PRV projects were grouped into type 1 (generated by drawbacks or problems during execution) and type 2 (motivated by analysis of new information or preliminary results obtained during the first stages of execution)

As it becomes necessary to implement any type 1 change during the execution of an PRV investment project, the project leader at Technical Management reports directly to the Regional Management the impact of the change, so that an analysis can be made and the corresponding measures be implemented, thus permitting the optimum execution of the project. Type 2 changes are formalized during the monthly project committee meetings of the respective Regional Management, where the results and the route to follow are analyzed for each particular case; during such meeting budget modifications required by the different activities are approved by Regional Management and through the project leader of Technical Management.

Graphs 3 and 4 show the comparison between the number of projects for each PRV management unit (classified as either direct or associated operation) existing when the PRV investment budget was approved in January 2006 with the number of projects actually executed to December of the same year and the total investment variation, respectively. Results show that fewer projects were carried out (124 out of 135 approved), but more resources were used than those initially approved. (794 vs. 695 M US\$ approved).



Graph 3. Variation of PRV 2006 projects

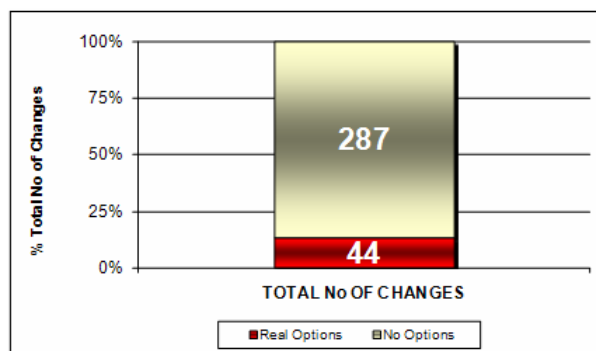


Graph 4. Investment variation PRV 2006

The execution of a smaller number of projects at VPR during 2006 was mainly due to the cancellation, by associated companies, of projects that required more maturity and to the lack of drilling equipment and well services.

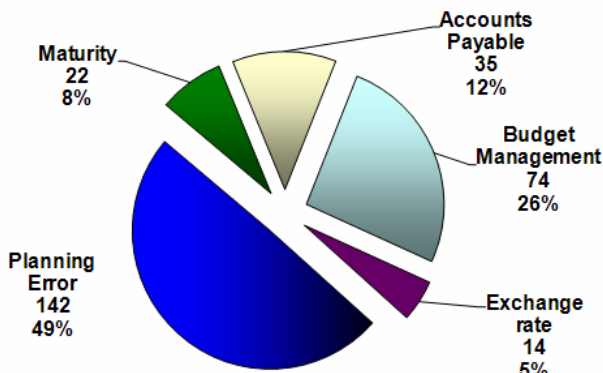
Additional investment resources approved to PRV resulted in additional production of 7,124 barrels of oil per day and sales of 28.96 million cubic feet of gas per day, for the year 2006.

During the year 2006, 331 changes were made to the 135 investment projects at PRV, such changes included cost overruns, greater activity, cancellation of activities and projects, approval of new projects, releasing of resources, requirements brought about by the variation in the currency exchange rate, savings, and by a large percentage budget adjustments due to deficient structuring and maturity. The analysis of the changes made to the projects at PRV identified 44 of those changes or adjustments as Real Options and 287 adjustments as being caused by deficiencies in planning and maturity.



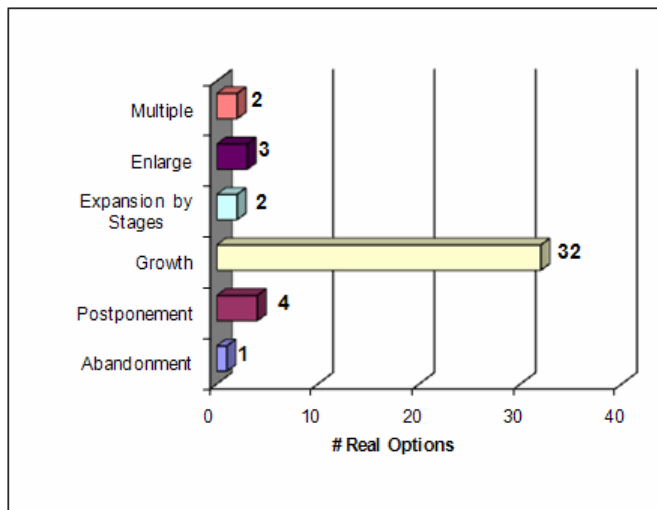
Graph 5. Changes to PRV projects 2006

The modifications that were not catalogued as Real Options were grouped according to the causes of change as shown in graph 6.



Graph 6. Other changes

The 44 Real Options identified within the adjustments made to the PRV portfolio in 2006 (graph 7), according to the types of RO previously mentioned, were Abandonment (1), Postponement (4), Growth (32), Expansion by stages (2), Enlarge (3) and Multiple (2).



Graph 7. Real Options of PRV in 2006

The variations shown by the projects conducted at VPR during the year 2006 were entirely the consequence of reactive decision making to the particularities of each project, which evidences the lack of formal technology and practice to evaluate the impact of the same, over the total value of the portfolio.

At Ecopetrol S.A., the value of the portfolio corresponds to the sum of the Net Present Values (NPV) of all projects; for the case of the PRV it is

equal and corresponds to the sum of NPV's of the 240 projects approved. Table 1 shows the values of the VPR portfolio at the beginning and at the end of the year 2006.

Magnament	No. Projects	NPV(14%) MUSS INICIAL	NPV(14%) MUSS FINAL	Variation	OBSERVATION
CO	94	2526	2685	159	Effect of Operanting Cost Optimization
GMM	26	492	502		
GEC	23	1120	1199		
GRN	9	505	555		
GRS	36	409	429		
OH	68	849	967	118	Effect of Project variation
GMM	16	25.2	104.2		
GEC	20	486.3	518.3		
GRN	6	299.8	302.8		
GRS	26	37.3	41.3		
EST	16	-12	-10	2	Effect of Project variation
GMM	3	-1.6	-0.9		
GEC	8	-5.7	-5.2		
GRN	2	-3.6	-3.3		
GRS	3	-1.2	-1.0		
RO	62	-283	-277	6	Effect of Project variation
GMM	12	-96	-95		
GEC	17	-76	-73		
GRN	6	-66	-65		
GRS	27	-45.6	-43.3		
TOTAL MUSS	94	2526	2685	159	Effect of Operanting Cost Optimization
TOTAL MUSS	146	553	679	126	Effect of Project variation
TOTAL MUSS	240	3079	3364	285	Total variation not affected by price of crude oil

Table 1. Impact Value of the Portfolio

It can be observed that eliminating the effect of the variation of the price of crude oil and other macro-financial variables and considering only the variation of the investments and the production obtained in every project, the PRV portfolio in the year 2006 experienced a positive variation of 285 M US\$, where 44% of that figure corresponds to the 331 changes made to 135 of the 240 investment projects of VPR.

An aspect that must be highlighted is that all the variations of the projects globally or grouped, represented for PRV a benefit in the value of the portfolio, but did not followed a methodological and formal analysis, which is the main objective of this study.

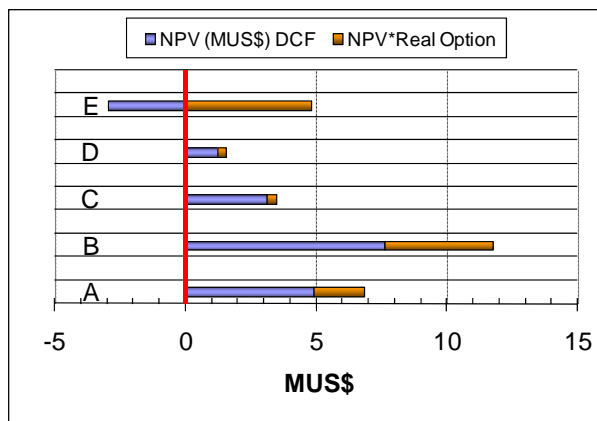
Proposed methodology

- During the first week of the year a list of projects approved and to be executed by PRV must be drawn, including the projects having growth potential (quantify the possible growth percentage), high variation and great uncertainty (quantify the variable with the greatest uncertainty).
- Check the degree of maturity and consistency of the variables of every project (investments, operating costs, equipment availability, internal and market variables) and the projection criteria of the same.
- Static models of Discounted Cash Flow (DCF) are created or updated for each project, at the

- official discount rate of the company and the NPV is calculated or (recalculated).
- d. Once the updated economic results for each project are available, the projects with a NPV near the breakeven point and the projects with a NPV defined (positive or negative) are categorized.
 - e. According to the weight given to the technical percentage of growth for each project and of the grading given by the specialized technical team of the percentage of greater uncertainty for each project, the growth percentage (positive or negative) is determined, which is used to determine the NPV scenario per OR effect, called NPV* OR. It is very important to clarify at this stage that the NPV calculated as NPV* OR is not the definitive one, since that is calculated later using the Binomial Tree method. The aim behind this NPV* OR is to identify with the use of technical criteria the projects having priority in the analysis according to their growth potential and NPV and to locate them in the graph. To conclude this analysis, the format of Table 2 was designed to organize the information from each project and the respective exit graph (graph 8), using assumed data.

SAP name of Project	ID project	Scope	NPV (MUS\$) DCF	MBLS	Investment (MUS\$)	Technical Growth Potential	Probability of occurrence of the variable with the greatest uncertainty	Growth Net Technical Percentage	NPV With Growth	NPV*RO
ON ADDITIONAL DEVELOPMENT YARIGUI_CGO	A	7 Wells	4,87	5,45	16,06	100%	Productivity per Well 40%	40%	6,8180	1,948
ON ADDITIONAL DEVELOPMENT LISAMA	B	5 Wells	7,61	3,31	10,76	90%	Area Continuity 60%	54%	11,7194	4,109
ON ADDITIONAL DEVELOPMENT LLANITO	C	6 Wells	3,09	2,53	11,32	40%	Petrophysics 30%	12%	3,4608	0,371
ON DEVELOPMENT BONANZA	D	4 Wells	1,2	1,6	5,949	40%	Reservoir Continuity 70%	26%	1,5120	0,312
ON DEVELOPMENT NARE JAZMIN	E	30 Wells	-2,99	5,61	25,04	120%	Productivity per Well 50%	60%	1,7940	4,784

Table 2. Valuation of growth options



Graph 8. Project prioritization

- f. According to the previous table and graph, the projects that meet the characteristics necessary to have their Real Options independently valued, are identified. For the example of the previous table, maintaining the priority order, the possible RO's of projects B, A, E, and C respectively should be evaluated. Project D does not require additional RO valuation, due to its low impact on the NPV.

In order to better describe the valuation methodology of the RO Portfolio, such methodology will be applied to two projects of the 2006 PRV portfolio; due to confidentiality limitations these will be called Project ON Development and Project ON Alliance, respectively.

Description of the Project (1) ON Development:

A project whose objective is to incorporate 3.34 million barrels of crude after drilling seven (7) wells, with an average production of 1,194 barrels of oil per day. The approved budget for the year 2006 was 16.06 million dollars. The first change was requested in July 2006 with the addition of 23.11 million dollars for the drilling of five (5) additional wells in the year 2006; a second change was made in July 2006 to extend the scope of the project, which involved the drilling of nine (9) wells in the year 2007 and ten (10) wells in the year 2008, and a third change was made in September 2006 with the addition of 6.03 million dollars for the drilling of four (4) additional wells in the year 2006 and to cover greater drilling costs.

Description of the Project (2) ON Alliance:

A project whose objective is to incorporate 7.2 million barrels of non developed proved reserves, through the execution of reconditioning jobs and the drilling of production and injector wells; the scope of the project involves the improvement of the injection profile of 53 wells and the drilling of 16 more. A 23 million-dollar budget was approved for the year 2006. The first change was requested for 23,56 million-dollar in June 2006 for the drilling of 9 additional wells and to cover cost overruns of drilling services for the year 2006; a second change was made in June to expand the scope of the project, which was supported by the drilling of 14 wells in the year 2007 and 15 more in the year 2008; a third change was made in September 2006 with the request for 7.73 million dollars for the drilling of 5 additional wells in the year 2006 and to cover greater drilling costs of the wells already drilled; finally, a fourth change was

made in November 2006, where 0.64 million dollars are released due to the postponement of the drilling of 3 wells for the year 2007.

For the approval of the changes aforementioned the Discounted Cash Flow (DCF) method was used to calculate the net present value (NPV) of the new project (including the additional wells in each case), using a discount rate of 14% for such calculation.

The technical information of the projects was reviewed and the possible growth percentages were identified, the results were 80% for project (1) and 30% for project (2), in addition the variables of greater uncertainty were identified, which turned out as follows: for project (1) the production volumes (38% uncertainty), and for project (2) the completion time of wells drilled (uncertainty 50%).

Based on a drilling cost study conducted by the authors, the statistical distribution to be applied to the drilling costs of project (2) was identified; the distribution of production for project (1) was determined through the analysis of the information obtained from production yields from the wells drilled in previous operations.

Beginning with the static DCF models defined for the two projects, the economic results including the new investments and the updated production profiles were established.

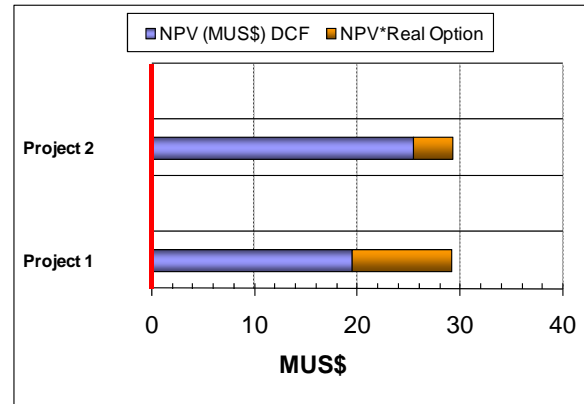
According to the weight percentage given to growth and the qualification of the percentage of uncertainty of the project, the NPV* RO is calculated; table 3 shows the information obtained for each project.

SAP name of Project	ID project	Scope	NPV (MUS\$) DCF	Investment (MUS\$) MBL	Technical Growth Potential	Probability of occurrence of the variable with the greatest uncertainty	Growth Net Technical Percentage	NPV With Growth	NPV*RO	
ON ADDITIONAL DEVELOPMENT YARIGUI_CGO	Project 1	16 Wells	19,45	3,34	29,14	80%	Productivity per Well 62%	50%	29,11	9,66
ON ALLIANCE CASABE	Project 2	39 Wells	25,43	7,2	30,65	30%	Well Completion 50%	15%	29,24	3,81

Table 3. Valuation of growth options

Table 3 and graph 9 show that both projects require that the Real Options of the two projects be evaluated independently, because there is evidence of investment increase, mainly in project (2) that has a low value promise. Likewise, it can be seen that project (1) has a better projection of

adding value than project (2), where in a scenario of a large number of projects to be analyzed would not be necessary to analyze the RO's, but in order to validate the proposed methodology, it will be done.



Graph 9. Prioritization of projects

- g. The next step is the valuation of the RO's of the projects through the Binomial Model, which assumes that in each period the value of the project will increase by a proportion u (UP) and with a probability of p , and will decrease by a proportion d (DOWN) with a probability $1-p$.
- h. Using the Excel model structured to calculate the base value of each project starting from the conventional DCF, it was determined that the random variables that most affect the NPV are the production profiles, the price and the investments; from these, the prices were correlated from one operation to the next and the respective probability distributions were correlated to each variable, according to the historical information available. Figure 3 shows an example of the distributions of the variables of project (1) that were extracted from the model run carried out using the *Crystal Ball* software.

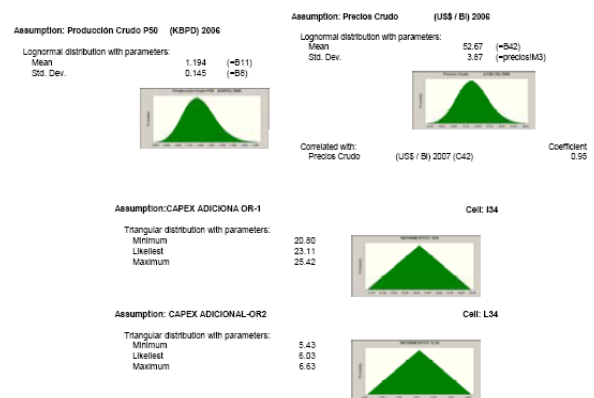


Figure 3. Variable distribution

- i. Using the model structured in Excel, the standard deviation of the returns from one period to another is defined as the variable to be simulated, and will be denoted as variable Z, expressed in the following formula:

$$z = \ln\left(\frac{VP_1 + FC_1}{VP_0}\right) \quad (1)$$

The standard deviation obtained in the simulation for variable Z will be the entrance parameter for the construction of the binomial event tree of the project.

- j. After obtaining all the variables that involve uncertainty with the respective distributions and dependencies, using the Montecarlo simulation all possible values that the returns may stochastically take from the subjacent asset (in our case the projects under evaluation, until expiration date; therefore, a sufficient number of runs is required before satisfactory results are shown) are simulated. From the statistical indicators table the standards deviation of variable Z is taken as the value of volatility. Graph 10 shows an example of the exit distributions of variable Z (standard deviation of returns) of the project (1), extracted from the running of the model in the *Crystal Ball* software.

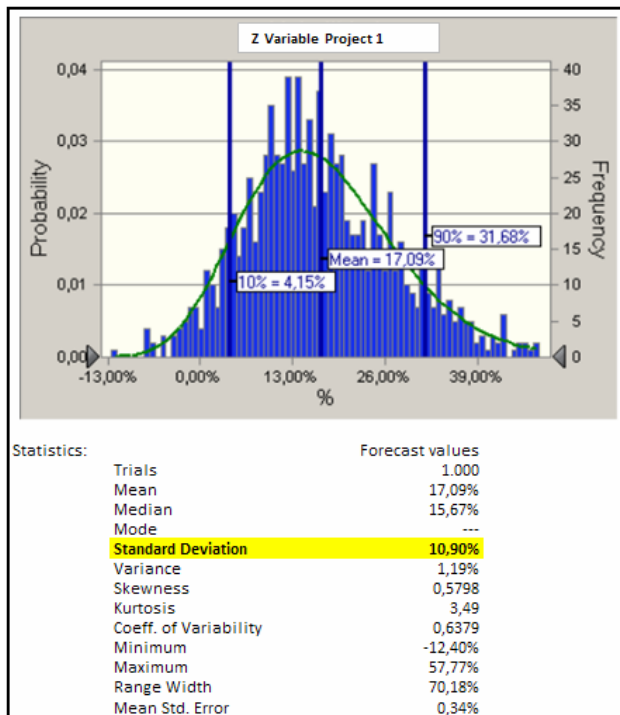


Figure 13. Distribution of variable Z.

- k. Using the value resulting from the simulation (volatility obtained), the event tree is built for each project, which was done with annual intervals. To calculate the value of an option using binomial trees, the use of neutral risk probabilities will be considered. Tables 4 and 5 show the multiplicative binomial trees for each project and the distribution of binomial probability associated to each.

Project 1						
Inputs:			Computed Values:			
volatility	10,3%		Up Step	1,12		
\$	13,46		Down Step	0,90		
rf	5,0%		Prob(up)	68,3%		
T (years)	0,50		Prob(da)	31,7%		
Cost to Keep Option	0,50%		discount factor	0,951		
Growth Factor	1,50					
Growth Cost	3,07		Value of Flexibility	6,68		
Asset Valuation Lattice						
Now	Year 1	Year 2	Year 3	Year 4	Year 5	
19,46	21,70	24,20	26,38	30,09	33,56	
	17,45	19,46	21,70	24,20	26,38	
		15,65	17,45	19,46	21,70	
			14,03	15,65	17,45	
				12,58	14,03	
					11,28	
Option Valuation Lattice						
	29,48	33,23	37,41	42,07	47,27	
26,14	23,16	26,13	29,48	33,23	37,41	
		20,48	23,14	26,12	29,48	
			18,06	20,43	23,10	
				15,86	17,38	
					13,85	
Decision Lattice						
Do Nothing	Exercise	Exercise	Exercise	Exercise	Exercise	
	Do Nothing	Do Nothing	Exercise	Exercise	Exercise	
		Do Nothing	Do Nothing	Do Nothing	Exercise	
			Do Nothing	Do Nothing	Exercise	
				Do Nothing	Exercise	
					Exercise	

Table 4. Binomial Tree Project 1

Project 2						
Inputs:			Computed Values:			
volatility	29,7%		Up Step	1,35		
\$	25,43		Down Step	0,74		
rf	5,0%		Prob(up)	50,3%		
T (years)	0,50		Prob(da)	49,7%		
Cost to Keep Option	0,50%		discount factor	0,951		
Growth Factor	1,15					
Growth Cost	2,52		Value of Flexibility	1,47		
Asset Valuation Lattice						
Now	Year 1	Year 2	Year 3	Year 4	Year 5	
25,43	34,22	46,03	61,93	83,31	112,07	
	18,91	25,43	34,22	46,03	61,93	
		14,05	18,91	25,43	34,22	
			10,45	14,05	18,91	
				7,77	10,45	
					5,77	
Option Valuation Lattice						
	36,88	50,48	68,78	93,39	126,51	
26,90	19,53	26,86	36,88	50,48	68,78	
		14,26	19,49	26,76	36,88	
			10,45	14,15	19,25	
				7,77	10,45	
					5,77	
Decision Lattice						
Do Nothing	Exercise	Exercise	Exercise	Exercise	Exercise	
	Do Nothing	Do Nothing	Exercise	Exercise	Exercise	
		Do Nothing	Do Nothing	Exercise	Exercise	
			Do Nothing	Do Nothing	Exercise	
				Do Nothing	Exercise	
					Exercise	

Table 5. Binomial Tree Project 2.

To calculate the value of an option using binomial trees, neutral risk probabilities are considered using the following formulas:

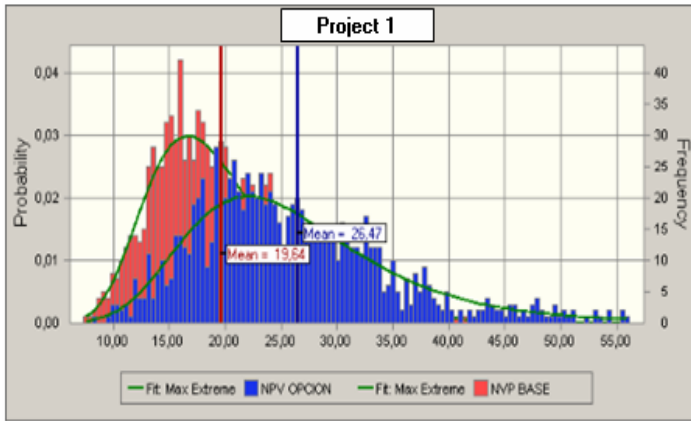
$$u = \exp(\sigma\sqrt{\Delta t}) \quad (2)$$

$$d = 1/u \quad (3)$$

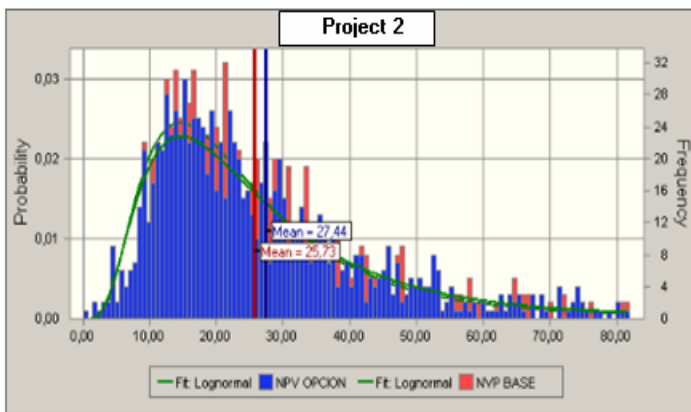
$$q = (1 + r_f - d)/(u - d) \quad (4)$$

Where σ corresponds to volatility calculated as Z.

1. From the values defined in the resolution of the binomial tree, the value of the RO for each project is obtained. Graphs 11 and 12 show the comparison between the distributions of the initial NPV and the NPV, with the definitive RO, for each project.



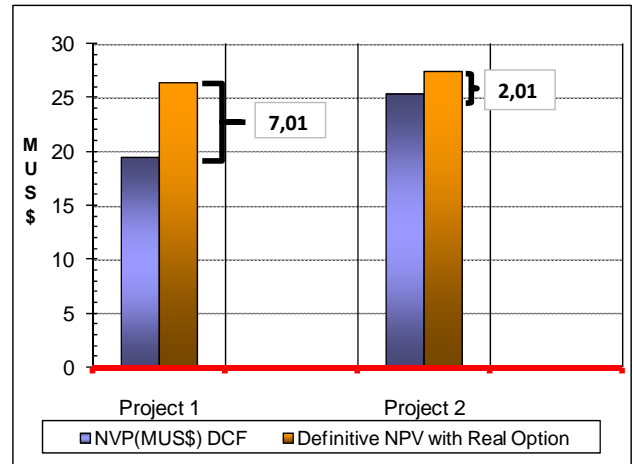
Graph 11. Comparison of NPV Distributions.
Project 1



Graph 12. Comparison of NPV Distributions.
Project 2

- m. The next step is to compare the definitive value of the NPV with the RO, with the value of the initial NPV calculated for DCF, to

define the added value of the RO included. Graph 13 shows the results.



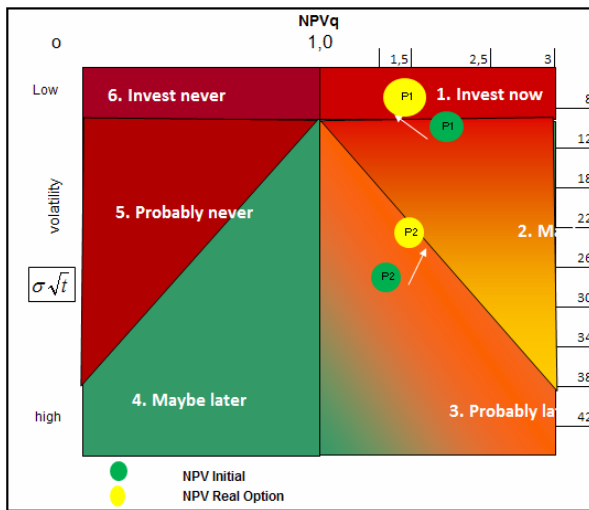
Graph 13. NPV projects with and without Real Options

The value promise of project (1) was 4.07 M USD, but in reality was 7.01 M USD. For the case of project (2), the value promise was 0.77 M USD, but in reality it was 2.01 M USD. The above validates the importance of applying the VPR investment portfolio valuation methodology, when faced with the adjustments and changes of investment projects, in order to have better decision making criteria.

It can be observed that the value promise given for the two projects evaluated at the time when the request for additional resources was made and on which the decision to approve was made, was less than the one calculated with the methodology proposed. At the time of approving the addition of resources for project (2), there was doubt of its viability and the decision to reject such request was considered, a situation which could have been avoided if RO's had been used according to the methodology proposed.

Considering that the added variation of projects (1) and (2) totalize 9.02 M USD, it can be observed that the value of the PRV portfolio increased 86% with regard to the one reported in the request for additional resources for such projects. On the other hand, it is important to take into consideration that the additional value given to the PRV portfolio was provided in proportions different from those initially defined and that supported the approval of each project.

- n. The next step is to represent the two projects analyzed through the Real Options portfolio according to the definition above as shown in graph 14.



Graph 14. Diagram of the Real Options portfolio

As can be observed in the 3D graph of the Real Options portfolio (graph 19), the growth RO considered to be exercised in project (1) increases the value of the NPV of the same (in the graph it is represented by a bigger circle). The volatility of the project decreases due to the learning curve obtained from previous drilling campaigns (in the graph this is shown by the upward displacement). Finally, the relation cost-benefit of this project is affected by the RO, due to drilling services costs overruns and the lesser productivity obtained from the wells, which can be a warning sign when defining cost reduction strategies and the optimization of investments, so as not to affect the relation cost – benefit.

The growth RO considered to be exercised in project (2) increases the value of the NPV of the same, reduces the volatility of the project due to the learning curve obtained from previous drilling campaigns and contrary to project (1), improves the relation cost benefit generated by the optimization of the commencement time of production in the wells and the greater productivity obtained from the same. Such behavior ratifies that the decision to exercise the RO of project (2) was the correct one, but the use of the methodology defined, gives it greater support.

With this methodology and through the graph of the RO portfolio, managers that need to decide the convenience to exercise a RO, will have available

in a fast and dynamic manner, the key variables of the project to be affected, which will help to make efficient decisions and to be aware of the impact of the same on the value of the investment portfolio of the company.

Conclusions

The majority of companies, in practice have project evaluation and selection processes under a static conception, limited to the specific moment of accepting or rejecting, but reality is different, since the dynamic and prolonged character given to corporate strategy, defined at one time but developed at another, force the evaluation methodologies to be more in agreement with the subsequent decisions and changes that progressively configure an investment project, such as the case of the methodology developed in this study and that is supported by the concept of Real Options.

Real Options provide a way to study investments and projects under a strategic lens, since it allows the redefinition of the company portfolio in terms of decisions and priorities for the allocation of resources, which in the end constitute the base of the present and future performance of the company.

In spite of having studied theoretical works, several real cases and lots of illustrative examples demonstrating the value of the Real Options methodology in the valuation of investment projects, this work gives empirical proof of the concept of Real Options applied to the portfolio theory, defined by authors such as Bravo and Sanchez that until now had not been proven. It was decided to work with information from the company Ecopetrol S.A. because there was availability of the information and in particular because of the urgent need of the company to have available a methodology to measure the impact of decisions over the portfolio of its strategic areas, a methodology with a solid structure but one easy to understand and apply.

The reason that justifies the changes in the investment projects is undoubtedly that of generating added value, but in spite of sounding so logical at the corporate level, there is no awareness of the impact of a change in any particular project over the integral value of the investment portfolio of the company. Only during the stage for the allocation and prioritization of resources the added

portfolio is assessed; and after the execution begins, only the indicators for each project are evaluated independently. The methodology proposed in this study assures that the impact of the changes in the projects on the value of the totality of the portfolio is assessed, and allows the discrimination of the real contribution of every project to the value of the same.

Based on the information analyzed it is possible to conclude that after Ecopetrol S.A. PRV's investment budget has been approved at the corporate level, and after the execution of the projects has commenced, the lack of a clear and structured methodology based on the principles of RO, has not permitted the evaluation of the real extent of the impact generated on the integral value of the portfolio by the decisions made to adjust, expand, postpone, downsize, or cancel a project being executed, decisions that are taken as the project advances and which result from incoming information, mainly regarding the uncertain behavior and the dynamic inherent to the petroleum industry. The methodology proposed can be used at any time, but its contribution is greater if used at the beginning of the year, because it allows the definition of the strategy to prioritize resources in the direction of the projects that deserve them most.

As a complement to the proposed methodology, a product of the revision process of the changes of the PRV projects was generated, it is an optimized flowchart to foresee the changes (Type 1 and 2) in any PRV investment project as described in chapter 2 of the thesis report of the authors.

Likewise, the results of this research are useful for petroleum sector companies that still have not worked or identified the impact of real options on investment portfolios, in accordance with the type of activity being developed and the particular culture of the organization. The results are also useful for students, teachers and researchers to complete their research work.

Note

M US\$ = Million Dollars.

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