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AVAILABILITY AND RISK ANALYSIS EFFECTS ON GAS PIPELINE TARIFF MAKING

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ABSTRACT

On a competitive market gas transportation rates must be as low as possible while recovering capital expenses - Capex and operating and maintenance expenses - Opex at a return rate expected by the project sponsors to recover their investment. To guarantee project feasibility, designers must be concerned not only with technical and direct economic aspects but should also incorporate availability and economic risk analysis to make sure that under operating conditions along the economic life of a project the cash flow will be kept inside predicted values and therefore will not expose project sponsors to undesirable negative Net Present Values - NPV. This paper will present a methodology to address these important aspects with focus on pipeline economics. Pipeline availability study associated with compressor stations failure analysis will be evaluated under Monte Carlo simulation and consequently their impacts on gas pipeline capacity will be economically evaluated. Quantitative economic risk analysis using Monte Carlo simulation is part of the methodology. The adoption of this methodology allows committing more pipeline transmission capacity to a level close to maximum without exposing the Transporter to losses of revenue and contractual penalties. Also prevents designing an oversized and less competitive system with unused spare capacity and consequently higher transportation rates.

INTRODUCTION

Gas pipeline projects are capital intensive and involve risks related to uncertainties that must be identified, quantified and then mitigated so as to satisfy project sponsors – according to their risk profile – that all significant items have been adequately addressed.

A competitive project is also dependent on an accurate and comprehensive quantitative risk analysis.

Throughout this paper the term *risk* will be related to the probability of occurrence of an undesirable economic outcome. Safety risk is not part of this case study.

As a reference for applying Monte Carlo simulation in compressor station project selection Santos (2003) has evaluated the impact of Capex, Opex, and construction and assembly schedule on the economic sustainability of a project while comparing two different alternatives for implementing compressor stations in Petrobras gas pipeline network as described below:

(a) Compressor station as a Transporter asset: in this alternative Capex, Opex are Transporter responsibility. Transporter will keep the ownership of the compressor station asset.

(b) Compression service contract: in this alternative Capex and Opex are the responsibilities of a service provider company that will be responsible for the installation, operation and maintenance of the compressor station and will be the owner of the asset. Transporter will pay for the compression service under a contractual relationship.

Monte Carlo simulation was of fundamental importance in supporting Petrobras final decision on contracting compression service in 2002 from a third party company instead of holding the ownership of the stations and being responsible for operation and maintenance of them. The selected alternative was more economic and less risky. Since 2002 more than 18 compressor stations have been installed under compression service contract.

In this case study Monte Carlo simulation is extensively used in conjunction with thermohydraulic simulation and economic feasibility studies.

AVAILABILITY AND RISK ASSESSMENT

Figure 1 presents a flow chart describing the assessment process that has been adopted in this case study.

(1) The process starts with Monte Carlo simulation on a pipeline model where all the compressor station units are modeled with their respective availability values and statistic probability distribution.

(2) Monte Carlo simulation runs provides information on the frequency of simultaneous unavailability of compressor units that are summarized on a table that incorporates the thermohydraulic simulation results in steady state or transient modes with their resulting pipeline transmission capacity for each unavailability configuration.

(3) Economic and risk analysis incorporates the information from the pipeline capacity frequency table and does the evaluation of each alternative of standby units installation. This step also incorporates Monte Carlo simulation to identify, quantify and mitigate risks that come from contractual firm capacity under different scenarios of pipeline availability related to the compressor stations adoption of standby compressor units.

(4) Economic and risk analysis will provide all necessary information with respect to risk exposure to allow project sponsors to make a final decision on the capacity that will be offered as firm contractual ship-or-pay capacity and the resulting transportation rate that will recover project Capex and Opex over its economic life.

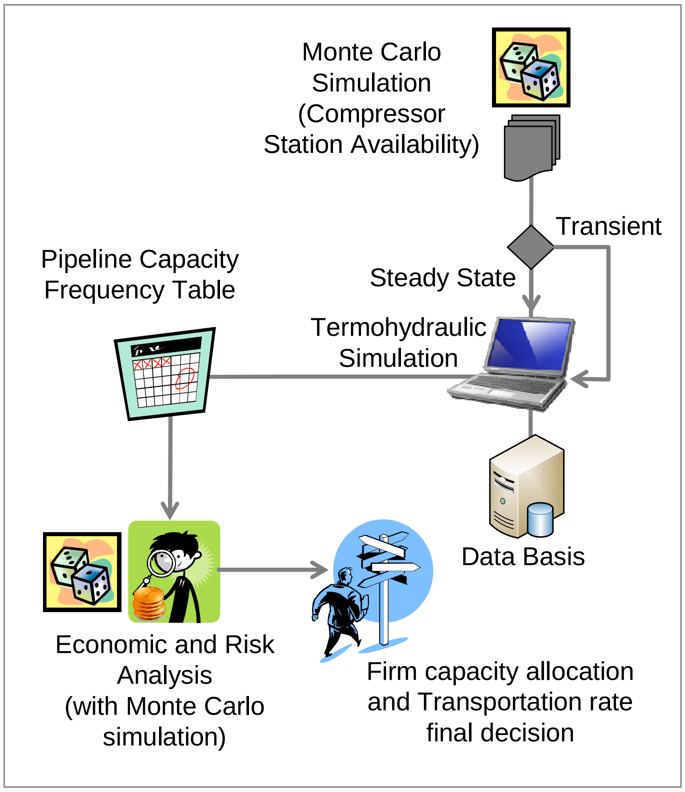

Figure 1 – Availability Evaluation Process Chart

CASE STUDY

This case study consists of a gas pipeline from a gas supply at the beginning of the pipeline and delivers the gas to a Local Distribution Company at other extreme end of the pipeline as illustrated in Figure 2.

The main characteristics of this pipeline are described below:

Nominal Diameter:	DN 32”
Total length:	1330 km
MAOP:	97.90 barg.
Pipe Material:	API 5L X70
Internal roughness (epoxy painted):	0.009 mm
Pipeline inlet pressure:	97.90 barg.
Minimum delivery pressure:	34.32 barg.
Soil temperature:	30 C
Depth of cover:	1 m
Pipe-soil overall heat transfer:	1.9 Kcal/h.m2.C
Gas specific gravity:	0.558
Capacity:	30.00 MMCMD
Compressor station quantity:	10
Compressor unit ISO power:	15000 hp
Suction/disch. manifold pres. drop:	0.5 bar
After cooler pressure drop:	1.0 bar
After cooler outlet temperature:	50 C
Site elevation:	0 m
Site average summer temperature:	28 C
Friction factor equation:	Colebrook-White

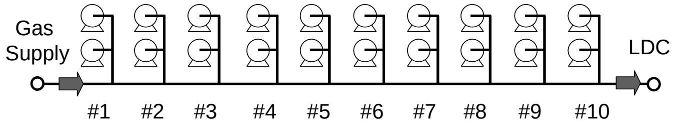

Figure 2 – Gas Pipeline Configuration

MONTE CARLO SIMULATION

According to Evans and Olson (1998) Monte Carlo simulation is basically a sampling experience the purpose of which is to estimate the distribution of an outcome variable that depends on several probabilistic input variables. Monte Carlo simulation is often used to evaluate the expected impact of policy changes and risk involved in decision making.

According to Ragsdale (2001) simulation is a technique that is helpful in analyzing models where the value to be assumed by one or more independent variables is uncertain.

Credit for inventing the Monte Carlo method often goes to Stanislaw Ulam, a Polish born mathematician who worked for John von Neumann on the United States’ Manhattan Project during World War II.

The Monte Carlo method, as it is understood today, encompasses any technique of statistical sampling employed to approximate solutions to quantitative problems. Working with John von Neuman and Nicholas Metropolis, he developed algorithms for computer implementations, as well as exploring means of transforming non-random problems into random forms that would facilitate their solution via statistical sampling. This work transformed statistical sampling from a mathematical curiosity to a formal methodology applicable to a wide variety of problems. It was Metropolis who named the new methodology after the casinos of Monte Carlo. Ulam and Metropolis published the first paper on the Monte Carlo method in 1949. Available at : <http://www.riskglossary.com/link/monte_carlo_method.htm>. (visited in June 12, 2008).

QUANTITATIVE RISK ANALYSIS

According to Hertz (1984) risk analysis denote methods which aim to develop a comprehensive understanding and awareness of the risk associated with a particular variable of interest (be it a payoff measure, a cash flow profile, or a macroeconomic forecast). In other words, a forecast is obtained for a variable of interest in the form of a probability distribution.

According to Vose (1996) risk and uncertainty are key features of most government problems and need to be understood for rational decisions to be made. Quantitative risk analysis, using Monte Carlo simulation, offers the user a powerful and precise method for assimilating the various uncertainties of a problem and producing a realistic appreciation of the problem's total uncertainty.

A common approach is to model the problem with its independent uncertain variables (correlated or non-correlated) and then have the risk quantified for a target dependent variable in a spreadsheet with a risk analysis tool. The uncertainties are modeled by using statistical distributions in connection with random number generation.

For this case study Microsoft Excel and @Risk 4.5 were used for availability study and economic evaluation.

AVAILABILITY STUDY

According to Mohitptour (2005) reliability can be defined as the measure of confidence in a given system to meet the desired purpose/function over a given time. It is a measure of dependability of the system. Availability is defined as the fraction of time that a item is able to perform a required function under stated conditions.

For those who are not familiar with Monte Carlo simulation, Santos (2006) compares the availability study results for the Bolivia-Brazil Gas Pipeline compressor system from two different approaches: using binomial distribution and Monte Carlo simulation and proves that they are equivalent. Monte Carlo simulation has the advantage of simplicity and applicability for different types of compressor unit that can be modeled on a unit basis.

Other sources of failures that can impact gas pipeline availability were not considered in this case study since their economic impact is not as significant as compressor stations and also for simplicity of showing the application of Monte Carlo simulation.

Compressor Station

A comprehensive and accurate survey on compressor station reliability and availability was carried out by EPRI (1998) and their findings, as presented below, provide input for the evaluation of this case study that uses gas turbine drivers and centrifugal compressors:

Average Compressor Station	Reliability	Availability
Electric motor + Centrifugal compressor	99.4	98.9
Gas turbine + Centrifugal compressor	98.2	97.1
Gas motor + Reciprocating compressor	97.1	94.3

Station reliability and availability were evaluated as follows:

$$\%Station\ Availability = \frac{H - (SD + USD)}{H} \times 100$$

$$\%Station\ \mathrm{Re}\,liability = \frac{HRS - USD}{HRS} \times 100$$

Where:

H: Total hours per year
SD: Scheduled downtime hours
USD: Unscheduled downtime hours
HRS: Total hours requested for service

In this case study and with focus on economic risk evaluation and its impact on gas pipeline tariff making the availability value of 97.1% or 0.971 is applied for the compressor units as if each compressor unit was a complete compressor station. Parallel arrangement was adopted for the compressor units and each compressor unit was modeled for each compressor station for Monte Carlo simulation runs. Each of the 10 compressor stations has two running compressor units in parallel.

Monte Carlo Model

All 10 pipeline compressor stations with 2 units per station were modeled in Microsoft Excel spreadsheet and Monte Carlo simulations were run using @Risk 4.5. Table 1 shows the compressor station availability model used for this case study.

Table 1 – Compressor station availability model

n = 2 Compressor Units per Station

p =	0.0290			
X	BC(X,n)	p^x	(1-p)^(n-x)	P(X)
0	1	1.00000	0.94284	0.94284
1	2	0.02900	0.97100	0.05632
2	1	0.00084	1.00000	0.00084
				1.00000

Unavailability

X	P(x)
0	0.943
1	0.056
2	0.001

The binomial distribution equation was used to produce the results shown on Table 1 above.

$$P(X) = BC(X,n) \times p^{X}(1-p)^{n-X}$$

$$BC(X,n) = \frac{n!}{X!(n-X)!}$$

$P(X) = probability\ of\ X\ unavailable\ units$

$BC = binomial\ coefficient$

$n = sample\ size = 2$

$p = unavailability\ of\ one\ compressor\ unit = 1 - 0.971$

$X = number\ of\ unavailable\ units$

@Risk 4.5 RiskDiscrete({X},{P(x)}) function was used to model compressor unit's unavailability. Monte Carlo simulations results constitute a data basis that allows making frequency distributions for the unavailability of compressor units at each compressor station. Thermohydraulic simulations are then run to evaluate pipeline capacities.

@Risk Model settings:

Iterations:	5110
Sampling type:	Latin Hypercube
Random Generator Seed:	Fixed = 1
Standard Recalc:	Expected Value
Collect Distribution Samples:	All

THERMOHYDRAULIC SIMULATION

Unavailability of compressor units derived from 5110 iterations from Monte Carlo simulation were filtered and grouped in significant configurations for capacity evaluation.

Filtering Process

The filtering process consists of evaluating each unavailability configuration and defining the ones that are more representative in producing useful pipeline capacity results without having to simulate all possible configurations. For example an unavailability of (i) one compressor unit at stations #1 and 3 has an occurrence of 0.928 per year and resulting capacity of 22.9 MMm3/d; for (ii) one compressor unit at station #1, an occurrence of 11.71 per year and capacity of 24.76 MMm3/d. The simplification of considering (i) as (ii) has a very small impact as demonstrated below and saves a lot of simulation works:

(30 – 22.9) x 0.928 = 6.589 MMCMY, as (i)

(30 – 24.76) x 0.928 = 4.863 MMCMY, as if (i) = (ii)

(i) – (ii) = 6.589 – 4.863 = 1.726 MMCMY

= 0.0047 MMCMD

To quantify the unavailability frequency of compressor units we can apply binomial distribution as shown on Table 2 below.

Table 2 shows that three and more units unavailable is a very infrequent event supporting the filtering approach adopted as a simplification method.

Table 2 – Compressor units' unavailability

p =	0.0290				
X	BC(X,n)	p^x	(1-p)^(n-x)	P(X)	days/year
0	1	1.0000	0.5551	0.5551	202.62
1	20	0.0290	0.5717	0.3316	121.03
2	190	0.0008	0.5888	0.0941	34.34
3	1140	0.0000	0.6064	0.0169	6.15
4	4845	0.0000	0.6245	0.0021	0.78
5	15504	0.0000	0.6431	0.0002	0.07
6	38760	0.0000	0.6623	0.0000	0.01
7	77520	0.0000	0.6821	0.0000	0.00
8	125970	0.0000	0.7025	0.0000	0.00
9	167960	0.0000	0.7235	0.0000	0.00
10	184756	0.0000	0.7451	0.0000	0.00
11	167960	0.0000	0.7673	0.0000	0.00
12	125970	0.0000	0.7902	0.0000	0.00
13	77520	0.0000	0.8138	0.0000	0.00
14	38760	0.0000	0.8381	0.0000	0.00
15	15504	0.0000	0.8632	0.0000	0.00
16	4845	0.0000	0.8889	0.0000	0.00
17	1140	0.0000	0.9155	0.0000	0.00
18	190	0.0000	0.9428	0.0000	0.00
19	20	0.0000	0.9710	0.0000	0.00
20	1	0.0000	1.0000	0.0000	0.00
				1.0000	365.00

The filtering process applied for all 10 stations follows the structure shown on Table 3. The string of 10 digits represents 10 compressor stations. Number 1 and 2 means quantity of units unavailable and 0 means two units available at each station.

Table 3 – Compressor station availability model

1 Unit unavailable	2 Units unavailable	2 Units unavailable (Contiguous Sta.)
1000000000	**2**000000000	**11**00000000
0**1**00000000	0**2**00000000	0**11**0000000
00**1**0000000	00**2**0000000	00**11**000000
000**1**000000	000**2**000000	000**11**00000
0000**1**00000	0000**2**00000	0000**11**0000
00000**1**0000	00000**2**0000	00000**11**000
000000**1**000	000000**2**000	000000**11**00
0000000**1**00	0000000**2**00	0000000**11**0
00000000**1**0	00000000**2**0	00000000**11**
000000000**1**	000000000**2**	

Simulation Results

Three configurations for unavailable compressor units were simulated as explained below:

1. Failure of one compressor unit at one station
2. Failure of two compressor units at one station
3. Failure of one compressor unit at one station and failure of another one at a contiguous station (upstream or downstream)

Three different compressor station alternatives have been evaluated:

(a) Without stand-by compressor units;
(b) With 5 stand-by units (first 5 stations)
(c) With 10 stand-by units (all the stations).

Thermohydraulic simulations capacity results due to unavailability of compressor units are summarized on Tables 4, 5 and 6.

The table first column shows the unavailability configurations of 1 and 2 units per station and also 2 (1+1) units unavailable in contiguous stations. Second column shows the total frequency of occurrence of such unavailability measured in days per operating year. Third column shows resulting pipeline capacity at the downstream end of the pipeline that can be maintained under the defined unavailability of compressor units. The wider forth column shows the unavailability frequency of compressor units (1, 2 or (1+1)) at each compressor station as identified on the header (#1 to #10).

Gas pipeline overall availability is evaluated by dividing the average capacity by the l nominal (firm contractual) capacity and we get the following results for each alternative of standby compressor units installation.

(a) Without stand-by compressor units: 0.9145
(b) With 5 stand-by units (first 5 stations): 0.9464
(c) With 10 stand-by units (all the stations): 0.9984

Simulation Results Analysis

Compressor stations were modeled with two compressor units operating in parallel arrangement with standard flow of around15 MMCMD each.

Unavailability of one compressor unit at one compressor station cause the remaining unit to shut down or stay in idle speed because one single unit does not have power enough to sustain the operation. As an example the unavailability of station #2 causes pipeline capacity to drop to 24.84 that is 65.6% higher than one compressor unit design capacity of 15 MMCMD. Same situation happens with the unavailability of 2 (1+1) compressor units at contiguous stations. As an example the unavailability of stations #2 and 3 causes pipeline capacity to drop to 21.16 MMCMD that is 41.06% higher than one compressor unit design capacity of 15 MMCMD.

The risk exposure of not being able to deliver the contractual firm capacity as a probability number can be seen in Figure 3 for each alternative of standby compressor unit installation. From this figure we can see that there is a probability of 0.32 that pipeline capacity will be lower than 27.07 MMm3/d for alternative (a) 0.18 for alternative (b) and 0.01 for alternative (c).

Figure 4 shows pipeline capacities frequency on a yearly basis for each alternative.

From Figure 7 we can obtain pipeline capacities in MMCMD that can be committed as firm contractual capacity at a risk level of 5% – of being lower than those values – for alternatives (a), (b) and (c) as summarized below.

(a) Without stand-by compressor units: 22.0200
(b) With 5 stand-by units (first 5 stations): 22.0200
(c) With 10 stand-by units (all the stations): 30.0000

Selecting alternatives (a) or (b) would cause negative impact on the pipeline tariff since lower contractual firm capacity will be used for tariff making.

Table 4 – Failure Simulation Results for Compressor Station Units – Without Standby Units.

Unavailable Compressor Units per Station	Frequency (days/year)	Capacity, MMm3/d	Compressor Station No. # / Unavailability Frequency (days/year)									
			#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
0	204.43	30										
1	147.00	24.76	19.00									
		24.84		17.93								
		24.80			16.86							
		24.78				14.86						
		24.75					14.50					
		24.68						14.00				
		24.56							14.14			
		24.30								12.71		
		23.71									12.00	
		22.02										11.00
2	3.14	24.76	0.36									
		24.84		0.36								
		24.80			0.29							
		24.78				0.29						
		24.75					0.29					
		24.68						0.29				
		24.56							0.36			
		24.30								0.29		
		23.71									0.36	
		22.02										0.29
1 + 1 (At 2 contiguous Stations)	10.43		5&6	6&7	7&8	8&9	9&10	10&11	11&12	12&13	13&14	
		21.01	0.93									
		21.16		1.29								
		21.20			1.21							
		21.16				1.29						
		21.10					1.21					
		21.05						0.93				
		20.97							1.36			
		20.20								0.79		
		18.07									1.43	
Total days	365.00											
Average Capacity		27.4349										
Nominal Capacity		30										
Pipeline Overall Availability		0.9145										

Table 5 – Failure Simulation Results for Compressor Station Units – With 5 Standby Units.

Unavailable Compressor Units per Station	Frequency (days/year)	Capacity, MMm3/d	Compressor Station No. # / Unavailability Frequency (days/year)									
			#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
0	271.43	30										
1	87.36	24.76	0.36									
		24.84		0.36								
		24.80			0.29							
		24.78				0.29						
		24.75					0.29					
		24.68						19.43				
		24.56							17.79			
		24.30								17.07		
		23.71									15.71	
		22.02										15.79
2	1.57	24.76	0.00									
		24.84		0.00								
		24.80			0.00							
		24.78				0.00						
		24.75					0.00					
		24.68						0.29				
		24.56							0.36			
		24.30								0.29		
		23.71									0.36	
		22.02										0.29
1 + 1 (At 2 contiguous Stations)	4.64		5&6	6&7	7&8	8&9	9&10	10&11	11&12	12&13	13&14	
		21.01	0.00									
		21.16		0.00								
		21.20			0.00							
		21.16				0.00						
		21.10					0.00					
		21.05						1.00				
		20.97							1.36			
		20.20								0.86		
		18.07									1.43	
Total days	365.00											
Average Capacity		28.3926										
Nominal Capacity		30										
Pipeline Overall Availability		0.9464										

Table 6 – Failure Simulation Results for Compressor Station Units – With 10 Standby Units

Unavailable Compressor Units per Station	Frequency (days/year)	Capacity, MMm3/d	Compressor Station No. # / Unavailability Frequency (days/year)									
			#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
0	361.86	30										
1	3.14	24.76	0.36									
		24.84		0.36								
		24.80			0.29							
		24.78				0.29						
		24.75					0.29					
		24.68						0.29				
		24.56							0.36			
		24.30								0.29		
		23.71									0.36	
		22.02										0.29
2	0.00	24.76	0.00									
		24.84		0.00								
		24.80			0.00							
		24.78				0.00						
		24.75					0.00					
		24.68						0.00				
		24.56							0.00			
		24.30								0.00		
		23.71									0.00	
		22.02										0.00
1 + 1 (At 2 contiguous Stations)	0.00		5&6	6&7	7&8	8&9	9&10	10&11	11&12	12&13	13&14	
		21.01	0.00									
		21.16		0.00								
		21.20			0.00							
		21.16				0.00						
		21.10					0.00					
		21.05						0.00				
		20.97							0.00			
		20.20								0.00		
		18.07									0.00	
Total days	365.00											
Average Capacity		29.9512										
Nominal Capacity		30										
Pipeline Overall Availability		0.9984										

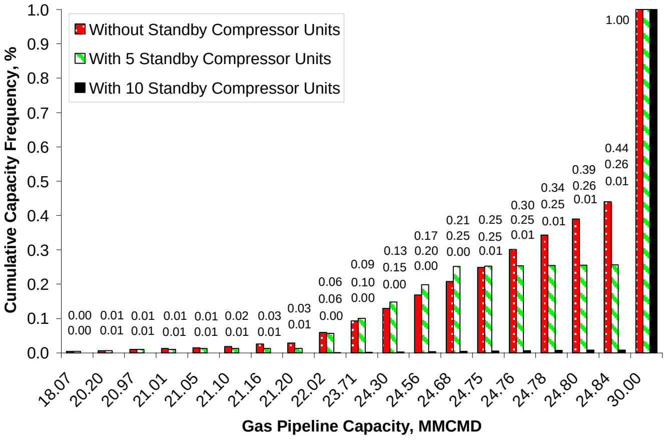

Figure 3 – Pipeline Yearly Capacity versus Cumulative Probability

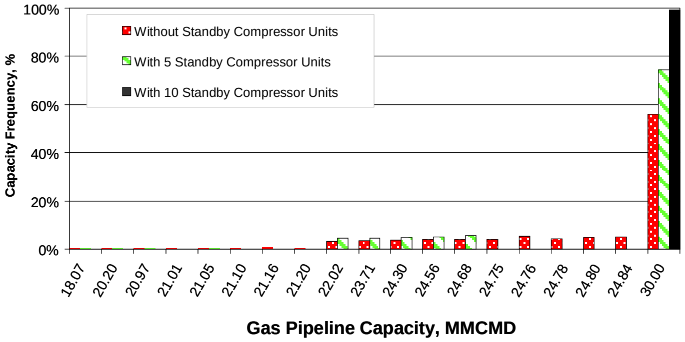

Figure 4 – Pipeline Yearly Capacity Frequency

ECONOMIC ANALYSIS

According to Hertz (1984), a project is subject to uncertainties related to the volatile behavior of several of its components that can produce high degree of uncertainty. Such uncertainties include costs of materials and services, implementation schedule, acquisition of environmental permits and numerous other factors the probability of occurrence of which and correlations between them must be considered if we shall clearly identify and quantify the project associated risks to mitigate them accordingly. Combined uncertainties can multiply, generating a total uncertainty of critical proportions, warns Hertz (1984).

With the growing availability of powerful and faster computers, and a better understanding of quantitative risk modeling from extensive use of spreadsheets, risk simulation has become a very popular approach in recent years among active managers in that area of business analysis, Evans and Olson (1998)

The use of discounted cash flow method (DCF) and the adoption of the net present value (NPV) associated with the project expected internal rate of return (IRR) for project selection has been recommended by many authors such as Ross et al. (2002) and Copeland (2000). Its use has been widespread in the business world and has increasingly relied on supporters. But according to Vose (1996) the use of the DCF method alone, even when combined with sensitivity studies (what if scenarios), is not sufficient for effective decision making. Without quantitative risk analysis same weight is applied to all probabilistic scenarios including those in which all the variables are at their maximum or minimum values.

The increasing computer power enabled the development and use of risk simulation software for project selection by many major companies worldwide. Monte Carlo simulation has been used for probabilistic risk assessment on projects that use the method of DCF. Thus project sponsors can measure project risk and identify actions to mitigate them or even define discount rates that can absorb the risk identified in order to reduce or even eliminate their exposure to risk. Consequently, if the uncertainties are not adequately addressed in the evaluation of a project they can generate adverse future results, and may produce negative NPV or even become a complete economic disaster with adverse repercussions within a corporation and also undermine the image of the company before its shareholders and the society.

The use of Monte Carlo simulation with thermohydraulic simulation has the basic purpose to determine the availability of the transmission system and to identify its firm capacity to offer on a ship-or-pay agreement. Firm capacity is normally considered in the evaluation of the pipeline transportation rate to repay the Capex and Opex over the economic life of the pipeline.

The economic objective of the study is to identify the level of redundancy suitable for managing the exposure to the risks of loss of revenue and contractual penalties. It is adopted the method of DCF and the results are compared to the three alternatives, in order to identify the one with the lower risk exposure. The present value of the potential losses (revenue + penalties) – as shown in figures 5, 6 and 7 and Table 7 – dependent on the firm capacity of the alternatives (a), (b) and (c) are compared to support defining the appropriate redundancy level according to Transporter risk profile.

The transportation rate of each alternative incorporates all Capex and Opex associated with the pipeline and standby compressor units and represents gas pipeline total cost of the transportation service on energy basis.

Economic Assumptions

For the purpose of this paper the following assumptions were adopted:

Construc. & assembly sched.:	3 years
Capex schedule:	1/3 each year
Fuel price:	2.5 US$/MMBTU
Compressor station O&M:	5% of Capex
Pipeline O&M:	0.8% of Capex
Firm capacity:	30.00 MMCMD
Low heat value:	32440 BTU/m3
Transportation rate:	US$/MMBTU
Revenue losses:	1 x non-delivered flow
Contractual penalties:	1 x non-delivered flow
Economic life:	20 years
Return rate:	12% per year.

Economic Evaluation Results

(a) Without Standby Units – Base Case

Capex		
Pipeline	1,436.00	MMUS$
Compressor Stations	416.00	MMUS$
Opex		
Pipeline	11.49	MMUS$
Compressor Stations	20.82	MMUS$
Fuel gas	33.30	MMUS$

Transportation rate	1.6031	US$/MMBTU
Average PV of potential losses	(579.9)	MMUS$

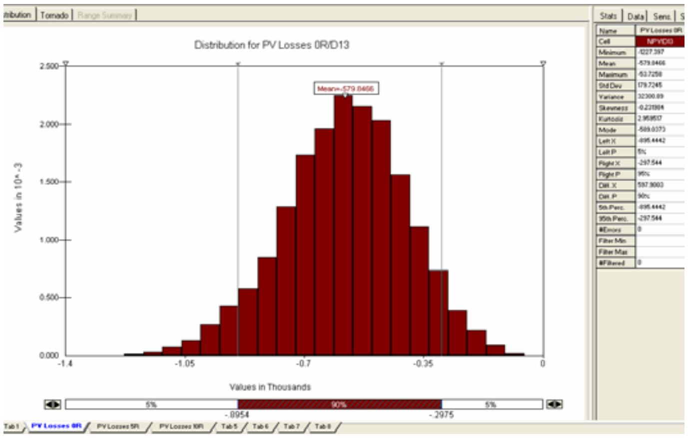

Figure 5 - Present Value of Potential Losses (revenue + penalties) Without Standby Compressor Units

(b) With 5 Stand-by Units

Capex		
Pipeline	1,436.00	MMUS$
Compressor Stations	486.00	MMUS$
Opex		
Pipeline	11.49	MMUS$
Compressor Stations	24.32	MMUS$
Fuel gas	34.46	MMUS$
Transportation rate	1.6592	US$/MMBTU
Average PV of potential losses	(376.1)	MMUS$

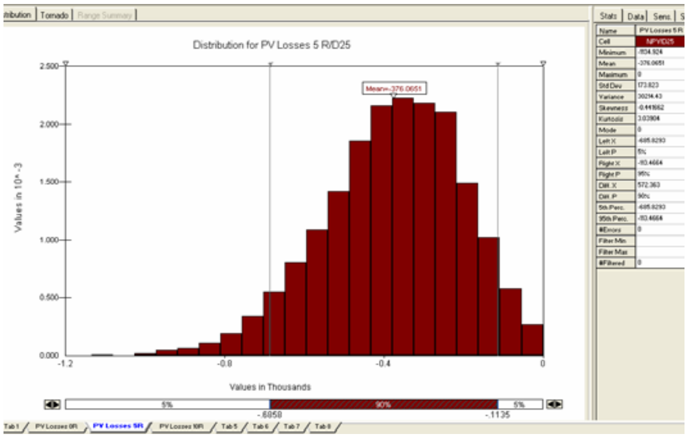

Figure 6 - Present Value of Potential Losses (revenue + penalties) With 5 Standby Compressor Units

(c) With 10 Stand-by Units

Capex		
Pipeline	1,436.00	MMUS$
Compressor Stations	556.00	MMUS$
Opex		
Pipeline	11.49	MMUS$
Compressor Stations	27.81	MMUS$
Fuel gas	36.36	MMUS$
Transportation rate	1.7174	US$/MMBTU
Average PV of potential losses	(11.7)	MMUS$

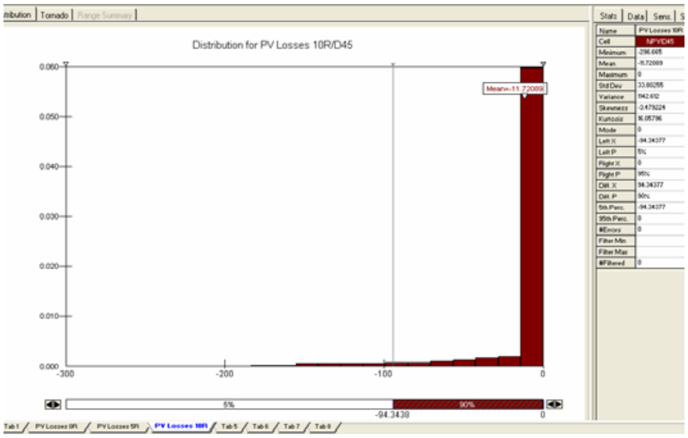

Figure 7 - Present Value of Potential Losses (revenue + penalties) With 10 Standby Compressor Units

CONCLUSIONS

Based on the information presented on Tables 4, 5 and 6 and figures 5, 6, and 7 the better alternative is the installation of 10 standby compressor units - alternative (c). Table 7 presents a summary of the alternative (a), (b) and (c) with the main variables with their average values and also the confidence interval of 90%. Table 7 presents very important information to support the decision making process. From the results we can easily identify that the alternative of installing 10 standby compressor units is the one which presents the lowest risk related to potential losses as shown in Figures 5, 6 and 7.

As shown in this paper tariff making process should incorporate availability study and Monte Carlo simulation to allow quantitative risk analysis and therefore provide good quality information to support the decision making process.

Table 7 - Risk Results Summary for Project Alternatives

Name		Minimum	Mean	Maximum	x1	p1	x2	p2	x2-x1	p2-p1
Without Stand-by Compressor Units - Transportation rate of 1.6031 US$/MMBTU										
Capacity	MMm3/d	18.0700	27.4349	30.0000	22.0200	5%	30.0000	95%	7.9800	90%
Capacity Loss	MMm3/d	-11.9300	-2.5651	0.0000	-7.9800	5%	0.0000	95%	7.9800	90%
Loss of Revenue	MMUS$	(613.70)	(289.92)	(26.86)	(447.72)	5%	(148.77)	95%	298.95	90%
Loss due Penalty	MMUS$	(613.70)	(289.92)	(26.86)	(447.72)	5%	(148.77)	95%	298.95	90%
PV of Potential Losses	MMUS$	(1,227.40)	(579.85)	(53.73)	(895.44)	5%	(297.54)	95%	59790%	90%
With 5 Stand-by Compressor Units - Transportation rate of 1.6592 US$/MMBTU										
Capacity	MMm3/d	18.0700	28.3926	30.0000	22.0200	5%	30.0000	95%	7.9800	90%
Capacity Loss	MMm3/d	-11.9300	-1.6074	0.0000	-7.9800	5%	0.0000	95%	7.9800	90%
Loss of Revenue	MMUS$	(567.46)	(188.03)	-	(342.91)	5%	(56.73)	95%	286.18	90%
Loss due Penalty	MMUS$	(567.46)	(188.03)	-	(342.91)	5%	(56.73)	95%	286.18	90%
PV of Potential Losses	MMUS$	(1,134.92)	(376.07)	-	(685.83)	5%	(113.47)	95%	57236%	90%
Recovered Capacity	MMm3/d	-11.9300	0.9577	11.9300	-6.2900	5%	6.2900	95%	12.5800	90%
With 10 Stand-by Compressor Units - Transportation rate of 1.7174 US$/MMBTU										
Capacity	MMm3/d	22.0200	29.9512	30.0000	30.0000	5%	30.0000	95%	0.0000	90%
Capacity Loss	MMm3/d	-7.9800	-0.0488	0.0000	0.0000	5%	0.0000	95%	0.0000	90%
Loss of Revenue	MMUS$	(148.33)	(5.86)	-	(47.17)	5%	-	95%	47.17	90%
Loss due Penalty	MMUS$	(148.33)	(5.86)	-	(47.17)	5%	-	95%	47.17	90%
PV of Losses	MMUS$	(296.67)	(11.72)	-	(94.34)	5%	-	95%	9434%	90%
Recovered Capacity	MMm3/d	-7.9800	2.5163	11.9300	0.0000	5%	7.9800	95%	7.9800	90%

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