IBP1162_13

FEASIBILITY OF GAS PIPELINE PROJECTS – IMPACTING VARIABLES

Sidney P. Santos[1], Matt Lubomirsky [2], Rainer Kurz[3]

Abstract

Infrastructure projects are characterized as being capital intensive, with long economic life and high level of economic risk due to many players involved in the natural gas business chain. Project sponsors of a gas pipeline project need to carefully manage its most important variables in order to optimize its implementation. This paper highlights some of these variables – such as economic life, internal rate of return, market gas demand growth, design pressure, strength of steel, pipeline internal coating, compression station design, compression system redundancy level and compression ratio – that impacts transportation tariff that in turn, associated with gas commodity price, composes the final gas price for end users. Natural gas final price must be competitive when compared to other energy supplies and this alone underline the need of a well performed feasibility analysis for a gas pipeline project. A case study with a methodology is presented in this paper along with sensitivity curves for each variable studied to help gas pipeline designers to understand and manage their impact on the project.

1. Introduction

The appropriate management of the impacting variables of a gas pipeline project has a direct effect on its feasibility. According to Hertz (1984) a project is always vulnerable to the uncertainties created by the volatile aspects of its variables. Some of these variables, once defined, e.g. economic life, internal rate of return, market gas demand growth, design pressure, strength of steel, pipeline internal coating, compression station design and compression ratio will become part of the project assumptions and others variables such as capital expenditure – CAPEX, construction schedule and operation expenditures – OPEX, might be better evaluated under a risk analysis approach using Monte Carlo simulation as presented by Santos (2009). This paper will focus on variables that are directly related to the design phase of a gas pipeline project prior to quantitative risk analysis – QRA.

2. Methodology

The methodology adopted for this case study considers the following steps:

1. Identify technical and economic assumptions;
2. Identify or estimate a market gas demand profile;
3. Select a configuration of nominal diameter versus quantity of compressor stations as Santos(2009) running thermohydraulic and Monte Carlo simulations;
4. Define compression system level of redundancy as Santos(2009);
5. Obtain gas pipeline and compressor stations maintenance and operation costs;
6. Run quantitative risk analysis – QRA and risk mitigation;
7. Make Project final decision based on previous items results.

[1] Master, MBA, Mechanical Engineer – At Work Rio Engenharia e Consultoria Ltda.
[2] Consulting Application Engineer – Solar Turbines Incorporated
[3] PhD, Manager, Systems Analysis– Solar Turbines Incorporated

2. Case Study and Base Case

The case study and base case for the purpose of this paper, as seen in figure 1, was taken from Santos et al., (2011) and is based on an internally coated pipeline project that goes from a gas supply receipt point to a target market 1,000 miles (1609 km) away. Delivers 1,059.4 MMSCFD (30 MMm3/d) at design capacity with nominal diameter of 36 inches and with 7 compressor stations with two running compressor units and one stand-by (2+1).

2.1. Technical Assumptions

Pipeline	
Diameter	: 36 inches
Length	: 1000 miles (1609 km)
Design code	: ANSI B31.8
Design factor	: 0.72
Max. Allowed Working Pres. – MAOP	: 1420 PSIG
Pipe material	: API 5L X80
Pipe internal roughness (epoxy painted)	: 350 μ inches (0.009 mm)
Pipeline Inlet Pressure	: 1420 psig
Minimum Pipeline Delivery Pressure	: 498 psig
Pipeline overall heat transfer	: 0.39 Btu/h.ft2.F
Gas specific gravity	: 0.6
Soil temperature	: 77 F (25 C)
Depth of cover	: 3.28 feet (1 meter)
Compressor Station	
Maximum Compression ratio	: 1.4
Suction and Discharge Header pressure drop	: 7 psi (0.5 kgf/cm2)
After cooler pressure drop	: 14 psi (1.0 kgf/cm2)
After cooler outside temperature	: 122 F (50 C)
Site elevation	: 0 feet (0 meter)
Site Temperature	: 82.4 F (28 C)
Flow Equation	: Colebrook

2.2. Economic Assumptions

Construction schedule	: 2 years
Pipeline material cost	: 2300 US$/ton
Pipeline C&A cost for 36”	: 27,583 US$/mile-inch 17.14 US$/meter-inch
Compressor Station CAPEX	
(3) x 10300 hp ISO	: 48.50 MMUS$
(4) x 10300 hp ISO	: 59.55 MMUS$
O&M Compressor Station (without Fuel)	: 5% of Compressor Station CAPEX
O&M Pipeline	: 0.8% of Pipeline CAPEX
Depreciation	: Equal economic life, years
Taxes	: 40%
Fuel price	: 4.0 US$/MMBTU
Discount rate	: 12% a year
Economic life	: 30 years (base case)

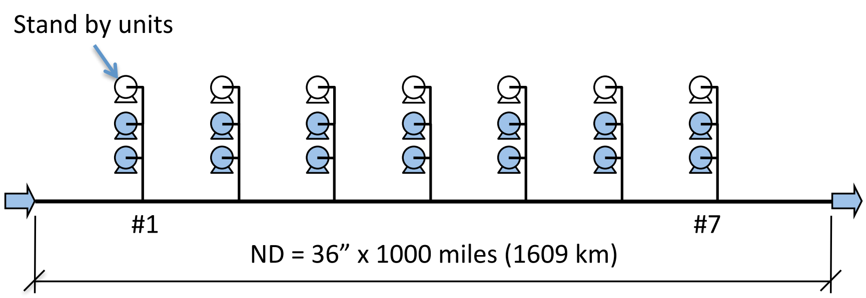

Figure 1 – Case Study and Base Case

2.3. Thermohydraulic Results

The thermohydraulic results are shown on table 1 below.

Table 1 –Thermohydraulic Results

Nominal Diameter ND inches	Desiogn Capacity MMCFD (MMCMD)	Pipeline Length miles (km)	Discharge Pressure (At Comp. Flange) psig (kgf/cm2)	Compression Ratio (Pd/Ps)	Station Quantity	Total Required Power hp (kW)	Average Required Power per Station hp (kW)	Fuel required MMCFD (MMSCMD)	Compressor Unit Size hp ISO (kW)
36	1059 (30)	1000 (1609.3)	1420 (99.84)	1.3383	7	106003 (79046)	15143 (11292)	21.2524 (0.6018)	2 x 10300 2 x (7680)

3. Gas Pipeline Project Impacting Variables

The impacting variables detailed below – as an example and for the purpose of this case study – such as economic life, internal rate of return, market gas demand curve, design pressure, strength of steel, pipeline internal coating, compression station design, compression system redundancy level and compression ratio have influence on the Project transportation rate or tariff and may affect directly its competitiveness. Transportation rate is calculated at a Project Net Present Value – NPV equal to zero at a pre-defined discount rate.

Each impacting variable is evaluated against the project base case and is the only independent variable changed.

3.1. Economic life

This evaluation assumes that all CAPEX is depreciated linearly along the selected economic life. As can be seen from the figure 2 the most important impact on transportation rate happens below 30 years of economic life. After 30 years of economic life transportation rate approximates to a horizontal line. Since gas pipeline projects are capital intensive, lower economic lives impacts heavily on transportation rate and therefore my impact negatively on the feasibility of a project.

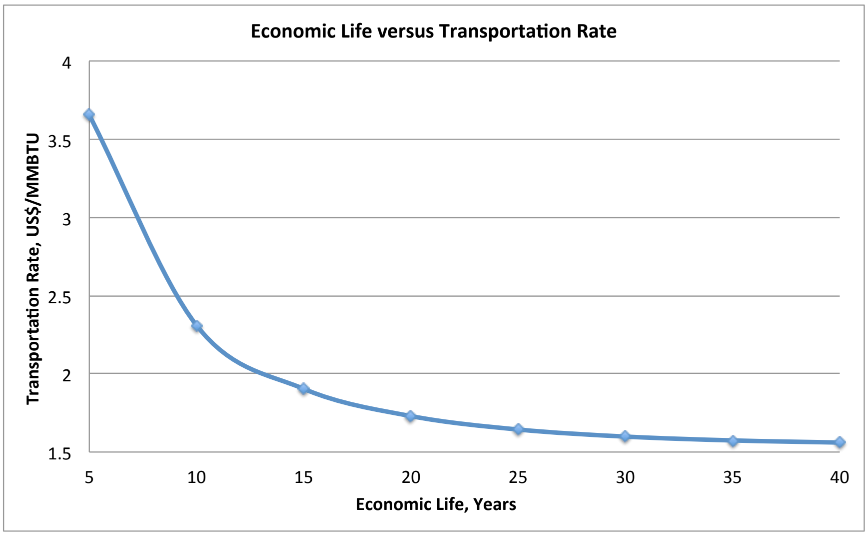

Figure 2 – The impact of Project's Economic Life on Transportation Rate

3.2. Internal rate of return – IRR or Discount Rate

The IRR is evaluated using Microsoft® Excel® spreadsheet economic model with discounted cash flow – DCF approach (and adjusting the net present value – NPV to zero for each simulated discount rate and using the economic assumptions defined on paragraph 2.2. When it comes to evaluating projects, one of the most powerful approach is the use of DCF associated with NPV and IRR as strongly recommended by Ross et al., (2004) and Copeland et al., (2000). As can be seen from figure 3, transportation rate varies linearly with discount rate.

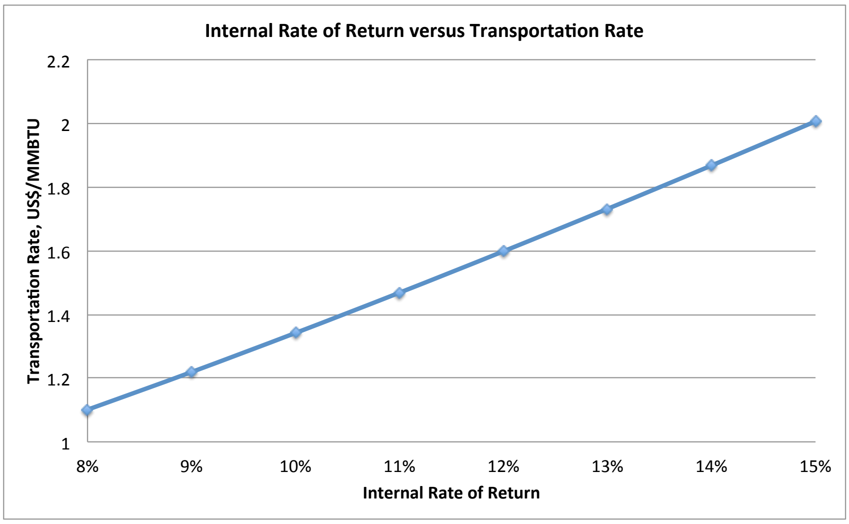

Figure 3 – The Impact of Discount Rate or Internal Rate of Return on Transportation Rate

3.3. Market demand curve

Gas pipeline's transportation system is normally designed to operate most of the time at full capacity. This approach optimizes (minimizes) transportation rate and in turn makes the gas pipeline project more competitive in the gas market since the end price of gas is made of commodity + transportation rate + distribution rate. This evaluation assumes base case of 30 MMSCMD with no impact on CAPEX and OPEX. In this evaluation, the only variable that is changed is transportation capacity all others are kept constant. Fuel demands are accounted separately from OPEX for each capacity since lower capacities require lower fuel gas for transportation. The effect of market demand reduction on transportation rate is shown on figure 4. Lower transportation capacities require higher transportation rates to keep the same gross income to the Transportation Company to cover OPEX and repay the investment on the project. Transportation rates above base case (0% market demand reduction) represents the risk to be mitigated by the Shippers – companies who contract transportation service from Transportation Companies. Uncertainty scenarios for market demand that demands lower transportation capacities impacts Local Distribution Companies – LDC or End Users that will be charged higher transportation rates than the one derived from base case.

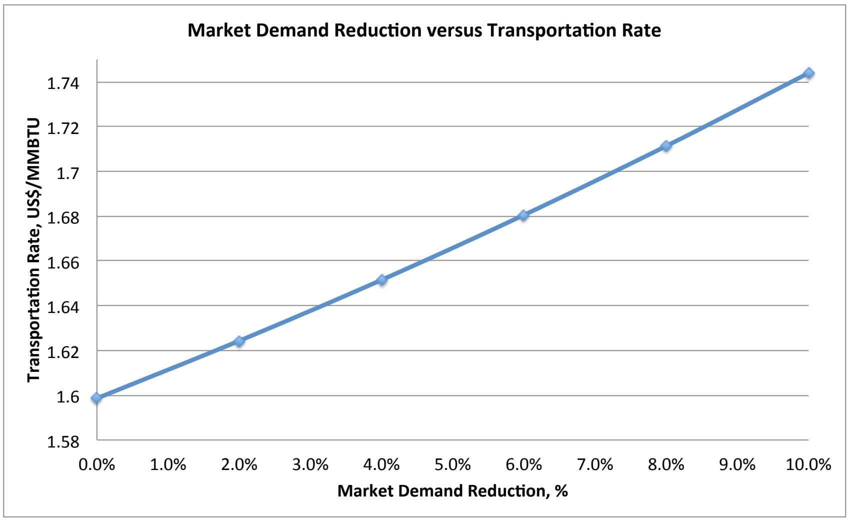

Figure 4 – The Impact of Market Gas Demand Reduction on Transportation Rate

3.4. Design pressure

This evaluation assumes base case of 30 MMSCMD with design pressure of 1420 psig (99.84 kgf/cm2g) in comparison with design pressure of 1778 psig (125 kgf/cm2g). Note that for MAOP of 1778 psi and compression ratios of 1.4759 and 1.3070 the quantity of compressor stations and compressor units per station have been changed substantially in comparison with base case as show in figure 5. Since pipe material specification is the same for all these configurations the impact of elevating the design pressure had increased the transportation rate (see figure 5 and table 2) and therefore did not prove to be attractive. As design pressure increases, also increases its effect on pipeline thickness and consequently on pipeline weight and this linear effect swallow the benefit that higher design pressure normally gives to a project. What is normally done in conjunction to increasing design pressure is to increase material tensile strength (e.g. from X80 to X100). This is better seen on item 3.5.

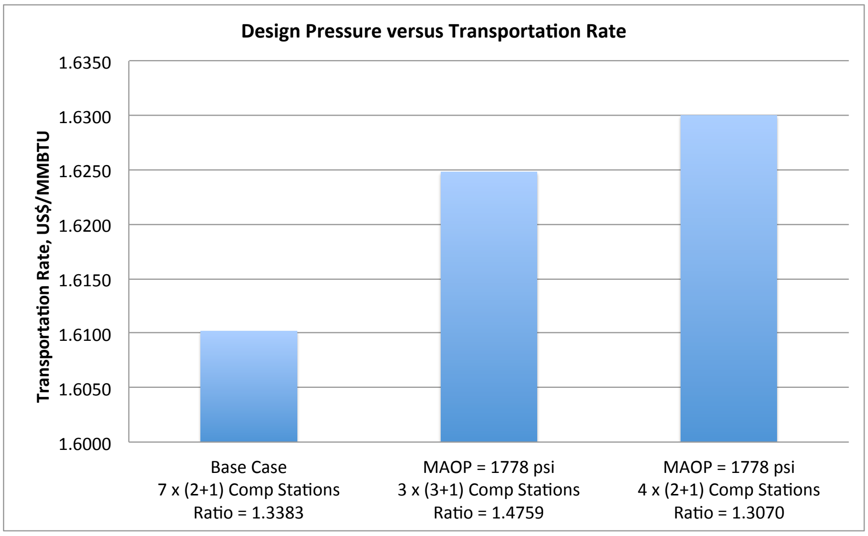

Figure 5 – The Impact of Design Pressure on Transportation Rate

Table 2 – Present Value of Costs and Transportation Rates

Gas Pipeline Configuration	Present Value of CAPEX		Presente Value of OPEX		Present Value of Fuel Gas	Total Present Value	Transportation Rate, US$/MMBTU
	Pipeline	Compressor Station	Pipeline	Compressor Station			
Base Case 7 x (2+1) Comp Stations Ratio = 1.3383	(2,343.00)	(321.34)	(142.44)	(122.10)	(223.16)	(3,152.04)	1.6102
MAOP = 1778 psi 3 x (3+1) Comp Stations Ratio = 1.4759	(2,616.40)	(169.10)	(159.06)	(64.25)	(123.47)	(3,132.28)	1.6248
MAOP = 1778 psi 4 x (2+1) Comp Stations Ratio = 1.3070	(2,616.41)	(183.62)	(159.06)	(69.77)	(110.62)	(3,139.48)	1.6300

3.5. Strength of steel

This evaluation assumes base case of 30 MMSCMD with design pressure of 1420 psig (99.84 kgf/cm2g) and pipe material API5L X80 compared to API5L X100. Cost of pipes with API5L X100 was considered as 5% higher than API5L X80. The results are presented on figure 6 and table 3. Note that the configuration with API5L X100 required fewer compressor stations (6 units) but more compressor units per stations (3+1 units) in comparison to base case.

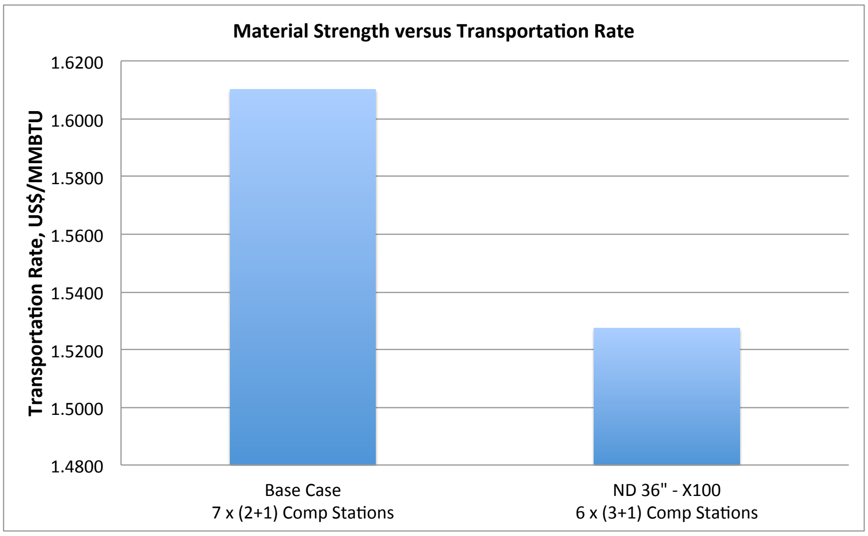

Figure 6 – The Impact of Material Strength on Transportation Rate

Table 3 – Present Value of Costs and Transportation Rates

Gas Pipeline Configuration	Present Value of CAPEX		Presente Value of OPEX		Present Value of Fuel Gas	Total Present Value	Transportation Rate, US$/MMBTU
	Pipeline	Compressor Station	Pipeline	Compressor Station			
Base Case 7 x (2+1) Comp Stations	(2,343.00)	(321.34)	(142.44)	(122.10)	(223.16)	(3,152.04)	1.6102
ND 36" - X100 6 x (3+1) Comp Stations	(2,169.29)	(338.18)	(131.88)	(128.50)	(232.02)	(2,999.87)	1.5274

3.6. Internal coating

Internal coating is primarily used to reduce the surface roughness of a pipe. It reduces friction between flowing gas and the internal surface of a pipe providing the benefit of lower pressure drops, lower compression power requirements and lower fuel gas for compressor unit drivers. Additionally protects the pipes from atmospheric corrosion attack while the pipes are in storage prior assembling. Since worldwide trend is in favor of internal coating, the base case shown in figure 7 considers the gas pipeline project internally coated. Note that alternative without internal coating requires 1 (one) more compressor unit per station. Santos et al., (2011) has emphasized the economic benefit of applying internal coating to gas pipeline projects.

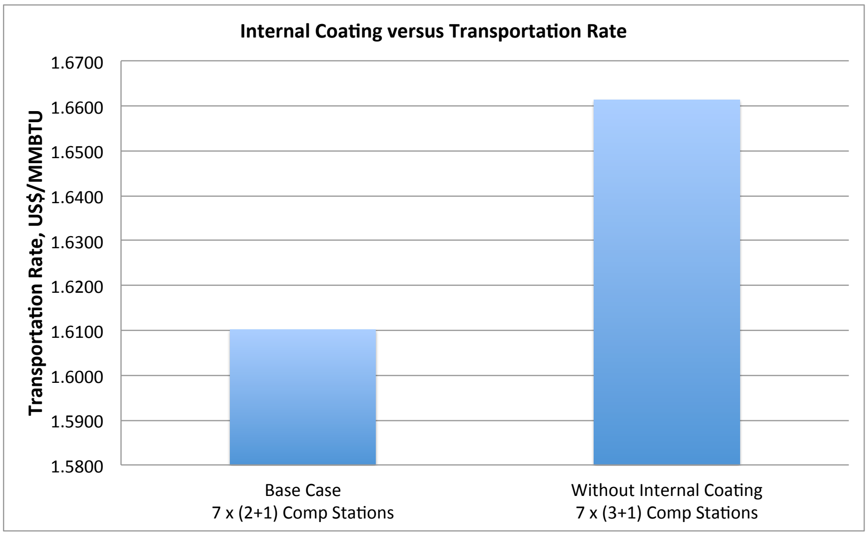

Figure 7 – The Impact of Pipeline Internal Coating on Transportation Rate

Table 4 – Present Value of Costs and Transportation Rates

Gas Pipeline Configuration	Present Value of CAPEX		Presente Value of OPEX		Present Value of Fuel Gas	Total Present Value	Transportation Rate, US$/MMBTU
	Pipeline	Compressor Station	Pipeline	Compressor Station			
Base Case 7 x (2+1) Comp Stations	(2,343.00)	(321.34)	(142.44)	(122.10)	(223.16)	(3,152.04)	1.6102
Without Internal Coating 7 x (3+1) Comp Stations	(2,314.89)	(394.54)	(140.73)	(149.91)	(271.82)	(3,271.89)	1.6614

3.7. Compression ratio

Compressor stations for transmission gas pipeline can vary from 1.2:1 to around 2:1. This maximum range of around 2:1 is not only related to centrifugal compressor design but rather to the economics of the pipeline project since gas flow behavior affects overall compression power requirements and fuel demand. Gas pipeline designer must take this into account while defining the configuration and quantity of the compressor stations to be adopted for one specific project. Compressor station optimum arrangement of compressor units – size and quantities – is dependent on the availability of equipment (compressors and drivers) from manufacturers. As can be seen from figure 8 and table 5 compression ratio impacts transportation rate as consequence of compressor station quantity and compressor units per station.

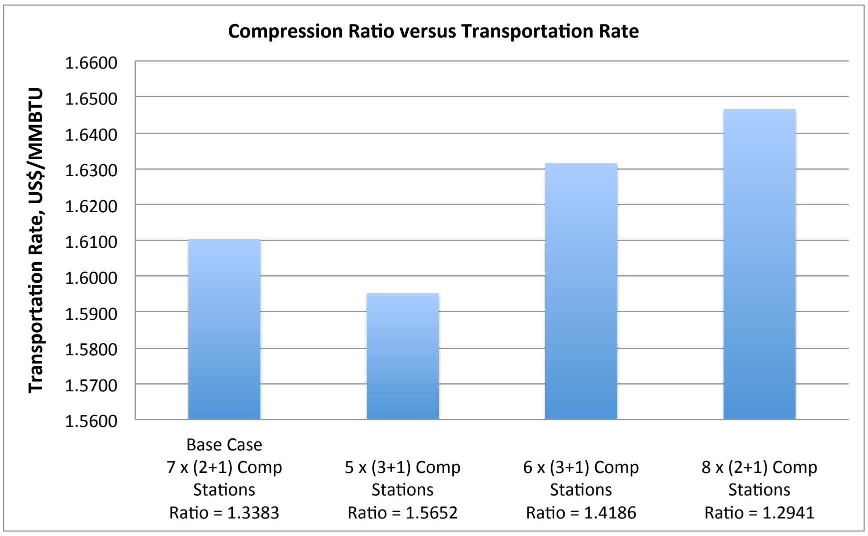

Figure 8 – The Impact of Compression Ratio on Transportation Rate

Table 5 – Present Value of Costs and Transportation Rates

Gas Pipeline Configuration	Present Value of CAPEX		Presente Value of OPEX		Present Value of Fuel Gas	Total Present Value	Transportation Rate, US$/MMBTU
	Pipeline	Compressor Station	Pipeline	Compressor Station			
Base Case 7 x (2+1) Comp Stations Ratio = 1.3383	(2,343.00)	(321.34)	(142.44)	(122.10)	(223.16)	(3,152.04)	1.6102
5 x (3+1) Comp Stations Ratio = 1.5652	(2,343.00)	(281.82)	(142.44)	(107.08)	(255.66)	(3,130.00)	1.5952
6 x (3+1) Comp Stations Ratio = 1.4186	(2,343.00)	(338.18)	(142.44)	(128.50)	(250.73)	(3,202.84)	1.6315
8 x (2+1) Comp Stations Ratio = 1.2941	(2,343.00)	(367.24)	(142.44)	(139.54)	(238.22)	(3,230.44)	1.6466

3.8. Compressor station design

As presented by Santos et al., (2011) any improvement in cost reduction will affect positively the pipeline project feasibility. Compressor units exposed to the weather conditions – without housing and where applicable – may reduce costs in the range of 5 % of the total compressor station CAPEX in comparison with a compressor station with traditional housing. Other improvements includes containerized control station pre-assembled and pre-tested at manufacturer will reduce costs in assembling and commissioning time and will provide flexibility should there will be any need to replace the compressor station. Figure 9 and table 6 below present this impact on transportation rate.

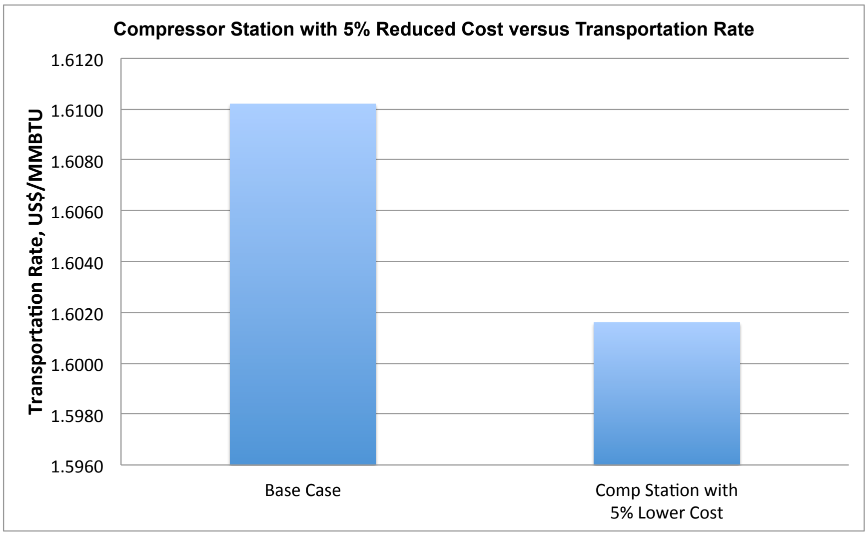

Figure 9 – The Impact of Compressor Station Lower Cost Design (5% Lower) on Transportation Rate

Table 6 – Present Value of Costs and Transportation Rates

Gas Pipeline Configuration	Present Value of CAPEX		Presente Value of OPEX		Present Value of Fuel Gas	Total Present Value	Transportation Rate, US$/MMBTU
	Pipeline	Compressor Station	Pipeline	Compressor Station			
Base Case	(2,343.00)	(321.34)	(142.44)	(122.10)	(223.16)	(3,152.04)	1.6102
Comp Station with 5% Lower Cost	(2,343.00)	(305.27)	(142.44)	(115.99)	(223.16)	(3,129.87)	1.6016

3.9. Compression system redundancy level

The evaluation of the redundancy level has used Monte Carlo simulation with a risk analysis toll (@Risk from Palisade Corporation) running as add in in Microsof® Excel®. Santos (2009) and Santos et al., (2011) presented a methodology to evaluate the feasible level of redundancy a gas pipeline project may adopt associated with contractual transmission capacity. In this redundancy level analysis, the availability of 0.971 for compressor units (gas turbine driver + centrifugal compressor) was adopted as recommended by Electric Power Research Institute, EPRI (1999). The conclusion is that installing one stand-by compressor unit at each compressor station allows increasing contractual capacity – on a firm basis – and gives better economic results for the project. Figure 10 presents the sensitivity of the stand-by compressor unit quantities on the NPV of a Project. NPV increases as firm capacities increase providing more revenue for the Project. The case with 2 stand-by units one unit was installed on station #3 and the other on station #6. The case with 3 stand-by units the units were installed on stations #2, #4 and #6. The case with 4 stand-by units the units were installed on stations #1, #3, #5 and #7. The case with 7 stand-by units one unit was installed at each compressor station.

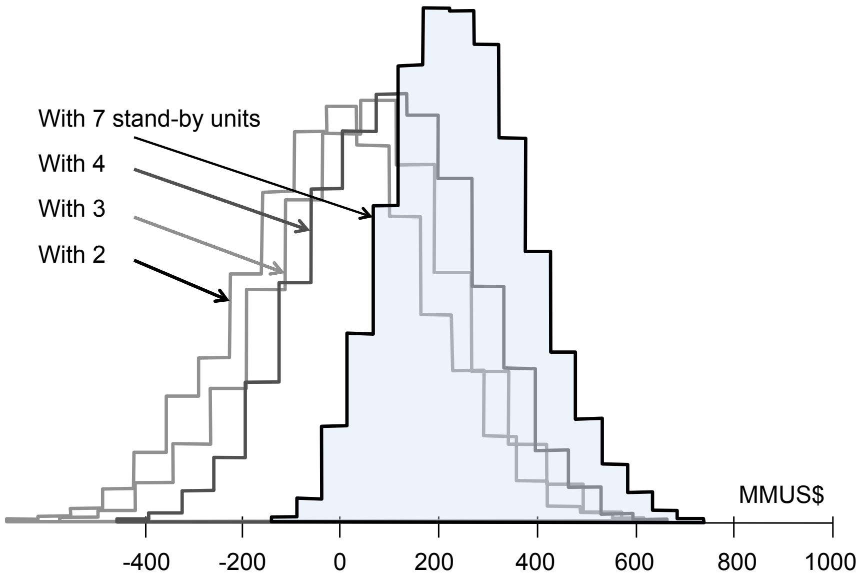

Figure 10 – Volatility of Project NPV as a function of Stand-by Units Quantity4. Conclusion

4. Conclusion

In conclusion, some independent variables affect significantly gas pipeline projects. and Project Sponsors and Pipeline Designers should be aware of their influence and consider them while designing a feasible gas pipeline project. From the results presented in this paper we may be guided to adopt – whenever possible – the following, for new gas pipeline projects:

- Economic life: as close as possible to 30 years although this is related to gas supply reserve and market demand;
- Internal rate of return: The lower the best in relation to project competitiveness. However, this is directly related to the cost of capital of the transportation company;
- Market demand: must be as close as possible to design capacity. This is a critical item and normally is solved by signing a transportation contract prior to construction of the gas pipeline;
- Design pressure: the higher the best since it lower transportation rate. This should be done in conjunction to pipe material selection and environmental requirements;
- Internal coating: must be a standard as provides multiple benefits to the project;
- Compression ratio: a value around 1.4 is recommended. Lower values requires more compressor stations and higher values demands more fuel gas and increase OPEX and transportation rate. Designer should simulate some alternatives and select the best one for his project as Santos(2009);
- Compressor station design: the simpler the better. CAPEX savings impact directly on transportation rate.
- Compressor system redundancy level: Santos (2009) has proved that installing 1 (one) stand-by compressor unit per station is feasible. Losses from revenue shortage and contractual penalties for not delivering contractual capacities are far higher than the CAPEX and OPEX of installing stand-by units.

Care should be taken as note rely on sensitivity studies alone to support the decision making process since they do not provide a comprehensive quantitative risk analysis of a project. Quantitative risk analysis – QRA with Monte Carlo simulation is a key factor for a feasible gas pipeline project as Santos (2009).

5. Acknowledgements

The main author tanks PETROBRAS where he worked as gas pipeline designer for 25 years – at Corporate Engineering and at Gas Business Unit – as Senior Consultant, while developing gas pipeline and compressor station basic designs with thermohydraulic simulations, failure analysis, economic evaluations and Monte Carlo simulations. The author also developed some technics during his master on logistics at PUC-Rio University where he developed his thesis on Logistic Management System for Natural Gas Transportation by Pipeline in 2008.

5. References

Copeland, T., Koller, T., Murrin, J., 2000. Valuation:measuriong and managing the value of copmpanies. John Wiley & Sons, New York.

Electric Power Research Institute, Epri, 1999. Report no. RP 4CH2983. California.

Hertz, D., 1984. Practical risk analysis: An approach through case histories. John Wiley & Sons, New York.

Ross, S. A., Westfield, R. W., Jaffe, J. F., 2004. Corporate Finance. McGraw-Hill, Boston.

SANTOS, S. P., LUBOMIRSKY, M. KURZ, R. Gas pipeline design under market risk. In: Rio Pipeline Conference and Exposition, 2011, Rio de Janeiro, BR.

SANTOS, S. P., LUBOMIRSKY, M. KURZ, R. Economics of Internal Pipe Coating. In: Pipeline Simulation Interest Group, 2011, Napa Valley, CA, USA.

SANTOS, S.P., LEAL, J. E., OLIVEIRA, F., 2011. The development of a natural gas transportation logistics management system. Energy Policy, volume 39, issue 9, September 2011. Elsevier.

SANTOS, S. P. Monte Carlo simulation – A key for a feasible gas pipeline project. In: Pipeline Simulation Interest Group, 2009, Galveston, TX, USA.