PSIG 0905

The Challenges of Modelling a Probabilistic Pipeline

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ABSTRACT

This paper discusses the challenges in simulating the Dampier to Bunbury Natural Gas Pipeline (DBNGP) which has capacity transportation services defined by probability of supply with specific interruption limits.

There are two main types of capacity services, namely, Firm and Non Firm. The Firm Capacity Service has a 98% probability of supply and it may not be interrupted for more than 2% of the time. For Non Firm Capacity Service, up to 10% of the total contracted capacity could be interrupted per year.

These types of capacity services require a different flow modelling approach – the model must be able to simulate thousands of steady state runs under different pipeline operating configurations in order to derive each of the different capacity service levels.

This specific modelling requirement has resulted in the development of a modelling tool that offers:

- A robust spreadsheet-based model with full pipeline simulation capability
- The ability to carry out thousands of simulations unattended
- The capability to process and statistically analyse simulation results
- Error checking, data validation and reporting

In summary, a versatile pipeline modelling tool has been developed for the determination of the DBNGP's unique capacity services. This model can be used in both steady state and transient simulations. In addition, day to day capacity forecasting for both short and long term planning can also be performed using the same model.

INTRODUCTION

The DBNGP pipeline connects the gas processing plants located near Dampier in the North West of Western Australia to the customers in the state's South West. It has a total of ten compressor stations situated approximately 93miles (150km) apart from each other. All the gas inlets are located at the start of the pipeline and most of the outlets are located at the southern end of the pipeline. Interconnections with other pipelines are fairly limited. By world standards, it is a relatively small and simple pipeline.

However, operationally this pipeline differs from most other pipelines – Capacity Services are contracted by levels of firmness and probability of supply. It is easy to model the physical and flow characteristic of this pipeline but it is both time consuming and challenging to model the capacity services for this "probabilistic" pipeline.

This paper presents:

- An overview of the pipeline
- Definition of the different capacity services and the challenges in modelling these services
- An example of how the services are determined and modelled
- Discussion on the experience and methodology used to model this pipeline

BACKGROUND – THE PIPELINE

Overview of the Pipeline

The following lists the chronology of the pipeline:

- 1984: Built by the State Government of Western Australia
- 1998: After privatisation, it was acquired by Epic Energy (which was owned by El Paso, Dominion and other Australian Funds)
- 2004: Acquired by Alinta (20%), Alcoa (20%) and others (60%)
- 2007: Alinta's 20% share purchased by Babcock & Brown Infrastructure (BBI)

Figure 1 shows the route of the pipeline in relation to the major towns and cities of Western Australia. Technical information regarding the pipeline is included in Table 1.

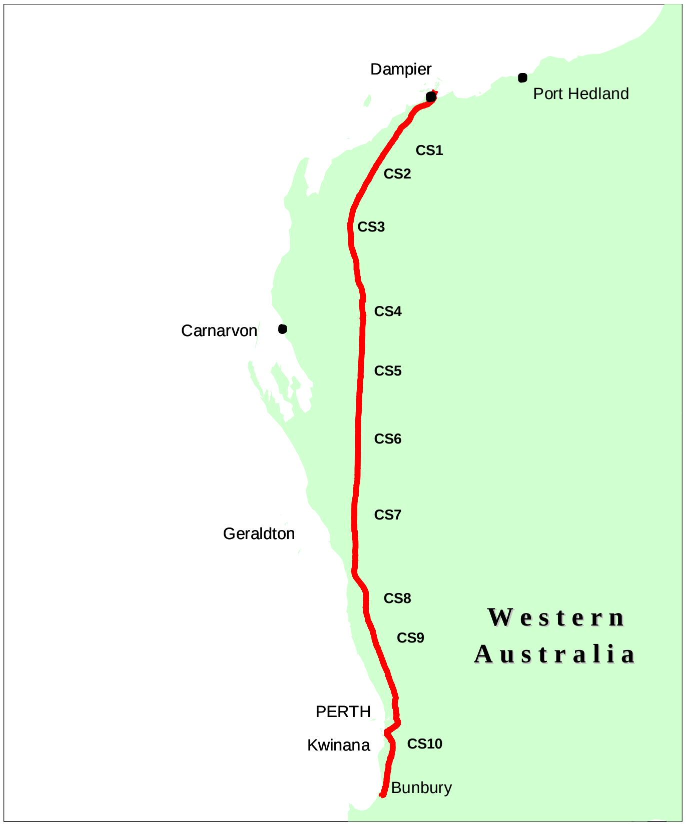


Figure 1 - The Dampier to Bunbury Natural Gas Pipeline and Compressor Stations 1 to 10

Mainline	26" x 990 miles (1596km)
Mainline Loops	26" x 488 miles (787km)
Laterals	6" to 12" x 160 miles (258km)
Maximum Allowable Operating Pressure	1230psi (8480kPa)
No. of Compressors	26 units in 10 compressor stations
Total Installed Power	310,000hp (230,000kW)
Nominal Capacity	795 mmscfd (850 TJ/d)
No. of Receipt Points	4
No. of Outlet Points	47

Table 1 - DBNGP Technical information

Pipeline Capacity and Operation

- Capacity is measured by the energy rate in Terajoules per day. Hence, energy content is an important measure of gas quality that will impact on the pipeline's capability to deliver the contracted capacity.
- Contractually pipeline full-haul capacity and throughput are measured by the quantity of gas leaving the last mainline compressor station at CS9.
- Mainline compressor stations (CS1 to CS9) are installed with two 15000 hp gas turbo compressor units in series operation. Five of the stations are also installed with older generation LM500 units that are operated very infrequently.
- CS10 is a smaller compression plant that does not directly impact on capacity but its main purpose is to ensure delivery of gas to the south west of Western Australia.
- CS10 is configured differently with two parallel Solar Centaur units connected in series to a Solar Taurus unit.

The pipeline schematic in Figure 2 outlines the pipeline and the major load centres.

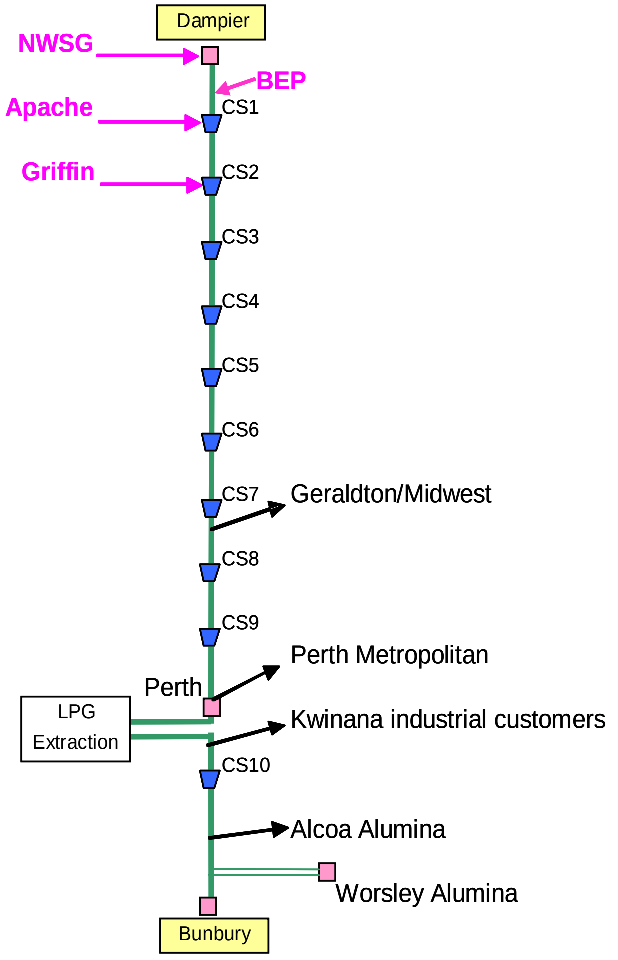


Figure 2 - Pipeline Schematic

Significance of the Pipeline to Western Australia

The DBNGP is one of the most critical infrastructures to the State of Western Australia as it supplies more than 95% of the State's natural gas demands. There is currently no other gas transmission pipeline in the region that can offer equivalent capacity services.

Interruption to gas supply will impact on the whole energy chain in the domestic, commercial and industrial sectors as well as electricity supply (through the gas fired power generators). The growing dependence on the pipeline is evident when a recent incident at the offshore facilities of one of the producers reduced the State's gas supply by 30% causing significant economical impact to the State and on a national level.

CAPACITY SERVICES

For the DBNGP, gas transportation capacity services are contracted by levels of firmness and interruption limits. These services are defined probabilistically and can be either time-based or volume-based.

Time based capacity services specify "*how often*" the capacity needs to be made available, whereas volume based capacity services stipulate "*how much*" capacity needs to be delivered.

The DBNGP has two main types of capacity services, namely, time-based "Firm" T1 and volume-based "Non Firm" Tx capacity services.

T1 Capacity Service

T1 (1^{st} Tranche) capacity is a time-based firm service that has the highest probability of supply at 98% of the time. The Pipeline Operator makes a commitment that within any gas year, the contracted T1 capacity may only be partly or wholly interrupted for no more than 2% of that time. This is equivalent to a maximum 7.3 days per year when gas supply may be interrupted. As this is a time based capacity service, the actual interrupted quantity is not specified.

Tx Capacity Service

Tx (extended) capacity is a volume-based, less firm service than T1. The Pipeline Operator makes a commitment to deliver at least 90% of the contracted capacity. Within any gas year, the Operator can interrupt the services for an unlimited duration provided that the total curtailment quantity does not exceed 10% of the annual contracted capacity. Contractually it is ranked behind T1 capacity, so any interruption or curtailment will apply to the Tx capacity service first.

Table 2 shows a sample calculation for contracted Tx capacity of 50 units of energy per day.

Contracted Tx Capacity	50 units per day	
Total Contracted Capacity per year	50 * 365 days	18250 units per year
Committed Delivery	90% of capacity	16425 units per year
Allowable Interruption	10% of capacity	1825 units per year

Table 2 – Example of Tx Capacity Calculation

Other Services

Apart from the above T1 and Tx capacity services, there are also other less firm (and oddly named) capacity services such as Ty, Tp, Tk and Spot capacity services which are all ranked behind T1 and Tx However, discussion of these different types of capacity services will not be covered in this paper.

EXAMPLE

As discussed, T1 and Tx capacity services are defined by different probabilities of supplies, one has a time based interruption limit and the other has a volume or quantity based interruption limit. These seemingly conflicting capacity services can become difficult to simulate, even for a relatively simple pipeline. The magnitude of the complexity will become apparent from the following work example.

Three Compressor Unit Pipeline

A simple scenario of a simple pipeline (with one compressor unit in each of three separate compressor stations) can be used as an example to demonstrate the method applied in determining the T1 and Tx capacity services.

Number of Simulation Cases

As shown in Table 3, there are eight possible configurations of how this pipeline can be operated in terms of the number of compressors online or offline. In this example, Compressor units A, B and C are compressors in each of the respective stations.

Case 1 has all three compressors online. Cases 2 to 4 have one compressor offline. Cases 5 to 7 have two compressors offline and Case 8 has all three compressors offline.

Case Number	Compressor Unit On/Off		
	A	B	C
1	On	On	On
2	Off	On	On
3	On	Off	On
4	On	On	Off
5	Off	Off	On
6	Off	On	Off
7	On	Off	Off
8	Off	Off	Off

Table 3 - Compressor Operating Cases

Steady State Capacity

Each of the different cases in Table 3 above can be easily simulated to determine its deliverable capacity. As shown in Table 4, Case 1 can deliver a maximum of 600 units of capacity when all three compressor units are operating. When Unit A in Case 2 is not available, the pipeline capacity reduces to 475 units. Lastly in Case 8, the capacity will reduce to 295 units when all three units are not operating (free flow capacity).

Case Number	Compressor Unit On/Off			Capacity
	A	B	C	
1	On	On	On	600
2	Off	On	On	475
3	On	Off	On	500
4	On	On	Off	470
5	Off	Off	On	400
6	Off	On	Off	450
7	On	Off	Off	380
8	Off	Off	Off	295

Table 4 – Pipeline Steady State Capacity

Probability of Occurrence

Assuming an average compressor unit availability of 90% for each of the units (10% unavailability due to either planned or unplanned unit outages), the probability of occurrence for each of the 8 cases can be determined. Probability of occurrence is the product of the probabilities of each unit on/offline. For example, Case 1 in Table 5 below has a probability of occurrence of 90% * 90% * 90% or 72.9% as each of the compressor units is available for 90% of the time. Probabilistically, there is a 72.9% chance that this operating configuration can occur and produce a maximum capacity of 600 units. Case 2 can only provide 475 units of capacity and has a probability of occurrence of 8.1% (10% * 90% * 90%) as Unit A is not available to operate. Probability of occurrence for other cases can similarly be determined as per Table 5 below.

Case Number	Compressor Unit On/Off			Capacity	Unit Availability			Probability
	A	B	C		A	B	C	%
1	On	On	On	600	90%	90%	90%	72.9%
2	Off	On	On	475	10%	90%	90%	8.1%
3	On	Off	On	500	90%	10%	90%	8.1%
4	On	On	Off	470	90%	90%	10%	8.1%
5	Off	Off	On	400	10%	10%	90%	0.9%
6	Off	On	Off	450	10%	90%	10%	0.9%
7	On	Off	Off	380	90%	10%	10%	0.9%
8	Off	Off	Off	295	10%	10%	10%	0.1%

Table 5 - Probability of Occurrence

T1 Capacity

T1 capacity can be determined by rearranging the capacity column in Table 5 in descending order and computing the cumulative probability of occurrences. The results show that the Operator of this pipeline can confidently make available at least 450 units per day of capacity for at least 98.1% of the time. Thus, T1 capacity can be set at 450 units per day.

Case Number	Compressor Unit On/Off			Capacity	Probability	Cumulative Probability
	A	B	C		%	%
1	On	On	On	600	72.9%	72.9%
3	On	Off	On	500	8.1%	81.0%
2	Off	On	On	475	8.1%	89.1%
4	On	On	Off	470	8.1%	97.2%
6	Off	On	Off	450	0.9%	98.1%
5	Off	Off	On	400	0.9%	99.0%
7	On	Off	Off	380	0.9%	99.9%
8	Off	Off	Off	295	0.1%	100.0%

Table 6 - Cumulative Probability of Supply

Observations:

- From Table 6, T1 capacity can be defined by simulating only five of the eight possible compressor on/offline cases, however, it is difficult to say which cases can be omitted unless all possible cases have been simulated and until T1 capacity is confirmed. This is a typical “what came first, the chicken or the egg” question.

- This leads to a difficult task of determining the number of cases needed to properly define T1 capacity level.

Tx Capacity

Tx capacity has a volume-based interruption limit and cannot be readily defined compared to T1 capacity. As Tx is ranked behind T1 capacity service, it will only be partly or fully delivered after all T1 capacity obligations are fulfilled. Tx capacity can only be determined by an iterative process which is demonstrated below.

Using the same example, the process begins with T1 capacity level of 450 units and in this instance, Tx is arbitrarily set to 100 units. The calculation in Table 7 shows the following:

- Case 1, which is capable of delivering 600 capacity units and a probability of occurrence of 72.9%, will be able to deliver both T1 (450 units) and all Tx capacities (100 units). Therefore, when the pipeline is operating with all three units online, the pipeline can deliver 72.9% *100 or 72.9 units of Tx.

- Case 3 occurs when Units A and C are online but Unit B is offline. This has a probability of occurrence of 8.1%; and the available capacity is 500 units. After delivering all 450 units of T1 capacity, only the remaining 50 units of capacity can be allocated to Tx. This results in a Tx allocation of 8.1% * 50 or 4.05 units.

- Similarly, Tx capacity allocations can be calculated for Cases 2 and 4.

- Cases 5, 6, 7 and 8 have steady state capacities equal to or less than T1 requirements, so no spare capacity can be allocated to Tx.

Continuing with this analysis for all the possible operating cases, it can be deduced from the results that only 80.6 units (or 80.6% of Tx) can be delivered out of the initial targeted 100 units. This does not meet the required 90% supply limit. Therefore, the set Tx must be reduced in the next iteration.

T1	450		Tx	100	Trial 1

Case Number	Compressor Unit On/Off			Capacity	Probability	Tx	Weighted Tx
	A	B	C		%	Available	Capacity
1	On	On	On	600	72.9%	100	72.90
3	On	Off	On	500	8.1%	50	4.05
2	Off	On	On	475	8.1%	25	2.03
4	On	On	Off	470	8.1%	20	1.62
6	Off	On	Off	450	0.9%	0	0
5	Off	Off	On	400	0.9%	0	0
7	On	Off	Off	380	0.9%	0	0
8	Off	Off	Off	295	0.1%	0	0
						Total	80.60

Total Tx Delivered	80.60
Required Tx Delivery	100.00

Tx Percentage Delivery	80.6%

Table 7 - Trial 1 with Tx Set at 100 units

In the second iteration, Tx is reduced to 50 units. The calculation in Table 8 below shows that this still does not meet the required 90% supply limit. Therefore, Tx level must be further reduced.

T1	450		Tx	50	Trial 2

Case Number	Compressor Unit On/Off			Capacity	Probability	Tx	Weighted Tx
	A	B	C		%	Available	Capacity
1	On	On	On	600	72.9%	50	36.45
3	On	Off	On	500	8.1%	50	4.05
2	Off	On	On	475	8.1%	25	2.03
4	On	On	Off	470	8.1%	20	1.62
6	Off	On	Off	450	0.9%	0	0
5	Off	Off	On	400	0.9%	0	0
7	On	Off	Off	380	0.9%	0	0
8	Off	Off	Off	295	0.1%	0	0
						Total	44.15

Total Tx Delivered	44.15
Required Tx Delivery	50.00

Tx Percentage Delivery	88.3%

Table 8 - Trial 2 with Tx Set at 50 units

The final iteration in Table 9 shows that the pipeline can support a Tx capacity of 40.3 units. The pipeline can deliver up to 36.05 units of Tx capacity (out of the 40.3 units) which equates to 90% of the contracted Tx capacity.

T1	450		Tx	40.3

Case Number	Compressor Unit On/Off			Capacity	Probability	Tx	Weighted Tx
	A	B	C		%	Available	Capacity
1	On	On	On	600	72.9%	40.3	29.38
3	On	Off	On	500	8.1%	40.3	3.26
2	Off	On	On	475	8.1%	25	2.03
4	On	On	Off	470	8.1%	20	1.62
6	Off	On	Off	450	0.9%	0	0
5	Off	Off	On	400	0.9%	0	0
7	On	Off	Off	380	0.9%	0	0
8	Off	Off	Off	295	0.1%	0	0
						Total	36.29

Total Tx Delivered	36.29
Required Tx Delivery	40.30

Tx Percentage Delivery	90.0%

Table 9 - Final Iteration with Tx Set at 40.3 units

In conclusion, the Operator can confidently offer a T1 capacity of 450 units per day and Tx capacity service of 40.3 units per day for this pipeline scenario.

Operationally, the capacity can be allocated as follows:

Operating Configuration	Deliverability
Case 1 & 3 Capacity > T1+Tx	Both T1 & Tx
Cases 2 & 4 T1 < Capacity < T1+Tx	T1 & part of Tx
Cases 5,6,7,8 Capacity < T1	All or Part of T1 but No Tx Allocation

Table 10 - Deliverability

Observations:

- Only cases with capacities exceeding T1 level can deliver any Tx capacity. Other cases that deliver less than T1 capacity can be omitted from Tx calculations.

- Tx is an additional capacity above T1 capacity, so as long as sufficient numbers of cases are simulated to define T1 capacity, no additional cases are required to determine Tx capacity level.

Probability of Supply Chart

A Probability of Supply chart is used to graphically represent the T1 and Tx capacity levels.

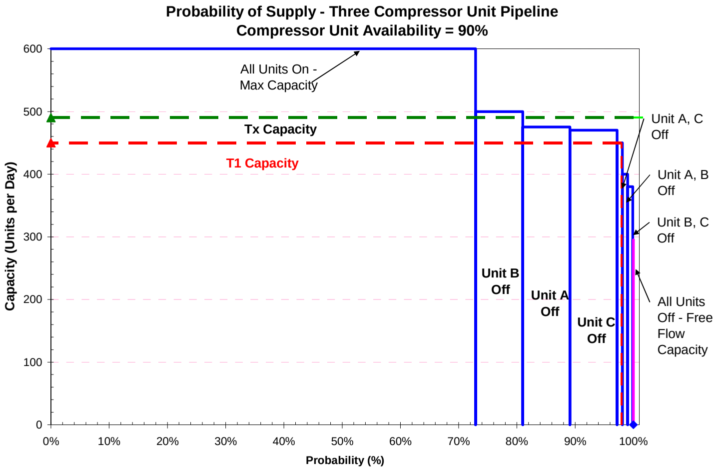


Figure 3 – Sample Probability of Supply

THE DBNGP MODEL

Evaluating the T1 and Tx capacity services is relatively straightforward for a typical three compressor unit pipeline which requires only eight steady state simulation runs. Applying the same methodology to a real pipeline such as the DBNGP with more compressor units will exponentially increase the number of simulations. While modelling each of the individual operating configurations may be relatively easy using commercially available software, it however becomes impractical to model many thousands of steady state cases.

Number of Compressor Operating Configurations

With DBNGP's eighteen main compressor units from CS1 to CS9, Table 11 shows the number of possible combinations of compressors offline. For example, there is only one possible operating configuration with zero units offline (all units are operating), but there will be 18 possible combinations with one unit offline, 153 combinations with two units offline, and so on.

Number of Units Offline	Number of Possible Configurations
0	1
1	18
2	153
3	816
4	3060
5	8568
6	18564
7	31824
8	43758
9	48620
10	43758
11	31824
12	18564
13	8568
14	3060
15	816
16	153
17	18
18	1
Total	262,144

Table 11 - Combinations of Offline Compressors

Even with today's advanced computer processing technology and powerful commercial flow modelling software, it is still not practical or possible to simulate 262,144 individual cases.

The approach adopted for the DBNGP is to reduce the number of compressors offline cases that need to be modelled.

As shown in the above example, it is not necessary to simulate those configurations that have lesser capacity than the T1 level. However, this presents the question of "how many cases are enough or required to determine both T1 and Tx capacity?"

Minimum Required Number of Compressor Operating Combinations

Table 12a shows the capacity ranges and probability of occurrence for the current DBNGP system (with average compressor availability of 95%). The results from 63,004 steady state simulation runs show that, when six or more compressor units are offline, the pipeline can only support significantly lower capacity.

			Capacity Range	
Number of Units Offline	Number of Possible Configurations	Probability of Occurrence Unit Availability 95%	Minimum	Maximum
0	1	39.7214%	885	885
1	18	37.6308%	845	867
2	153	16.8348%	675	863
3	816	4.7256%	675	857
4	3,060	0.9327%	541	851
5	8,568	0.1374%	541	840
6	18,564	0.015674%	468	817
7	31,824	0.001414%	468	808
8 to 18 units offline	199,140	0.0001086%		
Total	**262,144**	**100%**		

Table 12a - Unit Offline and Capacity Ranges

The results in following Table 12b show that T1 capacity will remain at the same level regardless of whether steady state cases with six or more units offline are modelled. Furthermore, these lower capacity cases only contribute to less than 0.02% of the total probability. Therefore, as far as the current DBNGP pipeline system is concerned, T1 and Tx capacities can be adequately defined by simulating only steady state cases with up to five units offline.

Number of Units Offline	Number of Possible Configurations	Total Cumulative Probability	T1 Capacity
0	1	39.721432%	Unresolved Total Cumulative Probability < 98 %
0 to 1 Units Offline	19	77.352262%	Unresolved Total Cumulative Probability < 98 %
0 to 2 Units Offline	172	94.187107%	Unresolved Total Cumulative Probability < 98 %
0 to 3 Units Offline	988	98.912678%	747
0 to 4 Units Offline	4,048	99.845356%	751
0 to 5 Units Offline	12,616	99.982803%	752
0 to 6 Units Offline	31,180	99.998477%	752
0 to 7 Units Offline	63,004	99.999891%	752
0 to 18 Units Offline	262,144	100.000000%	752

Table 12b - Unit Offline and T1 Capacity

Based on the above results, the total number of cases required for DBNGP modelling is effectively reduced to a manageable level. However, even with up to five units offline, it is still a challenging task to simulate up to 12,616 cases.

Requirement for the DBNGP Model

The DBNGP model must meet the following requirements:

- Input must be stored and editable within spreadsheets such as Microsoft Excel
- Simulations to be run "within" the spreadsheets to minimise manual interaction
- A robust model that can provide uninterrupted and unattended simulations
- Output or results from the simulations to be written directly to the spreadsheets for statistical analysis of appropriate T1 and Tx capacities
- Built in intelligence for error and data checking and verification of results

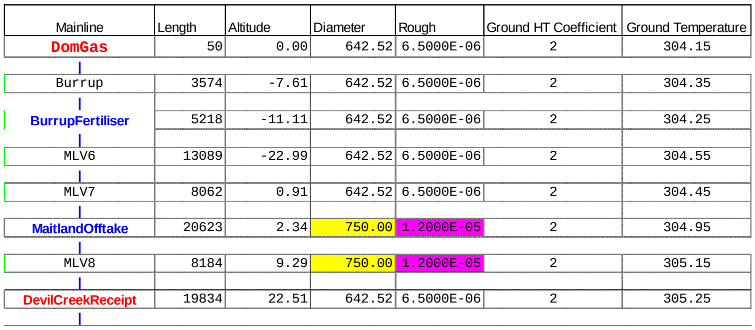
Model Input

The DBNGP flow model is set up with all inputs defined in Excel spreadsheets including:

- Pipeline physical characteristics such as length, diameter, elevation and roughness factor
- Flow and thermodynamic parameters such as friction factor, ground heat transfer coefficient and ambient ground and air temperatures
- Compressor configurations, site rated power, de-rating factor, fuel rate, aftercooler performance and actual wheelmaps
- Pressure, temperature and flow limitations at both receipt and outlet points

The model has been structured such that the above input parameters can be easily entered or modified. This allows external data from other sources, such as pipeline as-built database, SCADA database or GIS information, to be directly imported into the model. Also, the Excel built-in functions and formatting capabilities have been fully utilised for error-checking and data validation.

The following sample extract from the model shows the input with pipeline roughness and diameter highlighted by Excel Conditioning Formatting to show changed values.



Mainline	Length	Altitude	Diameter	Rough	Ground HT Coefficient	Ground Temperature
DomGas	50	0.00	642.52	6.5000E-06	2	304.15
Burrup	3574	-7.61	642.52	6.5000E-06	2	304.35
BurrupFertiliser	5218	-11.11	642.52	6.5000E-06	2	304.25
MLV6	13089	-22.99	642.52	6.5000E-06	2	304.55
MLV7	8062	0.91	642.52	6.5000E-06	2	304.45
MaitlandOfftake	20623	2.34	750.00	1.2000E-05	2	304.95
MLV8	8184	9.29	750.00	1.2000E-05	2	305.15
DevilCreekReceipt	19834	22.51	642.52	6.5000E-06	2	305.25

Table 13 - Typical Inputs Table

Model Integration within Excel Spreadsheets

The built-in Sirogas DLL (Dynamic Link Library) from the Flowtran Flow Modelling Package enables the DBNGP Flow Model to be fully integrated within Microsoft Excel. This Sirogas DLL is a hidden, full pipeline simulation engine that enables the model to execute the input data, carry out the simulation, and write the output back to the spreadsheets.

Full integration of DLL flow modelling engine with Excel spreadsheet facilitates routine execution of the powerful model to simulate large numbers of cases unattended in the background.

This model has a very stable and robust numerical analysis routine to resolve difficult or unusual compressor configurations or pipeline conditions. Together with advanced VBA macros for “catching” errors and applying “fixes” during simulations, it enables flow modelling of this scale to be successfully carried out.

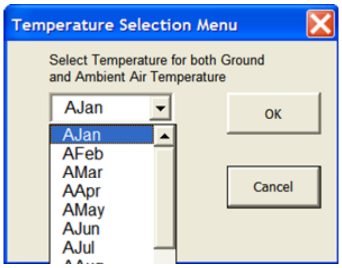
VBA Macros

The DBNGP Flow Model relies on both the Sirogas DLL and the powerful VBA macros to simultaneously run thousands of cases while checking and validating data.

Typically the VBA macros are used to:

- Read and validate the input parameters and pipeline configuration
- Simulate each of the steady state cases
- Write the results back to the spreadsheets
- Check the results and modify the input and re-run the same case as required
- Apply Excel formatting to highlight errors or unexpected results
- Process the results to determine the T1, Tx and other capacity levels
- Create tables and charts for reporting

The following extract shows one of the many VBA macros and dialogue boxes that enable simulation of changing conditions. Similarly advanced VBA macros have been created to simulate scenarios for different gas quality, compressor power and wheelmaps, and other pipeline operating parameters.



Select Temperature for both Ground and Ambient Air Temperature

Figure 4 - Example of VBA Macros

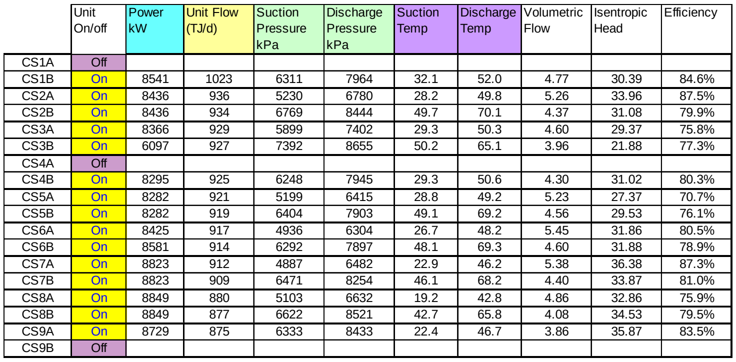
Model Output

Using the Excel functions, formatting and charting capabilities, the results and output from the thousand of simulations can be displayed in both table and chart formats for reporting purposes.

Output Table

The figure below shows the manner in which the results are presented after the simulation has been completed. Many elements of the results are automatically colour coded by conditional formatting to highlight the results. In addition, the data can be manipulated easily ranging from data validation to producing charts.

The many analytical tools produced from the results are also expressed in this section.



	Unit On/off	Power kW	Unit Flow (TJ/d)	Suction Pressure kPa	Discharge Pressure kPa	Suction Temp	Discharge Temp	Volumetric Flow	Isentropic Head	Efficiency
CS1A	Off									
CS1B	On	8541	1023	6311	7964	32.1	52.0	4.77	30.39	84.6%
CS2A	On	8436	936	5230	6780	28.2	49.8	5.26	33.96	87.5%
CS2B	On	8436	934	6769	8444	49.7	70.1	4.37	31.08	79.9%
CS3A	On	8366	929	5899	7402	29.3	50.3	4.60	29.37	75.8%
CS3B	On	6097	927	7392	8655	50.2	65.1	3.96	21.88	77.3%
CS4A	Off									
CS4B	On	8295	925	6248	7945	29.3	50.6	4.30	31.02	80.3%
CS5A	On	8282	921	5199	6415	28.8	49.2	5.23	27.37	70.7%
CS5B	On	8282	919	6404	7903	49.1	69.2	4.56	29.53	76.1%
CS6A	On	8425	917	4936	6304	26.7	48.2	5.45	31.86	80.5%
CS6B	On	8581	914	6292	7897	48.1	69.3	4.60	31.88	78.9%
CS7A	On	8823	912	4887	6482	22.9	46.2	5.38	36.38	87.3%
CS7B	On	8823	909	6471	8254	46.1	68.2	4.40	33.87	81.0%
CS8A	On	8849	880	5103	6632	19.2	42.8	4.86	32.86	75.9%
CS8B	On	8849	877	6622	8521	42.7	65.8	4.08	34.53	79.5%
CS9A	On	8729	875	6333	8433	22.4	46.7	3.86	35.87	83.5%
CS9B	Off									

Figure 5 - Typical Output Table

Probability of Supply Chart

Figure 6 plots the T1 and Tx capacity level on the probability of supply chart.

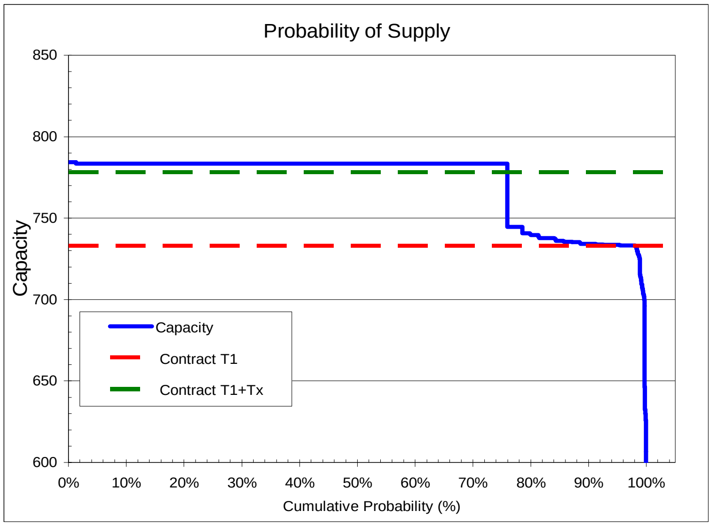


Figure 6 - Typical Probability of Supply

Unit Outage Capacity Chart

Unit outage capacity shows the impact of one single unit outage on the pipeline capacity.

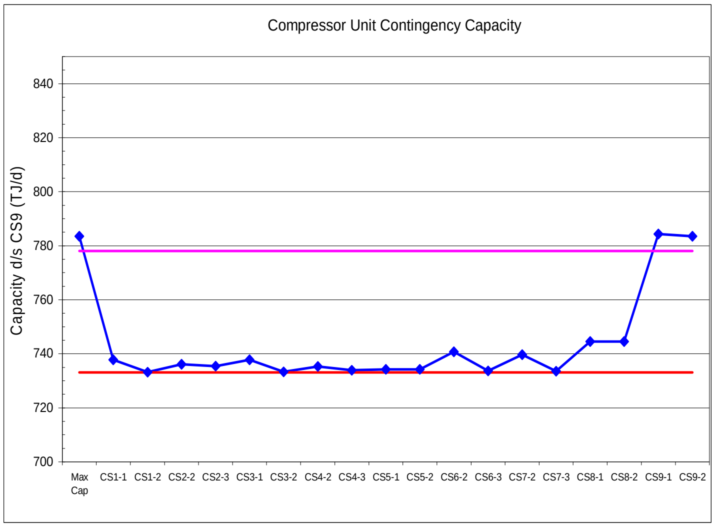


Figure 7 - Typical Unit Outage Capacity Chart

Fuel Consumption Curve

Fuel consumption can be plotted against pipeline capacity.

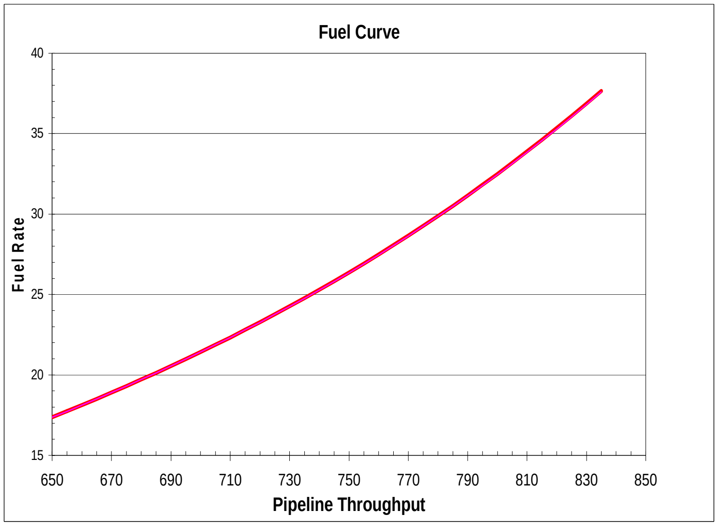


Figure 8 - Typical Fuel versus Capacity Curve

Wheelmap and Compressor Operation

Compressor Operating Points can also be plotted on a chart to determine compressor performance.

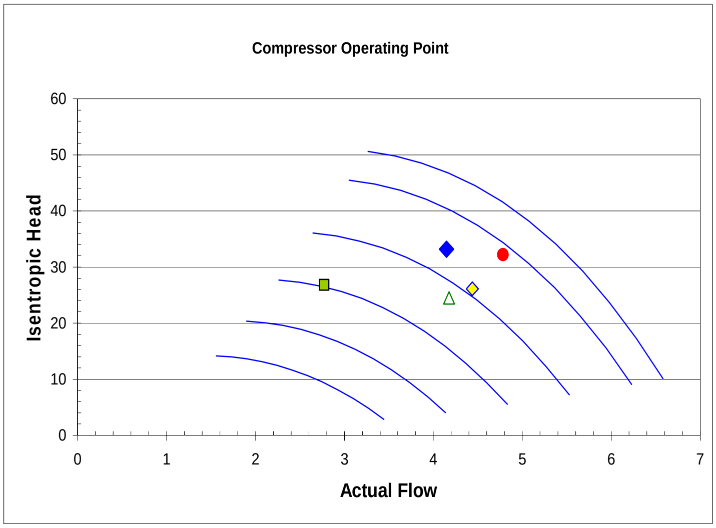


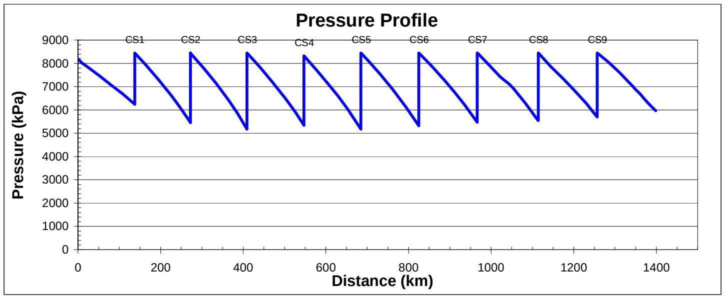
Figure 9 - Typical Compressor Operating Points

Operational Modelling

The same modelling tool can be used for operational purposes. For instance, impact of compressor outages can be evaluated by a "non pipeline modeller" such as the Control Room Operator.

Figure 10 shows pressure profile with all units online, but in Figure 11 compressor stations at CS2 and CS5 can be easily "switched off" to evaluate the impact of taking these two stations offline.

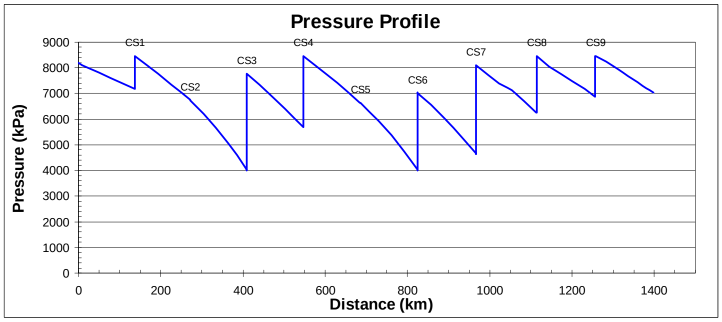
DBNGP Pipeline Capacity - All Units Operating



CS1		CS2		CS3		CS4		CS5		CS6		CS7		CS8		CS9	
Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2
☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On

Figure 10 - Case with All Units Online

DBNGP Pipeline Capacity - With CS2 & CS5 Off



CS1		CS2		CS3		CS4		CS5		CS6		CS7		CS8		CS9	
Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2
☑On	☑On	☐Off	☐Off	☑On	☑On	☑On	☑On	☐Off	☐Off	☑On	☑On	☑On	☑On	☑On	☑On	☑On	☑On

Figure 11 - Case with CS2 & CS5 Offline

Transient Modelling

Another important aspect of this model is its ability to model both steady state and transient conditions using the same pipeline model. The only requirement is to input the time dependent parameters such as flow, pressure or temperature into the model.

Figure 12 shows the extract of transient modelling with the time dependent variables entered into the model. In this example, one of the outlet flow profile varies with time and the unit at CS9 is to be shutdown at 0800 hours. This type of model can be used to simulate the impact of a compressor unit outage on pipeline delivery.

Time In Hour	Outlet Flow	CS9 Unit
1	691	on
2	688	on
3	687	on
4	688	on
5	696	on
6	716	on
7	751	on
8	785	off
9	805	off
10	813	off
11	814	off
12	805	off
13	800	off
14	804	off
15	810	off
16	816	off
17	822	off
18	823	off
19	818	off
20	812	off
21	800	off
22	783	off
23	734	off
24	703	off

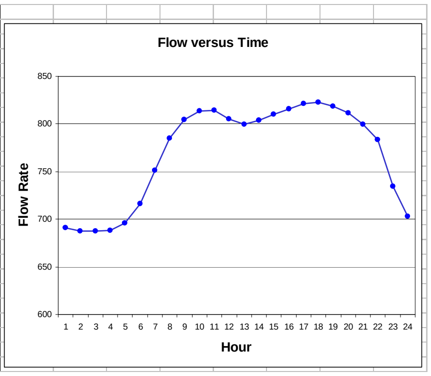


Figure 12 - Typical Transient Model

CONCLUSIONS

It is challenging to model the DBNGP pipeline:

- Capacity Services are contracted by levels of firmness and probability of supply. This requires an unconventional approach to pipeline modelling
- The model must be designed to handle all possible combinations of pipeline configurations
- Performing this time consuming process must be carried out in an effective and efficient manner
- The lack of commercially available flow modelling software capable of performing simulation to this large scale

The DBNGP model has now been developed into an intelligent and robust flow modelling tool for:

- Rigorous steady state and transient modelling within spreadsheet platform
- A systematic method of deducing the capability of the pipeline to meet current demands and the need for future expansions
- Advanced VBA macros for both error checking and data validation

In summary, a versatile pipeline modelling tool has been developed to meet the challenging requirement of defining the DBNGP's "probabilistic" capacity services. The same model can be used for both steady state and transient simulations. In addition, day to day operational modelling, short term and long term capacity planning can all be accomplished with the same model.

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