ASSET MANAGEMENT AND AVAILABILITY MODELLING

Mark Chadderton and Khalee Field

Summary:

Santos, with the assistance of Shell Global Solutions, has undertaken an overhaul of its Reliability and Maintenance Management System for its Cooper Basin Assets to improve equipment performance and reduce costs. This initiative includes modelling equipment availability and capacity through the usage of Availability Assurance and Reliability Modelling software. A major challenge was convincing management of the merits of availability modelling. Upon receiving endorsement, availability and capacity modelling of the CO_2 Trains in the Moomba Gas Processing Facility has highlighted key train specific vulnerabilities within this system.

Subsequently, this has demonstrated past reliability projects may not have always addressed the true causes of downtime. Availability assurance has ensured a movement away from a subjective and reactive approach to reliability to one based on failure history and equipment criticality. Consequently, this paper outlines how availability assurance has been successfully used to move from a system of deferred production between upstream and downstream assets, to a holistic business approach whereby effective production (based on equipment capacity and availability) is the key parameter of success.

Keywords: Availability Modelling, Reliability, Gas Processing.

1 INTRODUCTION AND BACKGROUND

A gas processing facility consists of many complex subsystems. The function of each system is imperative to fulfil production obligations. This is further complicated when a system of deferred production split between upstream and downstream assets is used to measure the effectiveness of gas production. The effectiveness of the system's ability to produce gas can be measured by the availability, reliability and maintainability of equipment (Barabady & Kumar 2008). It is proposed that the availability of a system offers a superior measure of plant performance, as it incorporates reliability and maintainability through the capture of equipment downtime.

In 2006, Santos Ltd undertook a benchmarking exercise to allow comparison between the Moomba Gas Processing Facility (Moomba Plant) against other gas processing facilities. The results indicated that:

1. Annualised maintenance costs per equipment unit were considerably higher than other facilities.
2. Operational availability was low.

A Shell Merit Pathfinder study conducted in 2007 confirmed these results. Subsequently, a Reliability and Maintenance Management System (RAMMS) was initiated to move from a reactive domain to a planned and ultimately a proactive environment for Moomba plant and an upstream processing facility. The program included a number of modules within the planned domain including an improved planning and scheduling process, maintenance management and focused shutdown management for preventative maintenance. Similarly, a number of modules were located within the proactive domain. Defect Elimination Management and Reliability Centred Maintenance (RCM) programs were implemented in 2008-09 to minimize equipment downtime. Availability modelling was identified as an important tool to shift from a reactive paradigm by revealing specific areas within a subsystem, which would benefit from RCM or analysis of defects.

Santos came to recognize the benefits of a proactive approach to maintenance. The equipment within the sub-systems may have a large range of potential failure modes with varying corresponding equipment downtime and failure distributions (Marquez, Heguedas & Iung 2005). A major component of operating expenditure is due to unplanned system outages for unpredicted failures. A preventative maintenance program driven by equipment availability can effectively reduce system failures lowering maintenance expenditure (Barabady & Kumar 2008). Capital expenditure may also be prioritized according to the expected system availability increase. In the absence of an availability model, risks are often evaluated qualitatively using limited data and typically include a human element whereby observations and personal preferences enter decision making processes.

The availability modelling tool provided by SGS has been used in a number of international companies, including but not limited to Woodside, Abu Dhabi Company for Onshore Oil Operation and Shell. When used for optimizing Greenfield projects, the model (and generic reliability data) can reduce overall capital expenditure and improve operational availability by 0.5-1.0% (SGS 2009). However, this paper considers the application of an availability model for a Brownfields site.

2 DEFINITION OF AVAILABILITY

Availability is a widely used term; however, confusion may arise as the term has various ways of computation depending on the application of the measure. Availability may be defined as a “percentage measure of the degree to which machinery and equipment is in an operable and committable state at the point in time which it is needed” (Katukoori, p5). Therefore, availability can be used to measure the performance of a repairable system accounting for both planned and corrective (breakdown) maintenance activities.

The availability measure adopted in this study is that of operational availability. Operational availability is defined as the average availability over a period of time. The period of time considered in this analysis was four years, one full maintenance cycle. This is calculated as the ratio of system uptime (where the equipment is operable), total time, and is given in Equation 1.0. Total time is defined as the duration of the time period under consideration.

Equation 1.0

$$Availability = \frac{Uptime}{TotalTime}$$

3 CALCULATION OF EQUIPMENT AVAILABILITY

Operational availability is calculated from two equipment parameters:

1. Mean Time to Fail (MTTF)
2. Equipment Downtime

MTTF is defined as the mean time before an item fails (International Standard 2006, A.C.5.4), or the frequency of equipment failure. Equipment downtime includes all aspects contributing to downtime, not simply maintenance tool time. This includes, but is not limited to operational, maintenance, logistic and resource constraint delays.

4 AVAILABILITY MODELLING CALCULATIONS

Analysis of the availability model using the availability software is centred on two key calculations; available capacity and effective capacity.

Available capacity calculations calculate the capacity levels at which the system is operable, and the fraction of time the system will operate at this level. For a binary system, available capacity is synonymous to the availability of the system. Effective capacity is the average capacity available from the system under consideration. This is calculated from the summation of the product of the capacity level and the fraction of time at that level. Such computations allow a quantitative assessment of the production capacity of an asset, and thus the ability to fulfil market obligations.

5 CONCEPT AND APPROACH USED FOR AVAILABILITY ANALYSIS OF MOOMBA PLANT

The approach used to construct an availability model of Moomba plant is described in Table 1.

Table 1 – Steps used to construct an availability model of Moomba Plant.

Step	Description	Primary Information Source	Output Required for Availability Modelling
Process Stream Selection	Determination of process output stream that is used to calibrate equipment capacities.	N/A	Process stream and associated measurement units.
System Configuration	Defines the sub-systems within the Asset, and identifies the functional relationship between sub-system components.	Piping and Instrument Drawings Operations Personnel Process Engineering Review	Reliability Block Diagram establishing the mathematic relationship between system components.
Data Collection	Collection of all data sources to enable the calculation of key equipment parameters.	Computerised Maintenance Management System, Production Performance Databases, Operator Logs, Maintenance Logs, Equipment Run Time	Equipment maintainable components and their respective failure modes, failure frequency and downtime duration.
Equipment Capacity Identification	Standardises all equipment capacity values based on the process stream selected.	Tested equipment capacities.	Equipment capacity values.
Results Analysis	Analysis of simulation results based.	N/A	Interpretation of results and relation to simulation discussion.

5.1 Process Stream Selection

The first step of any availability study is the identification of the process stream for which the analysis is focused. In a facility with more than one process stream (for example, gas and condensate), separate availability studies must be conducted to identify the ability to fulfil production requirements.

5.2 System Configuration

It is necessary to identify all sub-systems within an asset, and the functional relationships between system components. This can be achieved through the construction of a Reliability Block Diagram (RBD). An RBD establishes the mathematical relationship between system components to allow computation of system availability. The structure of an RBD shows the logical connection of system components necessary for successful operation of the system (Standards Australia 2008, p IV). The logical relationship between system components can be series or parallel and is defined by the failure interaction. An RBD can also be constructed for different levels; system level, sub-system level or equipment level (Standards Australia 2008, p 3). Functional blocks corresponding to various subsystems can be joined to form one RBD (Marquez, Heguedas & Iung 2005).

To construct an RBD, a number of assumptions must be made. The probability of an equipment failure is independent of any other equipment failures. Further, the block diagram will not necessarily represent the physical connection between system components, as it models the functional series and parallel relationships.

5.3 Data Collection

For each system component (equipment) identified in the RBD, it is necessary to define dominant failure modes corresponding to a maintainable item, and the failure frequency and downtime of this failure mode. Analysis of equipment at component level is an integral part of an availability study as it allows the exposure of system weaknesses (Barabady & Kumar 2008). This leads to a targeted approach to reliability improvements.

Equipment failure data can be obtained from numerous sources:

1. Public databases such as the Offshore Reliability Data Handbook (OREDA)
2. Plant History

For existing mature plants, it is recommended to utilize historical plant data rather than generic data sources. Historical plant data can be found in Computerised Maintenance Management Systems (CMMS), Production Performance Databases and various other sources. Where such data is not readily available, it can be agreed and obtained from experienced operations personnel. Equipment maintenance data must also be defined, typically from a CMMS.

5.4 Equipment Capacity Identification

Equipment capacities can be obtained from two main sources:

1. Equipment Nameplate Capacities
2. Tested Equipment Capacities

Experienced process personnel must translate equipment capacities into the same units of the process stream selected. For example, the flow rate of a steam condensate pump used in the processing of gas must be translated from m^3/hr into units of gas production.

6 CASE STUDY – MOOMBA PLANT

6.1 Process Stream Selection

The Moomba Plant utilizes a combination of process to condition raw gas prior to liquids separation. Although condensate, natural gas liquids, ethane and methane are processed, the availability study is concerned with methane (measured in standard cubic metres per day).

6.2 System Configuration Description

The operation of Moomba plant can be split into five series functional groups:

1. Plant Inlet Separation
2. Carbon Dioxide (CO_2) Removal
3. Dew Point Control
4. Liquids Recovery
5. Utilities.

The availability case study presented is focused on two crucial conditioning processes, CO_2 removal, and Dew point control. Atypical operating configurations were not modelled as this was inconsistent with the intended use of the model as a risk management tool.

The purpose of the CO_2 Trains is to remove CO_2 and hydrogen sulphide (H_2S) from raw gas. This is achieved using a two-step Benfield Process. Firstly, in the absorber vessel, the high-pressure raw gas containing CO_2 and H_2S contacts a hot lean potassium carbonate (K_2CO_3) solution, whereby these impurities are absorbed. The solution containing CO_2 and H_2S is transferred to the regenerator through a let-down power recovery turbine, which operates at near atmospheric pressure. The solution is regenerated (CO_2 and H_2S are removed) through pressure reduction and heat stripping with steam. The regenerated solution is pump to the absorber by a multi-stage steam driven centrifugal pump and the CO_2 and H_2S are vented to atmosphere. There are five CO_2 Trains (Trains 3-7) in Moomba plant. Trains 3 and 4 share a common spare pumpset consisting of a booster pump, centrifugal pump, steam turbine and power recovery turbine. Similarly, Trains 5 and 6 have a common spare pumpset. The process configuration of each train is near identical. The grouping used for the availability analysis is given in Table 2.

Sweet gas from the CO_2 Trains is saturated with water, which is removed in the Dew Point Control Units (DPCUs) prior to cryogenic cooling for liquids removal. A DPCU comprises three towers, a Controlled Heat Flux (CHF) Heater and a Regeneration Gas Circuit (RGC). The DPCUs are paired such that six towers are operational, with one standby RGC and CHF Heater (only one RGC / CHF Heater is required to regenerate the towers used for adsorbing the moisture laden sweet gas). This is illustrated in Figure 1. There are four DPCUs (DPCU 6-9).

The RBDs were validated by a cross functional team in a workshop environment.

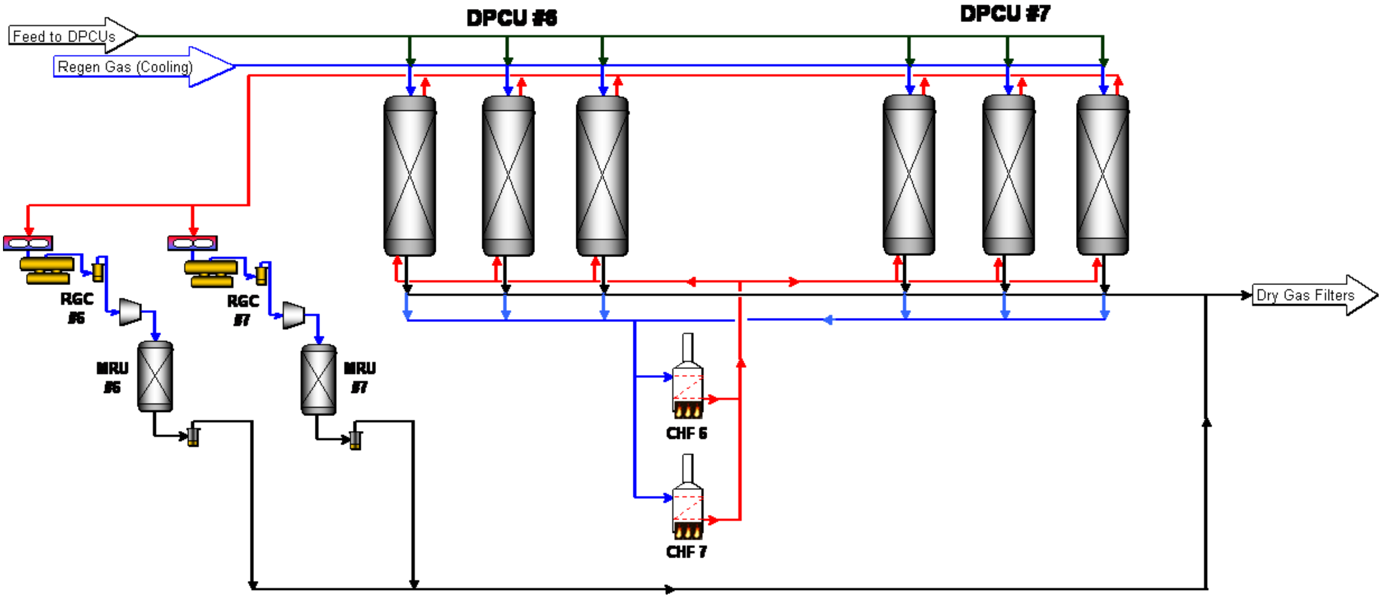

Figure 1 – Configuration of Dew Point Control Units in a Paired Arrangement.

Table 2 - Equipment components for sub-systems in Moomba Plant.

Sub-System	Group	Components (Equipment)
CO_2 Train 3	Regeneration Circuit	Regenerator Vessel Steam Condensate Pumps Reboilers Catchpot Vessel
	Pumpsets 3	Steam Turbine 3 Solution Pump 3 Power Recovery Turbine 3 Booster Pump 3 Pumpset Lubrication System 3 Pumpset Seal Water System 3 Steam Turbine 3/4 Solution Pump 3/4 Power Recovery Turbine 3/4 Booster Pump 3/4 Pumpset Lubrication System 3/4 Pumpset Seal Water System 3/4
	Gas Circuit	Heat Exchanger Absorber Vessel Gas Circuit Valves
	Planned Maintenance	Planned Shutdowns T3
DPCU 6	DPCU Towers	6 Centre Vessel 6 North Vessel 6 South Vessel
	Regeneration Gas Circuit	Regeneration Gas Cooler 6 Regeneration Gas Separator 6 Regeneration Gas Compressor 6 Compressor Lube Oil System 6 Regeneration Gas Motor 6 Mercury Recovery Unit 6 Controlled Heat Flux (CHF) Heater 6
	Planned Maintenance	Shutdown 6

6.3 Data Collection

A number of data sources were used to calculate MTTF and equipment downtime values for equipment failure modes. ISO 14224 failure mode classifications were used to ensure consistency with other Santos RAMMS programs. Initially, equipment trends were obtained from process data to determine equipment downtime. This was then classified using sources such as the CMMS (Maximo), Maintenance Logs and Process Logs in a time and labour intensive process. Due to the vast number of RBD components, a Pareto analysis was conducted to determine the greatest equipment contributors to train unavailability. The failure modes, failure frequency and downtime for this equipment are presented in Table 3 for CO_2 Trains.

Planned maintenance was not captured at an equipment level as a CO_2 Train is shutdown annually for maintenance on all equipment within the subsystem. Failure analysis proved that for a singular piece of equipment, the dominant failure mode MTTF and equipment downtime values varied greatly dependent on failure mode. This is consistent with Barabady & Kumar (2008) who outlined the important of component analysis as an integral part of availability analysis.

The initial outcome of the case study was to evaluate past reliability improvement projects and as such, a reliability analysis of the data has not yet been undertaken. However, the failure data was validated by a multi-discipline team. The large downtime associated with pumpset failures is due to the outsourcing of repair work to an external company geographically removed from Moomba Plant.

Table 3 - MTTF and Equipment Downtime values for CO_2 Trains.

Group	Equipment	Maintainable Component	Failure Mode	MTTF (years)	Equipment Downtime (hours)
Planned Maintenance	**Planned Shutdowns T3**	Annual Shutdown	N/A	3.17	263
		Major Shutdown	N/A	3.04	1370
	Planned Shutdowns T4	Annual Shutdown	N/A	1.02	429
	Planned Shutdowns T7	Annual Shutdown	N/A	1.57	261
		Major Shutdown	N/A	3.00	1850
Regeneration Circuit	**Regenerator Vessel T5**	Shell	External Leakage Process Medium	0.77	159
		Internals	Breakdown	2.17	1714
	Regenerator Vessel T7	Internals	Breakdown	3.06	1178
Gas Circuit	**Absorber Vessel T6**	Shell	Structural Deficiency	2.50	1676
Pumpsets 4	**Main Solution Pump 4**	Casing	External Leakage Process Medium	3.20	7
		Seal	External Leakage Process Medium	0.52	98
	PRT 4	Shaft	Breakdown	2.84	3094
		Seal	External Leakage Utility Medium	3.20	18
	Main Solution Pump 3/4	Overhaul	Breakdown	3.00	8760
		Seal	External Leakage Process Medium	3.18	125
Pumpsets T5	**Main Solution Pump 5**	Seal	External Leakage Process Medium	0.59	48
		Bearing	Vibration	1.02	1417
		Bearing	Overheating	2.45	127
		Impellor	Breakdown	2.06	2714
	Power Recovery Turbine 5	Bearing	Overheating	2.35	127
		Seal	External Leakage Process Medium	0.71	694
	Power Recovery Turbine 5/6	Seal	External Leakage Process Medium	2.69	12
		Shaft	Breakdown	1.08	926
	Power Recovery Turbine 6	Seal	External Leakage Process Medium	1.32	239
		Seal	External Leakage Utility Medium	2.68	102

6.4 Equipment Capacities

The limiting equipment capacity within each CO_2 Train (the Absorber Vessel) was obtained through operational testing and is presented in Table 4. Preliminarily analysis of the DPCUs did not require equipment capacities.

7 RESULTS AND ANALYSIS

7.1 CO_2 Trains

Initial analysis across each of the CO_2 trains showed vastly different availabilities and effective capacities. The difference in effective capacity cannot be attributed only to train capacity variances as evidenced by Train 5 and 6 in Table 4. Further analysis of the system indicated that the probability of achieving the total capacity of the system, 15.9Mscm/day was 53%.

Table 4 – Capacity, Availability and Effective Capacity for each CO2 Train.

Train	Train Capacity (Mscm/day)	Availability (%)	Effective Capacity (Mscm/day)
3	2.3	92.2	2.12
4	2.4	91.1	2.19
5	3.4	80.8	2.75
6	3.4	90.4	3.07
7	4.4	86.3	3.8

Consequently, the groups were analysed to determine the largest contributors to unavailability. The unavailable capacity of each group was calculated using the modelling software. A Pareto analysis was conducted to determine the percentage contribution to Unavailable Capacity for each group. A limitation of this method of analysis was identified as it assumes all equipment failures occur at different times. The error associated with this however was found to be negligible for trains with high availability (error in the order of 0.0001% magnitude) and was only small for Train 5 (the most unavailable train). However, at this early stage of analysis, the parameter is only used to standardise data across the trains (and not to evaluate effective capacity), it has a limited effect on the accuracy of analysis. The results of this analysis are given in Table 5.

Table 5 – Pareto analysis of contributors to CO_2 Train Unavailable Capacity.

Equipment / Group	Availability (%)	Unavailable Capacity	Percentage Contribution to Total Unavailable Capacity
Planned Shutdowns T7	91.7%	0.366	17.7%
Regenerator Vessel T5	89.6%	0.353	17.1%
Absorber Vessel T6	92.9%	0.242	11.7%
Regenerator Vessel T7	95.8%	0.185	9.0%
Pumpsets T5	95.4%	0.155	7.5%
Planned Shutdowns T3	94.2%	0.133	6.4%
Planned Shutdowns T4	95.4%	0.110	5.3%
Pumpsets T4	96.4%	0.086	4.2%

The results show past reliability improvement projects, which assumed identical failure behaviour of equipment across the trains, may have potentially focused on equipment that may not have contributed to system downtime. Further, Table 5 has highlighted key train specific vulnerabilities within the system. Surprisingly, planned maintenance on train 7 has the largest contribution to unavailable capacity. Planned maintenance for each train is expected to be similar in duration, and thus the large difference in unavailability of a particular train due to planned shutdowns is surprising. Consequently, a reliability improvement initiative has commenced to review shutdown management, and optimise outage durations. The root causes of vessel unavailability have been investigated, however a cross functional team will assess the quality and action completion resulting from past investigations. Prior to this study, only pumpsets and level control valves were previously identified as contributing to the unavailable capacity of the system. Further, reliability improvement projects were not previously targeted towards specific equipment and maintainable component failure modes. This analysis has shown the importance of identifying the root cause of defects to ensure the implementation of effective solutions thus reducing equipment downtime.

7.2 Dew Point Control Units

The DPCU case study was used to determine the risk profile associated with a number of previous operational decisions. Furthermore, the availability model has been used to present a risk profile of the current operating configuration and subsequently to justify or defer capital projects and operating expenditure decisions.

The availability of the Regeneration Gas Circuits (RGC) is given in Table 6. RGC 9 was unavailable for approximately two years due to serious internal corrosion of Cooler 9. This contributed to the low availability of 35%. However, the maintenance philosophy was not adapted to reflect this change in operating conditions. Subsequently, a gear-box failure on regeneration gas cooler 8 occurred, resulting in the shutdown of DPCUs 8 & 9 and a restriction to plant throughput. Although this analysis cannot mitigate this production loss, it provides a valuable lesson learnt regarding the operating and maintenance philosophy surrounding redundant equipment. Past approaches have typically scaled back the maintenance on equipment which has redundancy with little consideration given to the availability of the redundant equipment. Availability modelling has caused a shift from this view, to one where the functionality and availability of a system is considered when making significant operating decisions.

During validation of this data, the MTTF of Cooler 9 and Separator 6 have been modified to more accurately represent future plant performance. Subsequently, the availabilities of RGC 6 and 9 have increased significantly. This has allowed the prioritisation of resources and capital expenditure to be shifted from the DPCUs to less reliable systems such as the CO_2 Trains.

Table 6 – Availability of Regeneration Gas Circuits utilising historical and validated data.

Group	Availability (Historical Data)	Availability (Validated Data)
Regeneration Gas Circuit 6	40%	94%
Regeneration Gas Circuit 7	93%	93%
Regeneration Gas Circuit 8	98%	98%
Regeneration Gas Circuit 9	35%	97%
Regen Gas Circuit 6 & 7	96%	99.6%
Regen Gas Circuit 8 & 9	99%	99.9%

The availability model has also been used to create a risk profile used to optimize yearly capital expenditure. Using the model, a number of scenarios can be analysed to determine the necessity of completing an action during the current year, or to defer spending and thus maximise other opportunities. Consequently, RGC 7 and 8 were removed from service. However, the circuits are available for temporary usage. Table 6 illustrates that based on the availability of RGC 6 and 9, there is sufficient availability and functionality to defer maintenance activities until 2011.

8 FORWARD STRATEGY FOR AVAILABILITY MODELLING AT SANTOS

The analysis above demonstrates that there are numerous benefits from availability modelling. It is envisaged that the model will be used for daily prioritisation of corrective work requests. This will involve the assessment of equipment failure modes and the impact of equipment failure on plant effective capacity. High priority work orders will have a high likelihood of reducing plant availability if not completed. These outputs can also be compared with the current work plans to assess whether break-in work is required. Otherwise, work can be scheduled based on priority relative to other maintenance activities. This may help to minimise reactive work, and provide a quantitative measure of the Asset's risk level if the corrective maintenance is not completed. Subsequently, the availability model may be used to identify and rank equipment vulnerabilities captured in the Risk and Vulnerabilities Register. Therefore, the model can be integrated into the daily working of Reliability engineers, the Asset Management team and the planning team in Moomba Plant.

When selling a product into a market place it is critical to know the risks and costs associated with not supplying. Availability modelling can be used to identify critical elements of the production supply chain. Based on the probability of equipment failure, it is possible to quantify the probability that the Asset will satisfy production demands using a Monte Carlo Simulation. If plant vulnerabilities are identified, mitigation measures can be implemented.

Reliability improvement projects can be prioritised based on their expected impact on plant effective capacity. Therefore, project costs can be compared with the cost benefit associated with an improved plant effective capacity to justify capital expenditure. Availability modelling can also evaluate whether there is sufficient equipment redundancy, and the necessity of critical spares. Retrospective use of the model will determine if projects delivered their expected benefits through the elimination of failure modes, an increased MTTF or decreased equipment downtime.

Availability modelling allows the evaluation of current operating philosophies. One future scenario for Moomba Plant could be a steady decline in gas processing and market demand. Therefore, further rationalisation of redundant equipment may be undertaken. The model can be used to ensure this does not have a negative impact on the Asset's effective capacity, and that the maintenance strategies for remaining equipment are adequate prior to mothballing (or abandoning) any equipment. If availability modelling demonstrates a sufficient Asset effective capacity with equipment removed, then the rationalization should proceed. This will reduce overall operating costs, and improve site profitability.

9 CONCLUSIONS

Availability modelling of Moomba Plant has started to demonstrate clear benefits for Santos. The modelling process has allowed the quantification of risks to the effectiveness of gas production and better quantification of past project benefits.

Availability modelling can assist both short term and long term planning processes, and will enable the business to improve prioritisation of corrective maintenance activities. It can also optimise shut-down planning and may be used to evaluate the risk of extended shutdown durations.

The modelling process has highlighted a number of opportunities to improve equipment event capture (to clearly identify the causes of system downtime). This has slowed the development of the model as the quality of event data was difficult to obtain, and sometimes incomplete.

The benefits derived so far have demonstrated that availability modelling has widespread application, and as such is now being used to model other assets. Availability modelling is improving communication across engineering disciplines, improving the corporate understanding of the impact of availability on the effectiveness of gas production. The business is now focused on availability over reliability as a true measure of plant performance.

10 REFERENCES

Barabady, J & Kumar, U 2008, 'Reliability analysis of mining equipment: A case study of a crushing plant at Jajarm Bauxite Mine in Iran', *Reliability Engineering and System Safety*, vol. 93, pp. 647-653.

Dekker, R 1996, 'Applications of maintenance optimization models: A review and analysis', *Reliability Engineering and System Safety*, vol. 51, no. 3, pp. 229-240.

International Standard 2006, *Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment* (ISO 14224), ISO, Switzerland.

Katukoori, V.K *Standardising Availability Definition*, University of New Orleans, viewed 2 January 2010, <http://www.comp.lancs.ac.uk/~dobsong/teaching/dependability/>

Marquez, AC, Heguedas, AS & Iung, B 2005, 'Monte Carlo-based assessment of system availability. A case study for cogeneration plants', *Reliability Engineering and System Safety*, vol. 88, pp. 273-289.

Standards Australia 2008, *Analysis techniques for system reliability – Reliability block diagram and Boolean methods* (AS IEC 61078-2008), Standards Australia, Sydney.