“Hydro Maintenance Re-engineering within the Snowy Mountains Scheme”

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The Snowy Mountains Hydro-electric Authority has recently undertaken a program of analysing the routine maintenance completed on its main generation and hydraulic assets. Power industry deregulation and increasing competition have created the need to reduce costs while increasing productivity. Along with downsizing and organisational restructuring, considerable effort has been placed on improving processes and work methods. It is in this context that the objective to *“better align maintenance policies and plans with the operating context (market driven), eliminating non value adding maintenance and implementing the best maintenance practices and techniques”* was established as a strategic business issue.

To date, the routine maintenance plans for the major assets of six power stations, a pumping station, the tunnels and dam spillway gates have been re-engineered. This has enabled the development of maintenance programs that are “market driven” and aligned to the Authority’s business goals. It is providing a competitive edge by enabling the development of routine maintenance plans that are directly linked to the Authority’s asset performance requirements. In addition, the achievement of significant maintenance cost reductions and improved generating plant availability will enhance the ability of the business to create long-term shareholder value. The program also enables the owners of the Scheme to have greater confidence in the way the assets are being managed in that the decision-making processes are articulated and auditable.

This paper discusses the asset management and maintenance drives imposed upon the Authority by the changing business environment, the re-engineering methodology, its implementation and the benefits achieved within the Snowy Mountains Hydro-electric Scheme.

Introduction

Within the power generation industry deregulation and increasing competition have created the need to reduce costs while increasing productivity. In Australia deregulation of the power industry is occurring in line with the Council of Australian Government's micro-economic reform agenda. This includes both the establishment of the National Electricity Market (NEM) with the associated competitive business environment, and the segregation of power generation, transmission and distribution businesses. Within this environment the Snowy Mountains Hydro-electric Authority (SMHEA) manages the Snowy Mountains Scheme, one of the largest and most complex dual-purpose hydroelectric and irrigation systems in the world. The Scheme is located in the alpine region of Australia's Great Dividing Range where the Scheme's facilities are dispersed over an area of 3,200 square kilometres. The Scheme comprises of seven power stations (total generating capacity of 3,756 MW), a pumping station, 16 major dams, 225 kilometres of interconnected tunnels/aqueducts and 220 kilometres of 330 kV transmission lines.

The Scheme provides four major products:

❒ Regulated water, including flood mitigation, salinity control and flow augmentation during drought periods, primarily for the benefit of irrigators in the Murray and Murrumbidgee irrigation areas of New South Wales, Victoria and South Australia. The provision of this regulated water was the prime reason of the construction of the Scheme as it assists in underwriting the production of $8.5 billion of irrigated agricultural products from the Murray-Darling river system each year. The generation of electricity was seen as a by-product, which would help defray operational costs. Water management is the primary long term (>1 year) and medium term (>1 month) driver of electricity generation. The limited quantity of water available from Snowy catchments places a cap on the energy capable of being delivered by the Scheme over the long term. There is no revenue benefit to the Authority for the provision of its regulated water product.

❒ Electrical energy, supplied to the South Eastern Australian grid for use by electricity consumers in New South Wales, Victoria and South Australia. The Scheme delivers on average around 5,500 GWHrs of renewable energy per year. This amounts to 5% of total energy generated in the South Eastern Australian Grid. The sale of electrical energy provides the vast majority of revenues for the Snowy Hydro Trading Company, and is now the strongest driver on operations and asset management.

❒ Ancillary services, such as black start, synchronous condenser, frequency control, etc., supplied to the market operator (NEMMCO) for the purposes of grid security. The provision of ancillary services has traditionally been a major role of the Scheme. In fact, this was a particular role envisaged during the design of the Scheme and is one reason why the installed capacity of the Scheme far exceeds that required to move water through the Scheme. The Scheme has an average capacity factor of only 15% on an installed capacity of 3756MW (16% of total installed capacity of the South Eastern Australian Grid).

❒ Energy Risk Management, in the form of bilateral contracts with franchised electricity retailers, generating companies and electrical energy end-users. This is a purely financial product, with no physical delivery of electrical energy to the counter-party in the contract. Retailers and end-users utilise this product to reduce their exposure to spot market price volatility, and generators (usually large coal-fired stations) to reduce financial risks associated with unit failures.

Asset Management Drivers

The nature of the products produced by the Authority has generated the following set of asset management drivers, which directly affect the required levels, and types of maintenance.

- ❒ Availability, the objective being to maximise availability to maximise revenue-earning opportunities. This is especially the case for spot market trading, where the opportunities to earn large sums of money during high price periods usually occur without any notice and pass by quickly. Plant availability also underpins the delivery of regulated water ancillary services and our ability to provide energy risk management contracts.

- ❒ Reliability, the objective being to attain a consistent and high level of reliability so that risks to revenues and costs are minimised. Plant reliability also underpins the delivery of regulated water and ancillary services and our ability to meet energy risk management contract requirements.

- ❒ Costs, the objective being to reduce costs to the minimum, with the proviso that cost reductions do not result in even greater decreases in revenue or increases in life cycle costs. That is, cost reductions are made today with full consideration of the longer term cost and revenue impacts, recognising the long time lags between the implementation of asset management decisions and their final outcomes in terms of plant performance and condition.

- ❒ Capability Management, with the objective of sticking to outage plans to minimise risks to trading strategies (which assume a particular plant availability).

- ❒ Environmental protection, with the objective of protecting the Snowy's clean and renewable image, achieving legal compliance, and meeting stakeholder expectations.

- ❒ Flexibility, with the objective of responding to market driven changes to outage (including maintenance) plans.

These drivers have resulted in considerable change within the SMHEA over the last five years. Along with downsizing and organisational restructuring, considerable effort has been placed on improving processes and work methods. It is in this context that the objective to *"better align maintenance policies and plans with the operating context (market driven), eliminating non value adding maintenance and implementing the best maintenance practices and techniques"* was established as a strategic business issue.

This objective dictated that the maintenance program be "market driven" and not just aligned with the current operating context. Therefore the analysis would need to identify parameters which would indicate when the newly developed maintenance programs were "non optimal" to the extent that re-development of the maintenance procedures should be again considered. Minor changes would occur as part of the continuous improvement methodology already integral to SMHEA process.

Maintenance Re-engineering using RCM

"….. to better align maintenance policies and plans with the operating context (market driven), eliminating non value adding maintenance and implementing the best maintenance practices and techniques".

In the analysis of techniques to achieve this objective, the Reliability-Centred Maintenance (RCM) methodology, in conjunction with risk versus cost modelling, was identified as providing a level of maintenance optimisation previously not considered achievable. A number of systems for applying the RCM methodology were considered, however one system stood out in that it included a maintenance frequency optimisation module. By integrating the statistical RCM data with costing information about failure repairs, preventative/corrective maintenance actions, consequential repairs, and opportunity costs, an *estimation* of the optimum routine maintenance frequency could be determined.

The product selected was an "expert system" software package called Maintenance Plan Development System (now RCM *Turbo*). This system was developed by a leading Australia company BHP, and is marketed by Strategic Corporate Assessment Systems Pty Ltd. MPDS was chosen as it is a decision support software program that:

- Provides the capability to link RCM to risk/cost optimisation.
- Is built upon proven and commercially available database software.
- Simplified the documentation process by enabling the data to be linked to the maintenance management hierarchy.
- Is cost effective to use due to its inherent labour saving features.

The software included three major functions:

(1) Documentation and prioritisation of the equipment that is to be analysed.

(2) Facilitation/documentation of the function, failure, effects and task identification process, commonly known as the seven RCM questions.

Functional standards	"What is the function of the equipment in its operating context?"
Functional failures	"How can an item fail to fulfil its function?"
Failure Modes	"What causes each functional failure?"
Failure Effects	"What happens when each failure occurs?"
Failure Consequences	"In which way does each failure matter?"
Preventive tasks	"What can be done to prevent each failure?"

Default tasks	"What should be done if a suitable preventive task cannot be found?"

(3) Guidance as to the optimum primary maintenance action frequencies and their groupings using a risk/cost module. This module uses a combination of statistical RCM data and costing information generated from:

- Preventative/corrective maintenance actions[1]
- Failure repair and consequential costs[1]
- Opportunity costs[1]

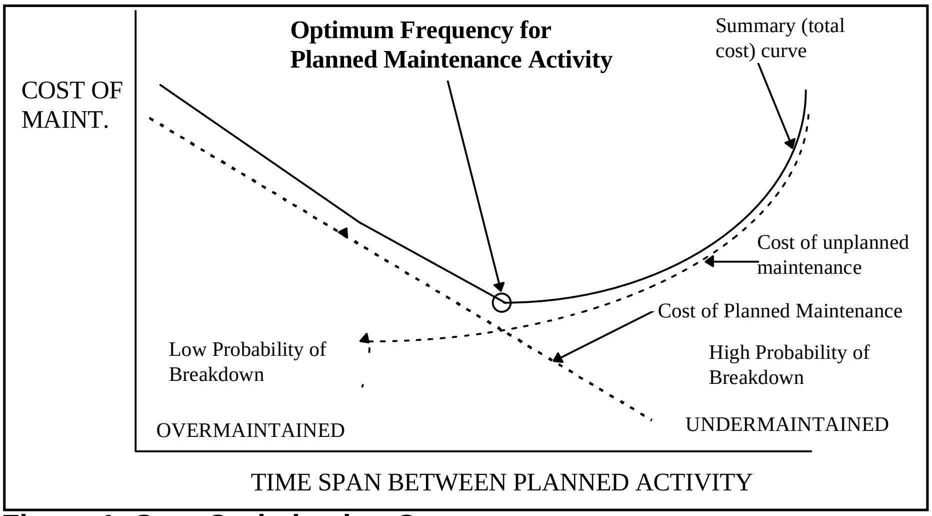

Figure 1. Cost Optimisation Curve

The above graph shows the general principle of the frequency optimisation module within MPDS. The basic assumption of the model is that as the frequencies of preventative maintenance activities are increased, the likelihood of failure diminishes. The optimum level of maintenance being that point above which the incremental cost of increased maintenance is no longer offset by the reduced risk costs associated with plant failure and equipment down-time. The actual relationship between the variables, and the subsequent optimisation curve being dependent on the costing and statistical data entered for each failure mode.

Modelling the failure modes in this manner enables the relationship between planned maintenance and production objectives to be defined. For the Scheme's requirements, the aim was to determine the required level and frequency of maintenance that provides the optimum balance of maintenance costs verses breakdowns, whilst sustaining an economic level of plant reliability and availability.

The software package did however have several limitations and shortfalls, these included:

- Insufficient ability to record assumptions and background information
- Only very limited assistance was provided for determining the optimum groupings of maintenance tasks. Since maintenance tasks, which require equipment outages, must be

1 Includes costs associated with labour, materials and production loss due to down time.

- grouped into blocks of maintenance (otherwise the equipment availability would be unacceptably low) there are potentially a large number of options, which must be considered if the overall maintenance plan is to be optimised.
- No assistance in estimating the level of plant reliability as a result of the selected maintenance plan.

To address these issues the SMHEA developed an add-on package called "SMA Tools" which linked to the MPDS database. In addition to creating additional data fields, the package included analysis algorithms designed to assist in grouping maintenance tasks and allowed whole maintenance program scenarios to be developed, compared and optimised. It also created the ability to cost effectively analyse the sensitivity to key input parameters. This enabled the allowable limits of these parameters to be determined, after which changes to the maintenance program would be required. These parameters (eg planned versus forced outage opportunity cost ratio) can be easily monitored and the validity of the maintenance program confirmed.

Subsequent to the development of this program the SMHEA worked with the software developer to incorporate the majority these features in the latest release of MPDS (now called RCM Turbo).

Implementation Process

Each re-engineering project was conducted according to the following process:

1. Complete an assessment including an economic evaluation to create a datum reference.

   Economic benefits were estimated based on the results of the pilot program, with the proviso that the RCM methodology is about determining the appropriate maintenance program and that it may suggest more maintenance is required. However, uncertainty as to the level of economic return (resulting from direct cost savings) was not considered as a high risk since the "qualitative" benefits of the program were sufficient to justify the re-engineering program.

2. Introduce participating staff to the principles of RCM and train them in the process to be used.

   The training was limited to a 2 to 4 hour training program covering the basic RCM theory and the overall re-engineering program. Further detailed on the RCM methodology and software package was provided during the analysis.

3. Complete the Failure Mode, Effects and Criticality Analysis (FMECA) of the main assets.

   Each item of plant in the analysis area was identified (using the maintenance management system hierarchy), loaded into the MPDS database and prioritised. For all items of plant analysed, a set of potential failure modes, primary (routine) and secondary (corrective) maintenance actions were identified. Each failure mode was then analysed and the optimum frequency of the preventative (routine) maintenance actions calculated.

   The key factor to the success of this analysis, was the participation of staff who had considerable knowledge of the:
   - plant condition, operation and function.
   - potential failure mechanisms.
   - failure effects, consequences and the impact upon production capability.

- mean time between and the mean time to repair failures.
- preventative maintenance actions.
- estimated resources required and the costs incurred to complete the preventative maintenance and repair.

4. Optimize the routine maintenance activities and conduct scenario modeling to determine the most economic plan.

On completion of the failure mode analysis, a report of all the primary maintenance actions for each (maintainable) item of plant was generated. Each primary action was categorised by the isolation requirements i.e. those maintenance actions requiring the unit to be out of service and isolated (**Out-of-Service Maintenance**) and those that can be completed while the plan is running (**In-Service Maintenance**) and by the optimal frequency for conducting the primary action.

To determine the groupings, an analysis on the frequency of maintenance actions was conducted. By graphing the parameters of primary maintenance action duration, resources hours and quantity versus frequency natural groupings of primary maintenance actions were determined. Based on this technique, a range of scenarios for timing of the Out-of Service (or “class”) maintenance outages were created and analysed. These were analysed for their projected cost, resource requirements and the expected plant reliability and availability. Using these criteria the most appropriate scenario determined (usually a combination of low resource requirements and low cost could be achieved while maintaining the required projected level of reliability). This plan was combined with the plan for the in-service maintenance actions to create the overall routine maintenance plan for the major assets within the power station.

5. Conduct a sensitivity analysis to test the robustness of the plan.

The three different scenarios considered were:

- A variation in production opportunity costs
- Changes to the ratio between production opportunity costs for planned and forced outages
- Changes in the Mean-Time-Between-Failure (MTBF) of key maintainable items

The first two scenarios reflected variations of opportunity cost in relation to long-term price fluctuations on the competitive wholesale electricity market. This test is particularly relevant as it is expected that the implementation of the national electricity market (NEM) will result in the price for peak load electricity falling until after the year 2000.

The parameter MTBF is the variable with the highest uncertainty. In determining the MTBF the assumption used was that, “no major maintenance was conducted prior to item failure”. The combination of long MTBF’s and the previous fixed time maintenance strategies resulted in little failure data being available. The MTBF values were therefore based upon industry data or by estimating based upon the plant condition reports and the knowledge of engineering, maintenance and operating personnel.

6. Develop the maintenance documentation to implement the plan.

This developed into a significant component of each re-engineering project due to the added requirement of restructuring the maintenance documentation and making significant changes to maintenance delivery processes. Recent organisational re-structuring and the desire to move towards a more team based maintenance approach, dictated the development of equipment based as opposed to skills based job procedures and documentation. In addition, it was identified that significant overhead savings could be achieved if the activities were grouped into larger “blocks” of work. These changes have resulted in a significant reduction in the number of job procedures (averaging more than 50% in areas analysed), with an associated increase in the content of the remaining procedures.

7. Evaluate the results and monitor the implementation of the re-engineered maintenance plan.

   Compare the new plant with the existing maintenance plan and monitor the implementation of each job procedure as it is used for the first time to determine if any changes are required. In particular to "sanity" check the content of each procedure and confirm that resource and time estimates were correct.

Implementation Program

The re-engineering program commenced in July 1995 with a pilot study at Murray 2 Power station. Since the successful completion of the study, the re-engineering program was extended to include Jindabyne Pumping Station, Murray 1, Tumut 1, Tumut 2, Tumut 3 and Blowering Power Stations and the Scheme's major water diversion tunnels.

The re-engineering program has been internally resourced and managed by a small engineering team. Whenever required, technical support has been drawn upon from other engineering, maintenance and operating teams within the SMHEA. The cost of re-engineering the routine maintenance plans for the main plant at each facility amounted to approximately 1500 man-hours. By comparative standards, this is a relatively low cost for completing an RCM analysis of this size and scope. Included in this cost is the arduous task of revising and creating the suite of maintenance documentation that is required to implement the outcomes of the analysis.

Outcomes

Power Generation Assets

The re-engineering program has resulted in a strategy where:

- There is a shift from a predominantly "Fixed Time Maintenance" strategy to one that relies on "Condition Based Maintenance" activities.
- The intervals between maintenance related generation outages have been extended and the cost of each outage reduced.
- Major overhauls can be programmed to occur between 12 to 20 years and are based on asset condition[2].
- Significant shift from "out of service" to "in service" maintenance activities.

2 The actual frequency of the major overhauls would be set based upon the condition of the critical components such as the stator winding, turbine runner and main inlet valve.

The quantitative benefits of the program is an estimated 30 % reduction in routine maintenance costs and a 25% reduction in maintenance that affects the generating capability for the assets analysed.

Water Diversion Assets

The key outcomes of the tunnel maintenance analysis have been the:

- Change from tunnel outages based on a fixed frequency civil inspection program, to programming outages based on the need to clean rock traps and to conduct corrective maintenance on the gate structures. The civil inspection is now to be inspected on an opportunity basis when the tunnel is drained for maintenance purposes.

- Identification of areas where equipment modifications would produce significant savings through reduced maintenance requirements.

While the changes have resulted in a less ordered maintenance program, the more flexible and tailored program will provide substantial savings through increased availability and reduced maintenance costs. The new program results in average tunnel availability increase of 28% and represent an increase in scheme wide tunnel availability of 0.3% from 99.1% to 99.4%. Over the next ten years this improvement will be partially offset by several additional outages required to allow repairs to inlet, outlet and control structures. This work is in addition to that previously programmed and would have resulted in lower tunnel availability had the improvements not be identified and implemented.

Qualitative Benefits

The qualitative benefits that have arisen as a result of the re-engineering program are listed below.

1. Development of the optimised routine maintenance program where the maintenance costs and business costs have been balanced in accordance with the requirements of the current operating context. The plans that have been developed also provide an indication of future resource requirements and plant performance.

2. Assurance that maintenance effort is directed where it is required, through the elimination of non-value adding maintenance. This enables maintenance staff to be better utilised on productive maintenance whilst achieving the required performance and long-term asset management objectives for the plant.

3. Increased ownership by maintenance personnel of both the equipment and the newly created maintenance programs.

4. Creation of an electronic model for each facility's routine maintenance plans, making any future refinement of the plan practical and cost effective.

5. Identification of areas where alternate maintenance techniques can be cost effectively implemented or where plant modifications are required.

6. Development of maintenance documentation that is consistent across the Scheme and is aligned to the current organisational structure, accountabilities and reporting processes.

7. Confidence that the appropriate maintenance actions have been included in the maintenance plan to mitigate equipment failures that may cause safety and environmental hazards.

8. Broadening of an understanding of the production processes and the process by which equipment may fail.

9. Capturing the knowledge of experienced staff through the creation of a reference library of plant failure modes that can be used for future reference.

10. Routine maintenance plans that assist and support the development of the Operator Technician role within the SMHEA.

Summary

Maintenance re-engineering provides a competitive edge in today's National Electricity Market by enabling the development of routine maintenance plans that are directly linked to the Authority's asset performance requirements. The re-engineering process introduced takes maintenance plan development a step beyond "just completing a reliability centred maintenance analysis" by including a risk versus cost model. This has enabled the development of maintenance programs that are "market driven" and aligned to the Authority's business goals.

The achievement of significant maintenance cost reductions and improved generating plant availability will enhance the ability of the business to create long-term shareholder value.

Other benefits include; cultural change, increased ownership of equipment and maintenance plans, increased equipment knowledge and improved maintenance documentation. The creation of an electronic "maintenance model" will both simplify and reduce the cost of future maintenance plan refinements.

It has been proven that using an expert system to facilitate the implementation RCM is not only practical but also very cost effective.

It is recognised that although the plans that have been developed from the outcomes of the analysis may not be precise, the plans were developed using sound engineering principles, a well structure process and the "best" knowledge at the time. Further to this, the data upon which the plans were based has been systematically documented, enabling the information to be easily scrutinised and to be relatively easily updated. Over a planned cycle and in conjunction with the on-going continuous improvement process, the precision of the plans can only be further enhanced.

Acknowledgments

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