Mining for a Reliable Budget

Zero Based Budgeting and Simulation Turn Around Iron Ore Operation

by Jason Ballantine & Michael Drew

The development of asset strategies and a zero based maintenance budget aligned to business goals is important for organizations seeking optimal asset management. The iron ore miner presented in this case study took over operations and maintenance of an existing crushing facility, which had very few historical records and challenged themselves to achieve reliability excellence. They identified that optimized maintenance strategies and a zero based budget aligned to business goals were required not only to achieve reliability excellence, but also to satisfy insurers and investors. The iron ore miner undertook this project using a methodology that combined traditional reliability analysis methods with Monte Carlo simulation for rapid and effective decision-making.

Background

In 2005, this Iron Ore miner took over the operations and maintenance of a 3 Million tons per annum iron ore crushing facility in Western Australia. During the change of ownership some shortcomings were identified in the maintenance and operational management practices.

The first of these was that no asset strategy existed that governed a planned, predetermined maintenance schedule. The existing contractor had only performed maintenance once the equipment had suffered problems. This type of approach is called "run to failure" maintenance and is reactive in nature because the maintenance activities occur in response to the need to restore equipment to operational service and reduce the amount of downtime. The owner had not considered the choices available to address the various failure modes, by eliminating potential failures, monitoring for warning signs of failure or preventing failure modes. In addition, only limited historical maintenance records were kept, of which none had been entered into a computer system.

All previous maintenance budgets had been set based on historical spending levels. The previous year's budget was adjusted by considering input from planners and technicians to determine any abnormalities in the previous year which could be removed and any major overhauls likely to appear in the coming year added. This process was repeated annually. The resulting budget prediction was difficult to challenge, could not be justified against business risk, did not provide a lifetime budget profile and so did not consider the impact of aging, nor did this process support continuous improvement.

Path to Excellence

The Zero Based Budget approach taken was to establish asset strategies based on the likelihood of failures that could occur over the stated lifetime. The chosen strategies and likelihood of failure were then simulated to predict the expected performance and maintenance costs of the equipment. By using a simulator to predict outcomes, different strategies were analyzed to consider the impact on the risk exposure to safety and environment. In this way, asset strategies were developed that gave the asset managers the information necessary to consider various alternatives, assess benefits of chosen tasks, and consider the impact of the chosen strategies on the business goals.

The study began by collecting as much site information that was available, including arrangement drawings, spares usage history and inspection check sheets. This information was used to develop a Reliability Centered Maintenance (RCM) model using a simulation software package, RCMCost™ developed and owned by Isograph.

A functional asset hierarchy was built based on area: system: subsystem: maintainable item: function drill-down. A function based asset hierarchy is essential for proactive asset management to ensure maintenance decisions and deployment through a Computerised Maintenance Management System (CMMS). As can be seen in Figure 1, the development of the hierarchy is the first step in the Failure Modes and Effects Analysis (FMEA) process.

The next step of the FMEA process is to consider functions, failures and failure modes. For each defined equipment function, the possible failures and likely failure modes were considered. The FMEA was completed with a crushing and grinding specialist who had worked as a supplier of crushing equipment for 20+ years previously. His input was necessary to provide the likely failures and failure modes based on his knowledge and experience, which helped overcome the lack of maintenance history. Also useful were the original equipment manufacture's (OEM) maintenance manuals. The inspection check sheets also provided an indication of possible failure modes. This first pass model was used at the mine for validation and further development through facilitation with the site team including engineering, trades and planners.

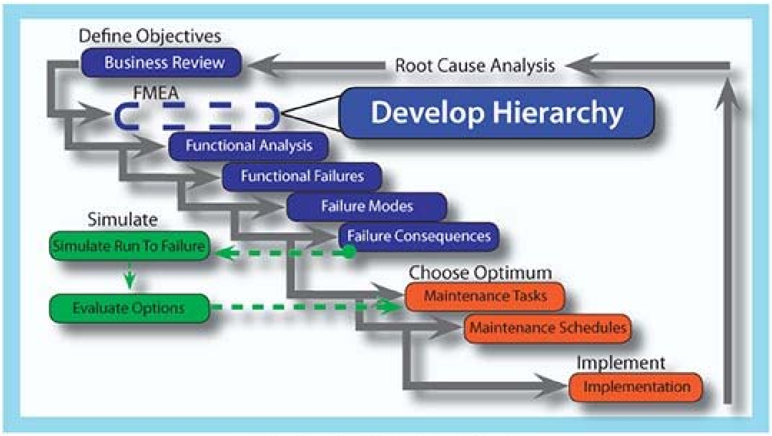


Figure 1 - RCM Simulation Process

Validation of the asset drilldown (shown in Figure 2) and FMEA by the onsite team ensures ownership by the team and a great starting point to add further information such as failure rates, effects and repair times. A side benefit is that on-site personnel, such as the reliability engineer, learns the FMEA technique on his own plant. The use of easy to use expert software provided the capability to fully document the site knowledge using a graphical interface. The addition of failure rate information allowed the plant to be simulated over a lifetime, and the impact of the maintenance tasks on the lifecycle costs and risk levels could be assessed. The simulations provide for rapid analysis, to determine those areas which had the most effect and so were more important to address than others.

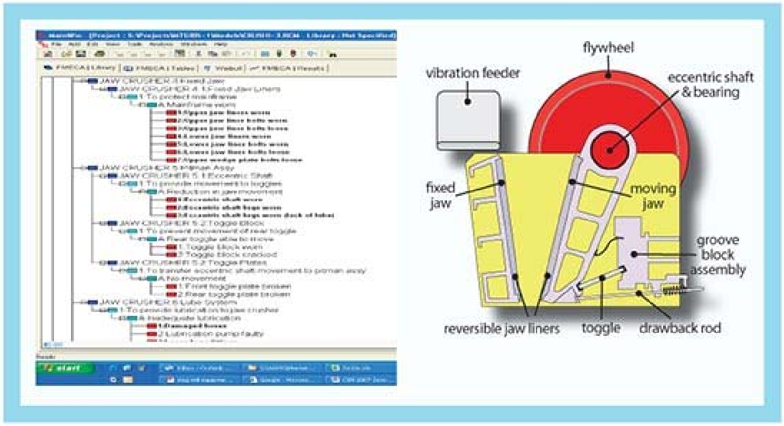


Figure 2 - FMEA Drilldown in RCMCost

Once the facilitation and model validation was complete the ARMS reliability engineer worked with the on-site reliability engineer and specialist to reality check and challenge the model results. This was carried out by first examining the Pareto charts that showed the most critical items. Lifetime costs are calculated during the simulation and include the cost impacts of failure, the labor and material cost of planned maintenance and the cost of unplanned maintenance. The chart shown in Figure 3 ranks the failure modes in order of total cost.

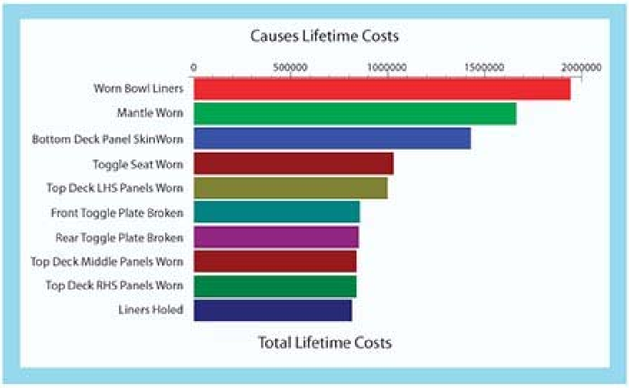


Figure 3 - Pareto chart showing failure modes in order of highest total cost.

Another method used to challenge and confirm the model predictions was to examine the historical maintenance costs and compare to the budget prediction of the current situation - i.e. before making any changes to the maintenance activities. The goal of this was not primarily to ensure the budget prediction matched the historical spend, but rather to clearly understand the reasons for any discrepancies in the results. The budget prediction in the simulator could be interrogated at many levels including system, sub-system, individual asset and individual failure mode level. This ability to challenge the budget predictions in such detail was something that was previously unattainable.

Optimization of maintenance plans was

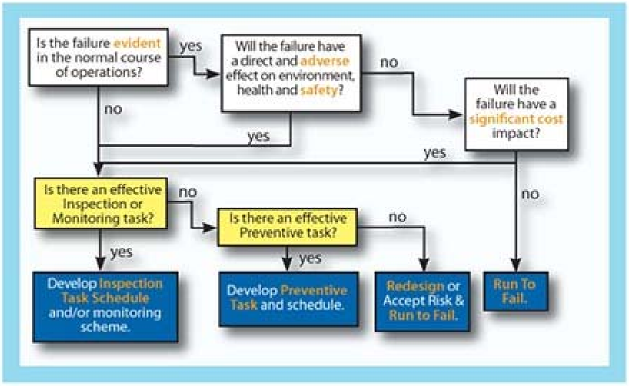


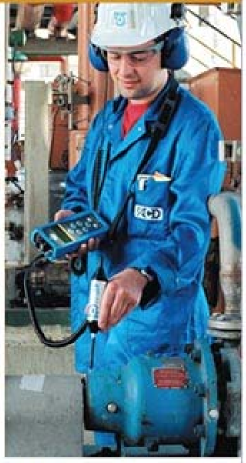
Figure 4 - RCM Task Logic

then conducted using standard RCM logic to address the failure modes in order of their importance (see Figure 4). By engaging the onsite employees during the development of the maintenance strategies, this Iron Ore miner was able to get buy-in from those who would eventually be carrying out the maintenance. The options for improvement included root cause analysis (RCA), to eliminate the failure mode, adding redundancy to reduce the failure rate, introducing a regular inspection or plant monitoring task to allow condition based maintenance on a planned basis or performing PM activities at a fixed interval.

In a similar way to the cost effect chart, criticality charts were also configured to display failure modes which had a safety/environmental/operational risk greater than the acceptable threshold levels. This enabled the plant to include safety/environmental/operational risk reductions in their continuous improvement plan.

Maintenance optimization using RCM Simulation empowers the team to make decisions whereby all maintenance tasks chosen are justified and the benefits expressed as a ratio. The ratios of interest are the cost benefit ratio (CBR), safety benefit ratio (SBR) and operational benefit ratio (OBR). Where tasks are ineffective they are easily identified as any task having a ratio greater than 1. Statutory and safety related maintenance activities can be ineffective from a pure cost perspective, but the benefit from a safety perspective must be considered. Table 1 shows a sample of the maintenance activities with the CBR less than 1. This table shows the at-risk cost if the maintenance task is not performed.

One of the benefits of using a simulator is the chosen task can be simulated and the frequency of performing the task examined on a cost versus interval chart. The chart in Figure 5 provides an indication of the optimal interval to choose. If the "JAW Crusher Offline PM Mech" is performed at an interval less than 600 hours the maintenance cost will be high, whereas if the interval is greater than 600 hours the cost of unplanned failures will be high. These curves can be considered for individual tasks, or also for the grouped tasks, and enable an immediate comparison of maintenance intervals. This can provide a recommendation as to the most effective time to carry out the proposed maintenance activity. These curves can be used to optimize the



Reference	Description	Perform PM?	Perform Inspection?	CBR	Tactic Lifeime Cost	RTF Cost	Risk
SCALPING SCREEN 2.3.1.A.15	Outer longitudinal rail worn	No	Yes	0.567	$17,578,403.75	$31,004,819.91	$13,426,416.16
SCALPING SCREEN 2.3.1.A.17	Inner longitudinal lower deck rail worn	No	Yes	0.567	$17,578,909.75	$31,005,325.91	$13,426,416.16
SCALPING SCREEN 2.3.1.A.5	Inner longitudinal lower deck rail worn	No	Yes	0.567	$17,578,909.75	$31,005,325.91	$13,426,416.16
SCALPING SCREEN 2.3.1.A.9	Inner longitudinal lower deck rail worn	No	Yes	0.567	$17,578,909.75	$31,005,325.91	$13,426,416.16
SCALPING SCREEN 2.3.1.A.1	Inner longitudinal lower deck F/E rail worn	No	Yes	0.567	$17,578,909.75	$31,005,325.91	$13,426,416.16
SCALPING SCREEN 2.3.1.A.23	Inner longitudinal lower deck D/E rail worn	No	Yes	0.567	$17,578,657.35	$31,004,755.51	$13,426,098.16
EL JAY SCREEN A.4.4.1.A.1	Liners Holed	No	Yes	0.06	$823,149.89	$13,696,196.80	$12,873,046.91
GRIZZLY 2.7.1.A.5	End liner worn	No	Yes	0.833	$40,490,294.29	$48,585,724.80	$8,095,430.51
GRIZZLY 2.7.1.A.2	Side liners worn	No	Yes	0.834	$40,539,638.29	$48,635,068.80	$8,095,430.51
GRIZZLY 2.7.1.A.1	Front pan floor liners worn	No	Yes	0.833	$40,510,565.49	$48,605,803.20	$8,095,237.71
GRIZZLY 2.7.1.A.9	Rear pan floor liners worn	No	Yes	0.833	$40,510,565.49	$48,605,803.20	$8,095,237.71
GRIZZLY 2.7.1.A.8	Middle pan floor liners worn	No	Yes	0.833	$40,510,565.49	$48,605,803.20	$8,095,237.71
SCALPING SCREEN 2.2.1.A.1	Side plate cracked	No	Yes	$1.187E^{-4}$	$807.35	$6,801,174.00	$6,800,366.65
SCALPING SCREEN 1.2.1.A.3	Drive shaft seized (lack of lube)	Yes	No	0.001	$5,155.68	$6,068,508.90	$6,081,353.22
SCALPING SCREEN 1.5.1.A.4	Bearings worn (lack of lube)	Yes	No	$2.135E^{-4}$	$129.43	$6,061,794.60	$6,061,665.17

Table 1 - CBR for a sample of failure modes in the crushing plant model extracted from RCMCost report

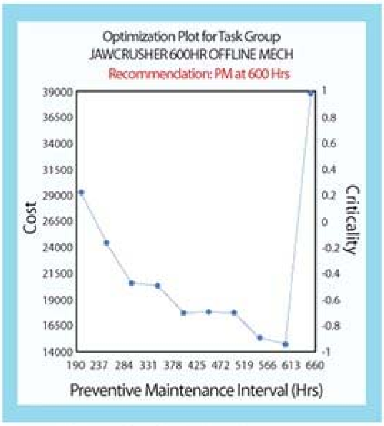


Figure 5 - Optimization curve

intervals of inspection or preventative maintenance routes taking into account numerous maintenance activities. Figure 5 shows an optimization curve for the 600 hr jaw crusher mechanical preventative maintenance.

Outcomes

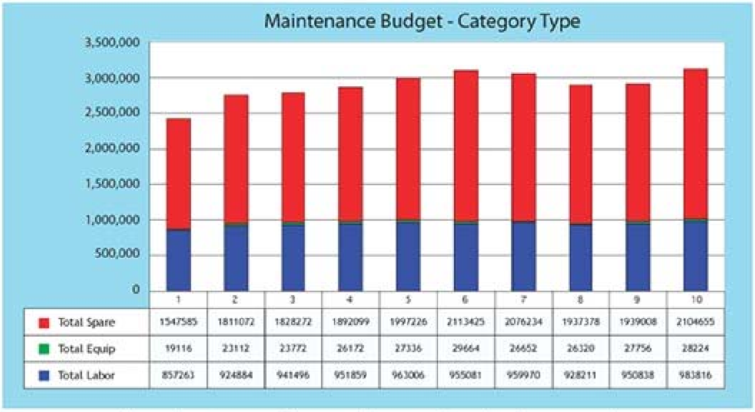
With all validation and reality checking of the simulation model complete, the reporting of budget predictions was quite simple. Figure 6 on the following page shows the overall budget profile over 10 years which has been configured to show the separation of labor, equipment and spares costs.

Note the variation across the profile which accounts for equipment aging characteristics, major equipment replacements and overhauls.

The chart in figure 7 (page 55) shows the budget profile separated into the proportion of breakdown, preventative and inspection cost. Both breakdown maintenance costs and secondary action costs as a result of inspections have been included in the budget prediction to reflect a true zero based budget.

As the budget prediction was developed based on the optimized maintenance practices the amount of corrective or breakdown work was found to be relatively small. This is very useful to use as a health monitor of actual spending. It is the comparison of what was predicted to what actually is achieved that provides a basis for review and Continuous Improvement. Figure 8 shows the dynamic that allows a set of Predicted Key Performance Indicators to be compared to Achieved Key Performance Indicators, which drives continuous improvement.

Alternative scenarios can be compared to show the impact of increasing the budget or decreasing planned activities and the corresponding impact on downtime costs, risks and corrective maintenance levels. The ease of comparing scenarios in a simulated environment arms the asset manager with information, so that if the presented budget is arbitrarily cut, the new budget can be used



	1	2	3	4	5	6	7	8	9	10
🟥 Total Spare	1547585	1811072	1828272	1892099	1997226	2113425	2076234	1937378	1939008	2104655
🟩 Total Equip	19116	23112	23772	26172	27336	29664	26652	26320	27756	28224
🟦 Total Labor	857263	924884	941496	951859	963006	955081	959970	928211	950838	983816

Figure 6 - Cost profile over 10 years showing the separation of labor, equipment and spares.

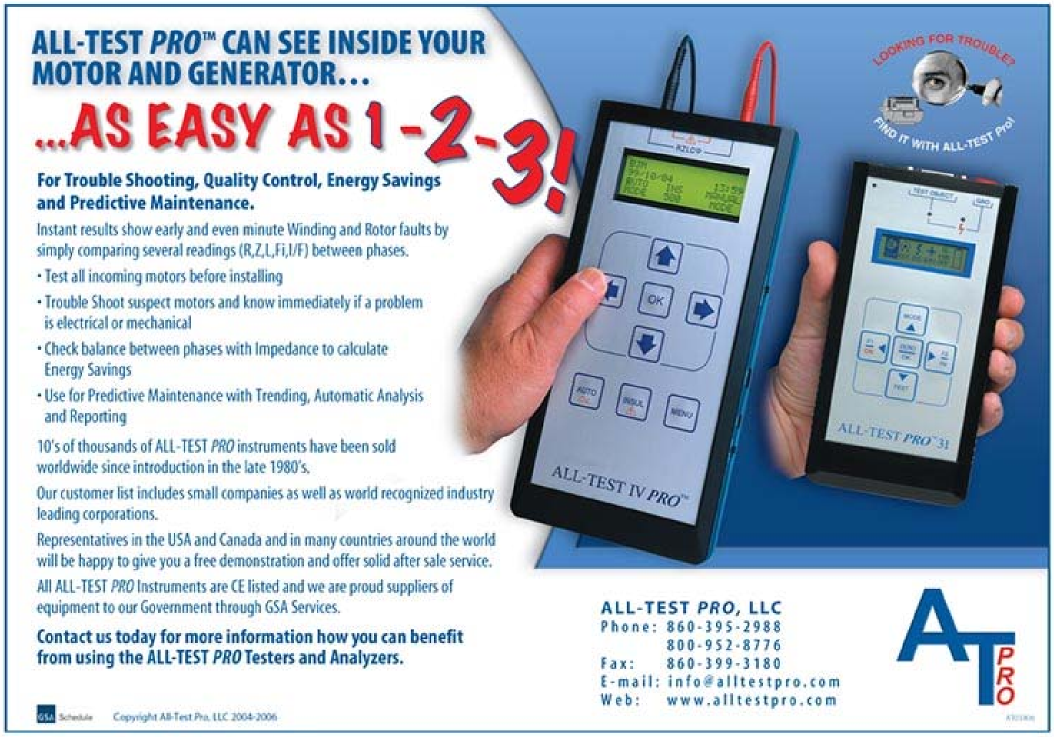
to evaluate the expense savings versus any impact due to increased reactive maintenance costs and the cost impacts of failure.

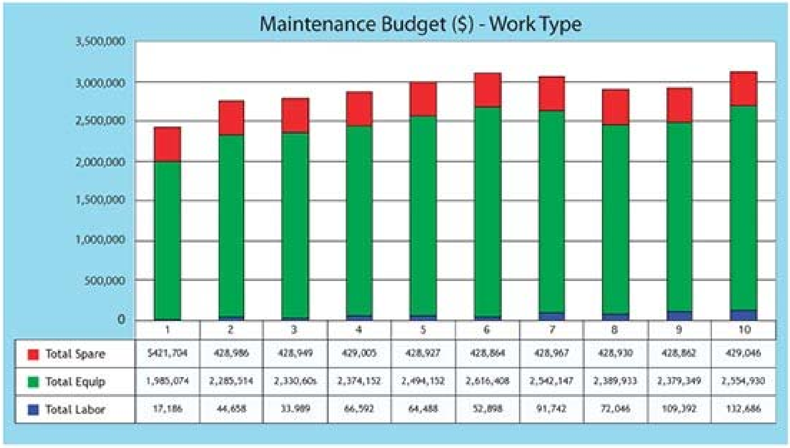
Conclusion

Using RCM and computer simulation to develop optimized asset management strategies, asset managers can predict zero based budgets, optimize task decisions and frequencies based on predicted impacts, compare alternatives and update the knowledge captured in the models. This process empowers decision makers to align maintenance plans to their organizations goals. The zero based budget is fully transparent and enables each maintenance decision to be challenged for accuracy and compared against business risks. The budget profile for the Iron Ore mine was generated over a 10 year lifetime allowing for long term budget forecasts and for rapid budget development in future years. The budget is a true zero based budget in that it includes both likely breakdown maintenance costs and secondary action costs as a result of inspections.

The outputs of this process enabled the optimized strategy to be formalized by producing maintenance strategy documents, such as Maintenance Plans, supported by check sheets and task lists. The RCM model now exists allowing for future maintenance strategy decisions at the failure mode or task group level, ensuring tasks continue to be performed at the optimal interval. The use of an easy to use software package allows the predictions to be readily updated with new data as it becomes available. So the knowledge behind the budget preparation has been captured and preserved.

Jason Ballentine works as a reliability engineering consultant in Vancouver, Canada for ARMS Reliability Engineers. He is trade qualified, has a Bachelor Degree in Mechanical Engineering (honors) from the University of Wollongong in Australia, and is a Certified Maintenance and Reliability Professional. Jason is an experienced reliability practitioner





	1	2	3	4	5	6	7	8	9	10
🟥 Total Spare	5421,704	428,986	428,949	429,005	428,927	428,864	428,967	428,930	428,862	429,046
🟩 Total Equip	1,985,074	2,285,514	2,330,60s	2,374,152	2,494,152	2,616,408	2,542,147	2,389,933	2,379,349	2,554,930
🟦 Total Labor	17,186	44,658	33,989	66,592	64,488	52,898	91,742	72,046	109,392	132,686

Figure 7 - Cost profile over 10 years showing the proportion of breakdown, preventative and inspection work.

providing consulting and training support in the areas of maintenance strategy development, maintenance strategy review, zero based budget predictions and system availability/capacity modelling. Jason regularly undertakes reliability improvement projects, working with onsite client teams to collate available information, analyze data, build reliability simulation models using both Reliability Centered Maintenance and Reliability Block Diagrams, facilitate the optimization of lifecycle plans, and generate required reports.

Michael Drew is director of ARMS Reliability Engineers based in Melbourne, Victoria, Australia. He is a qualified Metallurgist and a CMRP, has worked in industry for over 30 years in Steel making, Alumina Refining and Oil Refining. Michael is the author of ARMS training materials, presents at international conferences, and, as an ex-Maintenance manager and Engineering manager, has a practitioner view to balance the last 10 years consulting in the field of Reliability to many blue chip resource projects.

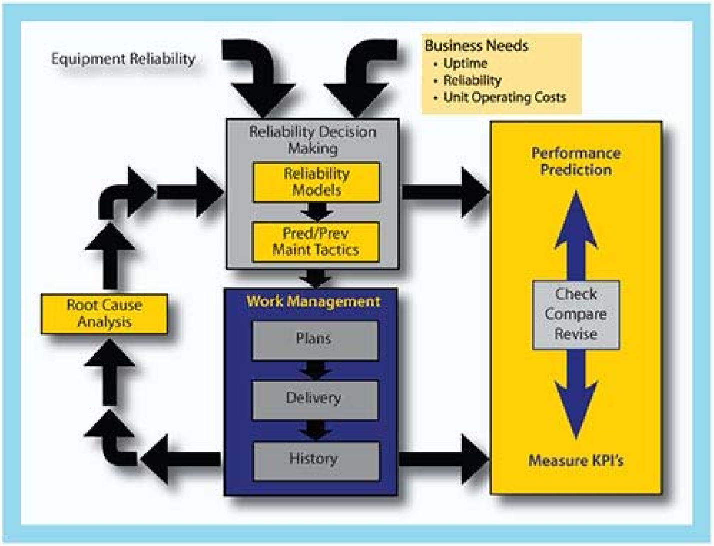


Figure 8 - Continuous Improvement Loop