



Title New Generation Of Reliability Tools Give Asset Managers Real Decision Making Power.

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Asset managers are now able to take advantage of the latest reliability engineering methods and easy to use computer simulation packages to make informed decisions on managing their assets to achieve their business goals. Using the latest tools, asset managers can collect knowledge from a variety of sources and use a systematic approach to making asset management decisions.

Improved reliability is all about reducing the business cost of failure. Businesses competing at a global level can no longer rely on over design and heavy maintenance regimes in order to meet the requirements of today's lean manufacturing environment. Asset managers need to be in control of their business performance and ensure maximum capacity is achieved for minimal capital invested. Unfortunately, maintenance is an area where traditional thinking is firmly entrenched and often the activities are fixed or overhauled using other static or unwieldy slow to respond programs. There is now available a new generation of decision making tools that ensures that one of the largest areas in the operator's budget is optimized, that is the contribution of assets to the business and the maintenance program required to ensure assets continue to contribute at a high level.

Key features of the new generation of reliability tools are:

- I. Simulated decision making to take control of assets that are capable of meeting the performance needs of the business replaces the traditional approach of assuming the maintenance of equipment is required to meet fixed standards or that the function of equipment is fixed and once defined remains the same throughout the asset life. The needs of a modern organization competing in the global market place are ever-changing. Costs, uptime, interruptions, safety compliance issues, environmental impacts have significant impact on the bottom line of a business and may well determine the level of profitability. Simulation provides a dynamic approach to decision making and replace the older static methods.
- II. The "What if" capability of the new generation allows new ideas to be tried in a low cost simulated environment. Rapid feedback of results is now possible in minutes or hours instead of years typically involved in the field trials of old. Today's design engineer or asset manager can utilise the knowledge of past performance, workshops, field repair teams, operators, inspectors, supervisors and engineers in electronic format. Simulation provides the means for this knowledge to accumulate and grow. It's application can ensure all the knowledge of today is used in forecasting future behaviour. Innovation and new ideas challenge the status



- quo and allow the organisation to bust existing paradigms and develop new levels of asset contribution and reduction of failure costs.
- III. Streamline use of resources through using forward looking predictions. Different business scenarios modeled in a simulated environment ensure the likely critical areas are addressed through either of the following improvement scenarios- improved design, redundancy, repair plans including spares holdings, preventive actions, predictive actions, monitoring or alarms, or planned retirement.
 - IV. Use of “dirty data” often upsets purists who want more failure data to be statistically significant. Reliability engineers want to avoid failure data, and so make intelligent use of the meager data on offer- looking for any source of previous failure, inspection, or experience, in order to make a failure forecast. Data driven models allow quantification of future expectations. Some models are built solely from shop floor knowledge, but once captured as failure parameters, the models can be enhanced as future data becomes available. Some models for new designs are built solely on the basis of predictions from sources such as MIL217 for electronic components. In this case stress levels and parameters can be varied to reflect expected conditions, and the standard reflects these changes in the failure rate prediction.
 - V. Use of Weibull parameters to reflect ageing modes in equipment, allows ready use of performance data to update predictions. Deterministic methods applied to in-service failures allows the root causes to be identified and reliable predictions updated, and asset management plans to be improved.
 - VI. Use of Monte Carlo simulation allows mixed modes, random, wear-out, and the interdependencies between multiple failure modes to be assessed over a lifetime.
 - VII. Overall system performance measured through metrics such as MTBF can be better understood by drilling down to dominant modes of equipment deterioration. Preventive maintenance regimes can be quickly reviewed to ensure fixed time actions are effective in reducing the cost of failures or extending the failure free period. Similarly, condition monitoring programs can be targeted at optimum frequencies ensuring effective warning to avoid the detrimental effects of failure.
 - VIII. New technologies can be quickly evaluated to gauge the impact and cost benefit of the latest in diagnostic methods
 - IX. In summary I can harvest existing knowledge and build a data model. Using this model I can rapidly simulate real world behaviour- like throwing the dice a thousand times but biased to reflect my failure distribution- and try out my best decisions. I can challenge existing paradigms with creative ideas, way out methods, latest advances in technology, and be able to compare their “worth” to my business. I can adopt the model that best suits me and use the data collected in my CMMS to update and keep pace with the “real world” and continue forecasting to the future.
 - X. Models can be also to improve the performance of individual pieces of equipment or System models allow me to model complex systems. Modeling of complex systems simplifies decision making. The simulation engine (Monte carol generator) will model the interdependencies so I can evaluate my individual decisions against the impact of the whole system. Multiple levels of redundancies, long series and parallel systems with long logistics supply chains, different modes of failure including random, burn in, wear out- can be daunting if performance is poor. Where do I start? What is the critical factor? Simulation using a systems availability simulation tool answers these questions in minutes, as well as providing a vehicle to prove the desired improvement mechanism.

Maintenance Optimization of Individual Equipment

Developing an Optimized Maintenance plan for an individual piece of equipment is a Simple Four Step Process

- I. Define the objectives
- II. Predict the behaviour
- III. Identify maintenance solutions
- IV. Implement



Phase 1.

In the first phase we are concerned with defining the asset contribution to the business goals and the impact of interruptions due to failures and equipment downtime. The consequences of failure will be assessed according to the severity of the impact on the business goals and objectives. A Corporate Risk matrix is often used to assist decision making regarding acceptable risks levels associated with failure events. An example of a business risk matrix is shown below.

Severity Ranking	Safety		Community		Environmental		Target Rate
1	S1	Risk of Minor Cuts, Bruises or sickness.	COM1	Risk of incident creating adverse localized site awareness.	ENV 1	Risk of Minor Environmental Event	<100/yr
2	S2	Risk of Medical Treatment Injury	COM 2	Risk of incident creating adverse general site awareness.	ENV 2	Risk of Incident with Off site Emission but no damage	<10/yr
3	S3	Risk of Serious Non-Permanent Injury (chosen as benchmark to assist with other targets)	COM 3	Risk of incident creating adverse local media impact	ENV 3	Risk of Incident with adverse effect on environment.	<1/yr
4	S4	Risk of Serious Permanent Injury	COM 4	Risk of incident creating adverse state media impact	ENV 4	Risk of incident with non permanent damage to environment	<1/10yrs
5	S5	Risk of fatality	COM 5	Risk of incident creating adverse national media impact	ENV 5	Risk of incident causing permanent local environmental damage.	<1/100yrs



In an RCM Study a failure effect table is developed so that each a failure mode can be assigned a consequence level. The use of Severity numbers differentiates each level as shown below for Safety.

Effects	Definition	Target Rate	Severity	Target Safety Criticality	Threshold no of Events In 100 yrs
S1	Risk of Notable safety event / minor injury	<100/yr	87.6	1	10000
S2	Risk of MTI	<10/yr	876	1	1000
S3.1	Risk of LWC	<1/yr	8760	1	100
S3.2	Risk of Permanent disability	<1/10yrs	87600	1	10
S4.1	Risk of Single fatality (chosen as benchmark to assist with other targets)	<1/100yrs	876000	1	1
S4.2	Risk of Multiple fatalities	<1/1000yrs	9E+06	1	0.1

A simulation run will determine how many events will occur per hour, and report a criticality number which will be severity per hour. .So if a S3.2 failure effect is predicted to occur in a 10 year (87600 hours) simulation run, the resulting criticality will be 1 as given by the severity number divided by the number of hours (8760/8760=1). So a target criticality of 1 for each of the failure effect levels corresponds to the threshold rate of each Safety level. As can be seen in this approach the risk of 1 Lost Work injury in a year is an equivalent level of safety performance as the risk of 1 fatality in 100 years, or similarly 100 S3.1 in 100 years is equivalent to 1 S4.2 event. The results of the simulation can be used to evaluate the alignment of equipment reliability with the risk management objectives for Safety, Environment and Operational events. The benefit of simulating performance in a computer environment of course, is that the simulated results does not require 100 years of plant operation nor is an actual fatality required in order to assess the Reliability of the equipment.

Cost Effects

In the field of simulation a direct contribution to the business can be measured in the dollars per occurrence of a failure event or dollars per hour of downtime. The dollar impact may be a reflection of direct costs such as contract penalties or fines, waste, poor quality or the cost of damage to other equipment, or indirect losses such as lost profit contribution, efficiency impact under utilized capital, waste, penalties, and cost of poor quality or the cost of damage to other equipment. A typical cost matrix is shown below.

Equipment Damage		Production Loss	
Dam 5k	Risk of Equipment Damage to \$5,000	LOSS 100K	Risk of Incident causing losses \$100,000 per incident.

Dam 50k	Risk of Equipment Damage to \$50,000	Loss 500K	Significant Production Deviation outside control limits. Pot loss up to \$500,000.
Dam \$100k	Risk of Equipment Damage to \$100,000	Loss 1 mil	Large Production Deviation outside control limits. Pot Loss up to \$1,000,000.
Dam to \$500k	Risk of Equipment Damage to \$500,000	Loss 2 mil	High Product out of specification. Pot Loss up to \$2,000,000.
Dam over \$500k	Risk of Equipment Damage over \$500,000	Loss 5 mil	High On going out of Specification. Pot Loss to \$5,000,000.

Table 2 – Financial loss per incident effects

Downtime	\$4,000 per hour.
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Table 3 – Financial loss per hour effects

A simulation run can forecast the expected cost of failure effects over any lifetime.

Phase 2

In the second phase an asset hierarchy is built that assembles equipment into subsystems to reflect a logical drilldown from the plant to subsystem to individual pieces of equipment. The Subsystems consist of equipment where there is a common purpose that contributes to the performance of the subsystem; the performance of the plant is then a result of each of the subsystems working in combination. The lowest level in the hierarchy is the asset whose function your trying to preserve by making various decisions regarding maintenance activities to preserve function or manage the consequences of functional failures. An FMEA is the next level of drilldown whereby for each asset the functions required, the possible functional failures, and the likely modes of failure are listed. It is at the mode level that decisions are made regarding the type and frequency of maintenance actions, so a failure effect level is assigned to each mode.

Failure parameters are assigned to each mode. These failure parameters describe the likelihood the failure mode will occur over the lifetime. There are six types of characteristic failure behaviors that can be described using the Eta, Beta and Gamma Parameters of the Weibull distribution.

Weibull Analysis:

- Traditional maintenance programs use MTBF to base their maintenance strategy, Reliability Engineering uses Weibull analysis.
- Traditional approaches define reliability using the following formula:

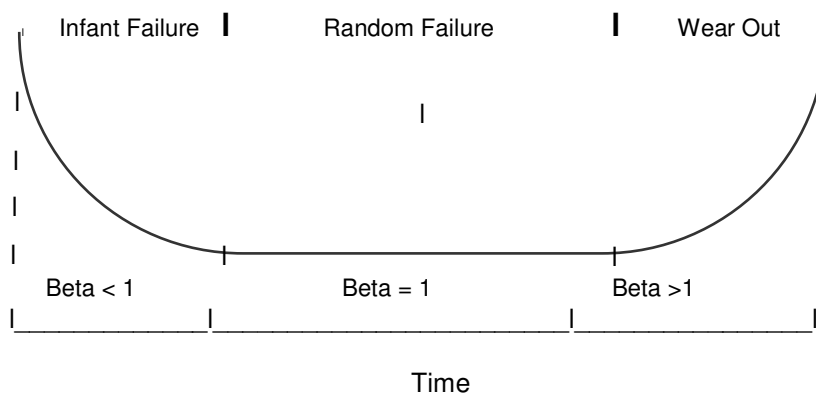
$$R(t) = e^{-t / \text{MTBF}}$$

- This assumes random failures with constant failure rate. In a Weibull analysis, this is where $\beta = 1$. Of course, no two types of component fail in the same way.
- RCM recognizes six different failure modes, they are:
 - Type A – Bathtub: $\beta =$ combination (system)
 - Type B – Worst Old: $\beta > 4$
 - Type C – Slow aging: $\beta = 2$
 - Type D – Best New: $\beta = 1.5$
 - Type E – Constant: $\beta = 1$ (traditional approach using MTBF)
 - Type F – Worst New: $\beta < 1$
- Each has a particular Beta (β), or failure curve shape. Reliability in this context is defined using the following formula:

$$R(T) = e^{-(T/\eta)^\beta}$$

- Note that the formula is similar to the “official” definition of reliability, but MTBF has been replaced by η (Eta) which is the “Characteristic Life” and is raised to the β power. When solving for $R(T)$, η & β must now be considered.

Weibull Failure Curves: **(Type A – Bathtub)** $R(T) = e^{-(T/\eta)^\beta}$



Understanding failure behaviour allows lifecycle performance to be predicted over any lifetime using simulation packages with a Monte Carlo simulation engine such as RCMCost or Avsim Plus from Isograph.

Assigning the details of how long to repair the failures for each failure mode and the resources required, allows a simulation of a run to failure strategy. Simulation results will indicate the cost of failures and the cost repairs over the system lifecycle. Criticality of safety issues, environmental issues and operational issues is also predicted in the run to failure simulation of RCMCost.

Phase 3



Identifying a maintenance solution that can reduce the effects of failure comes from understanding the root causes of the failure mode. A Root Cause Analysis may be performed at this stage in order to identify viable solutions. The Maintenance solutions are identified to challenge the causes and so reduce the likelihood of failure, or have sufficient warning of a failure condition in order to take corrective action without incurring the effects of failure.

Maintenance solutions can take the form of :

- Run to failure where the predicted costs of failure are so low as to not warrant action to be taken.
- Preventive actions that extend the useful life and prevent the failure mode occurring.
- Predictive actions that monitor the onset of a potential failure condition at a frequency to give sufficient warning of a failure so that restoration action can be taken. This is often called Just in time maintenance or Condition based maintenance.
- Condition monitoring where a hard wired system is installed to indicate an undesirable condition or state.
- Redundancy is added.
- Redesign the equipment to achieve a more favorable level of reliability in the period.

Selection of each maintenance action is based on a cost benefit, safety benefit or operational benefit. Often these tasks are then grouped to a convenient window to achieve least disruption to operations or greater efficiency in execution.

Phase 4

The decisions made on the optimum task, frequency and grouping require input to Maintenance Work Managements system to ensure effective implementation. The chosen tasks, the spares and resource requirements are adopted in the maintenance plan so that work orders for the regular tasks are performed at the optimum frequency. The output may be grouped into a work instruction, or maintenance documentation, or be included in routine checklists.

As work is executed, the opportunity to do things better, cheaper, differently can be fed back for improvement of future plans. Similarly, remaining life estimates, the presence of failure modes, of any equipment parts can be recorded and fed back with likely causes so that models are dynamic and firmly linked with reality. A periodic review of “Times to Failure” information allows the parameters to be updated and the model to be continuously improved.

Optimization of System Availability

System analysis recognizes that pieces of equipment belong to systems and the system performance is dependent on the interrelationships between equipment.

For example if the reliability of an individual piece of equipment over a year is say 0.9, it has a 90% chance of not failing in the year. But if I have 3 pieces of equipment in series whereby failure of either one can cause the system to fail then there is only a 73% chance of not failing in a year. Other complexities arise when resources are required. Do you plan resources for 1 repair, what about when all 3 fail together?. So modern generation tools for availability modeling uses both Monte Carlo simulation for predicting likelihood of failure as well as queuing theory for predicting the impact of logistics plans on system performance.

There are 4 steps to building an Availability model.

- I. Define the success path
- II. Set the logistics
- III. Check system performance meets goals
- IV. Implement



Defining the success path requires consideration of all equipment items in the system that can impact the availability of the system. Consideration is given to any parallel relationships or levels of redundancy where perhaps only 3 out of 4 equipment items are required in service for the system to be available. Equipment is represented by a block which carries its failure parameters, corrective maintenance details including spares, and any planned maintenance activities. Any Logistic delays are defined for spares and crew resources.

Simulation over a lifetime provides an estimate of the system failures that can be expected, the level of downtime expected, the costs, and resources likely to be needed. Comparison to performance goals allows the analyst to change intervals, optimize spares levels, and assess the impact of changes in the configuration or redundancy. Importance Analysis ensures the analyst can focus on those areas which are important – downtime, safety, costs, environment or operational.

RAM modeling (Reliability, Availability, Maintainability) of new or existing projects allows engineers to optimize the availability and reliability of production systems in a computer environment, allowing design and operational scenarios to be evaluated in short periods of time, with no adverse impact on the bottom line.

RAMS Targets are an essential component of the requirements specifications for any project. Contracts typically require demonstration of performance following commissioning and ramp up. Use of RAMS modeling techniques combined with Monte Carlo simulation engines provides:

- An early indication of a system's potential to meet the design availability and reliability requirements.
- Enables assessment of lifecycle costs to be carried out.
- An early indication of which components or areas contribute to the major portion of capacity loss.
- Enables trade offs to be made between reliability, maintainability, and redundancy and buffer capacity.
- Provides early assessment of Safety and Environmental compliance.

Application of RAMS modeling to existing facilities by inputting actual Times to Failure can also assist identifying weak areas of performance, identify Availability bottlenecks, allow alternative maintenance regimes to be evaluated or simply understand the criticality ranking of equipment as they impact site production.

AvSim+ from Isograph is a powerful availability and reliability simulator capable of analyzing complex and dependent systems efficiently and accurately. AvSim+ capabilities extend far beyond analyzing the availability and reliability of complex systems. The program's Weibull, spares tracking (through multiple echelon levels) and task management functions allow users to implement a Reliability-Centered Maintenance (RCM) strategy aimed at reducing costs, optimizing availability and managing planned maintenance tasks.

RAM modeling includes modeling the effect of:

- Labor availability,
- Spares availability,
- Maintenance strategies
- Equipment failure behaviour including infant mortality, random failures and aging.
- Production capacity,
- Size of intermediate buffers such as stockpiles or surge tanks,
- Standby equipment,
- Shutdown intervals,



- System configuration changes.
- Phased changes over time.

The Monte Carlo simulator engine enables AvSim+ to model complex redundancies, common failures and component dependencies that cannot be modeled using standard analytical techniques including those listed below.

- Warm and cold standby arrangements
- Queuing for labor
- Queuing for spares from site, depot and factory
- Hold for repair
- Opportunistic maintenance

AvSim+ will then analyze your system using efficient Monte Carlo simulation algorithms to provide availability and reliability parameters, life cycle costs, importance rankings etc. You may also optimize spare holdings and planned maintenance intervals.

ARMS Reliability Engineers distribute Isographs RAMS tools in Australia, Canada and USA and provide training and project services to companies in mining, refining, power, manufacturing and defense.