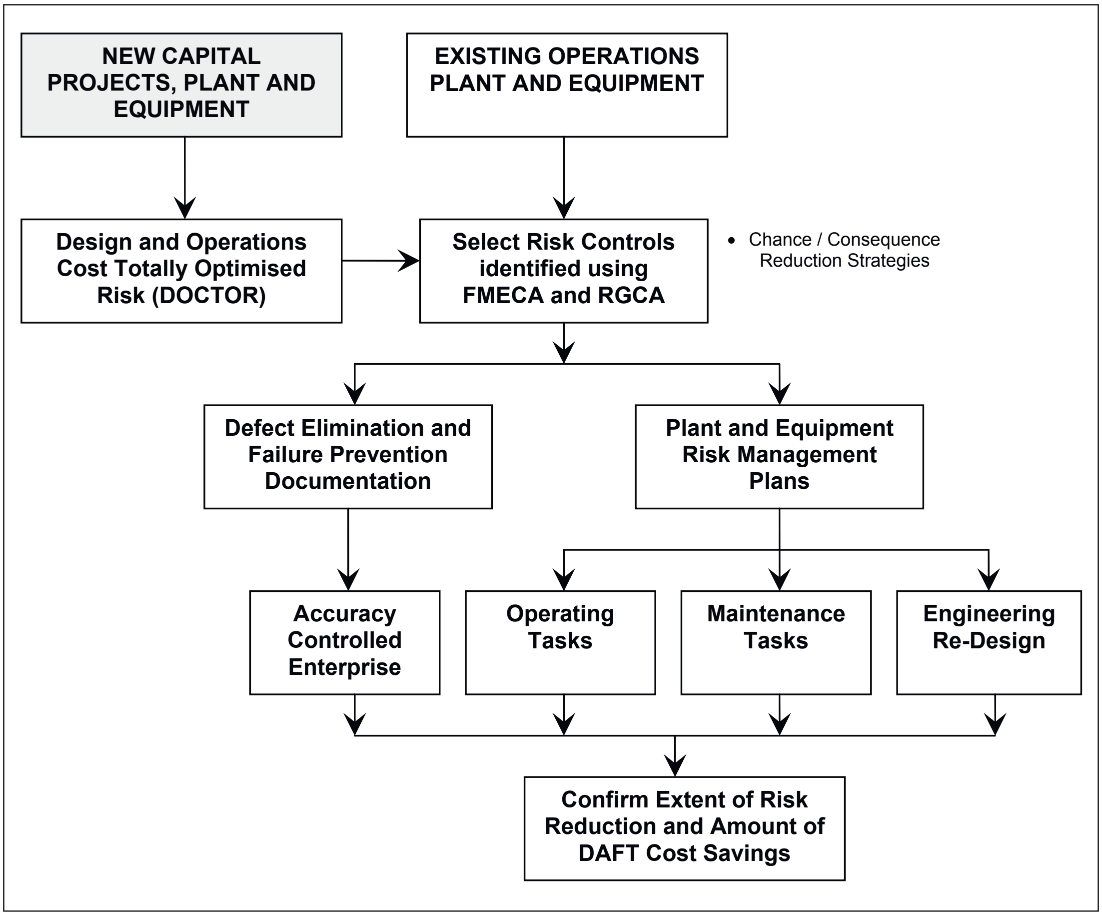
PROCESS 3 – Select Operating Risk Controls



Description of Process 3 – Selecting Risk Control Strategy

The risk control strategies chosen are critical to minimising operating costs and creating equipment reliability. Doing maintenance that does not reduce risk is pointless. Doing maintenance because of poor design and selection means carrying unnecessary operating costs. It is essential to apply a methodology to review operating costs imposed by design choices and pick good operating options in capital projects. When doing new capital project or plant upgrades the Design and Operations Costs Totally Optimised Risk (DOCTOR) methodology minimises future operating costs. It may not be possible to cut every operating cost, but the DOCTOR will make people look at how to reduce operating risk before making the final equipment and design choices.

Select Risk Control Options:

Operating plants that want to reduce costs need to identify the causes of their costs and remove them. Adding maintenance routines to control risks will immediately cause maintenance costs to rise. The added maintenance is beneficial if it reduces DAFT Costs by stopping risks becoming failures. It will be some months before new maintenance reduces failure frequency so that savings show-up in monthly reports. Doing the right maintenance limits risk but it will not remove the opportunity for failure. For the least operating and maintenance costs it is necessary to remove the chance of failure.

Select Risk Control Actions identified using FMECA and RGCA:

Go deep into the detail of what causes equipment failures in your operation. Find and understand the failure mechanisms in order to select the ideal solution for the root causes. Identify all possible failures using the FMECA and Root Cause Growth Analysis (RCGA) spreadsheets provided in the CD accompanying this book.

Chance and Consequence Reduction:

Chance reduction is proactive risk removal strategy. Chance reduction removes the possibility of failure. Chance reduction leads to world-class operations performance and least costs. Consequence reduction accepts that failure will happen and minimises its impact. Consequence reduction can never lead to least operating costs. Consequence reduction is the strategy of last resort. Companies do it because they think it is adequate and it looks like a cheap option. It never is on both counts. Only chance reduction leads to least operating costs and maximum uptime. In the Risk Control Plan Spreadsheet provided in the CD accompanying this book write the chance reduction controls that prevent failure incidents arising. For those that cannot be prevented write the consequence reduction actions to contain the losses.

Defect Elimination and Failure Prevention Documentation:

As part of risk control, list the documents and standards to write to prevent the defects that cause failures from entering your operation.

Plant and Equipment Risk Management Strategy:

Select the operating, maintenance, re-engineering and defect elimination strategies you will use.

Confirm Extent of Risk Reduction:

Check the proposed strategies remove, or at least substantially reduce the risk of each failure.

9. Use Process Maps to Identify Risk and Improve Reliability

A Process Map for a piece of equipment or a job allows use of reliability improvement principles to reduce the chance of failure. In Chapter 1 the reliability of series processes was explained. We found that series process reliability is improved by introducing parallel requirements for each step of the process. Once a process map shows all process steps we can investigate how to include parallel activities to increase each step's reliability. Better still would be to remove the step or find ways to error proof it so that nothing can go wrong.

Series reliability improvement revolves around applying the three Reliability Properties of Series Processes and building parallel arrangements to cause higher reliability. The three series reliability properties are repeated below.

- **The reliability of a series system is no more reliable than its least reliable component.**

Reliability Property 1 means that anyone who wants high series process reliability must ensure every step in the series is highly reliable.

- **Add 'k' more items into a series system of items, and the probability of failure of all items must fall an equal proportion to maintain original system reliability.**

Reliability Property 2 means that if you want highly reliable series processes you must remove as many steps from the process as possible. Reliability Property 2 says to simplify, simplify, simplify!

- **A small rise in reliability of all items causes a larger rise in system reliability.**

Reliability Property 3 means that system-wide reliability improvements pay off far more that individual step by step reliability improvements.

These three properties, and the paralleling of process steps, can be applied to reduce the risks in using operating equipment and in doing jobs. You can design the equipment reliability that you want by using processes with the practices and methods that deliver it.

Apply Series System Reliability Property 1

Figure 9.1 is a high level process map for a centrifugal pump-set when in operation. We will use the process map to design reliability improvements.

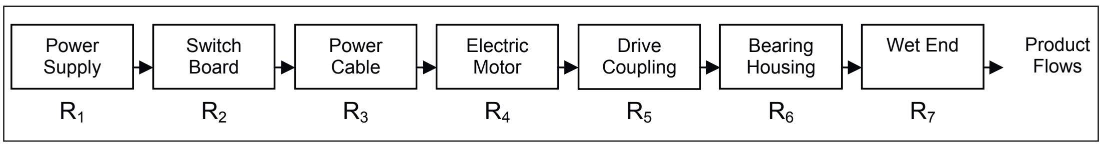


Figure 9.1 – A Centrifugal Pump-set Process Map.

We start by applying Series Process Reliability Property 1 – The reliability of a series system is no more reliable than its least reliable component. We need to identify the reliability of each assembly so that we can find the least reliable ones and see if they need improving. For the sake of the example select a minimum series reliability of 0.9999. This is the chance of 1 failure in 10,000 opportunities to have a failure, which is what would be expected from quality equipment. For a pump-set that runs say ten times a day it represents 1000 days, about three years, without a failure. To get that requirement from the pump-set, each of its assemblies needs a greater reliability. We can estimate the scale of the reliability required by using Equation 1.1 and assuming that all parts have equal reliability.

$$R_{pump\text{-}set} = R_1 \times R_2 \times R_3 \times R_4 \times R_5 \times R_6 \times R_7 = R_n^{\ 7} = 0.9999$$

$$R_{pump\text{-}set} = 0.99998571^7 = 0.9999$$

This is an individual assembly reliability of 0.99998571, or about 14 failures in every 1,000,000 opportunities for failure. In other words, each assembly can only have the chance of one failure every twenty years in order that the pump-set has the chance of only one failure in three years. One failure in twenty years is a very high reliability requirement for some assemblies in the pump-set, like the drive coupling and mechanical seal, but not impossible for many of the other parts. For the shaft drive coupling and mechanical seal it is not difficult to find dozens of reasons that cause them to fail sooner than once in twenty years. These include incorrect bore tolerances, shaft misalignment, torque overload, poor assembly on installation, corrosion, wear and impact, chemical decomposition of elastomeric items, along with many other common failure causes.

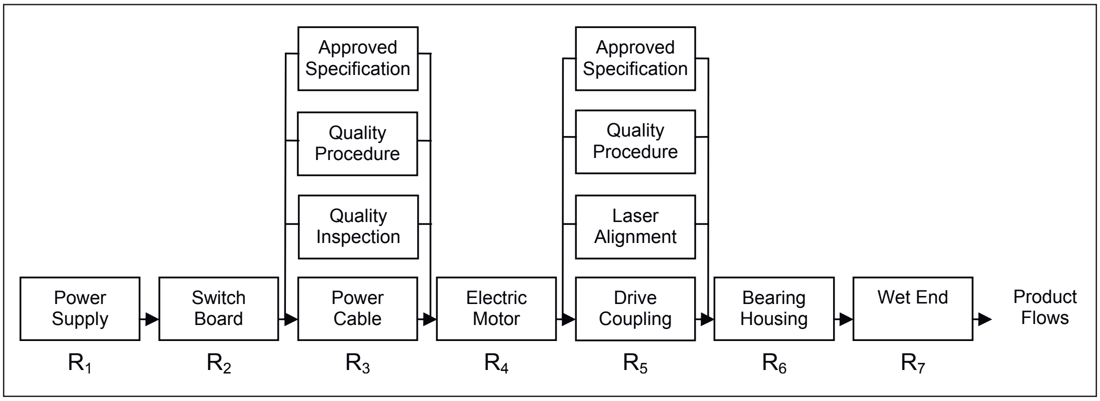


Figure 9.2 – Centrifugal Pump-set Reliability Improved by Parallel Tasks.

The power cabling is an example of an item with high reliability designed into it. Lugs crimp the cable wires at both ends. The cable enters into the switchboard and motor starter through gland connections. The lugs bolt to connections in a particular way to ensure firm contact so that hot-spots do not develop. Though early-life electrical failures from poor workmanship has occurred, better than twenty years of failure-free service is normally expected from industrial power supply systems. By using good methods and practices for cabling and connections, combined with good quality control, it is possible to get fewer failures than the one in twenty year opportunity required for our pump. The electrical components can deliver the required reliability by using installation best practices done with care. However, mechanically it is very unlikely that this pump-set will achieve the reliability required. Unless there are better solutions to prevent environmental degradation and mechanical stress the parts cannot last 20 years failure-free. This is where the process maps help us to identify more reliable options than those now used.

Figure 9.2 shows the tasks and requirements added in parallel on the cabling and drive coupling, that, if done correctly, will greatly improve the reliability of each step. For the coupling the added parallel tasks are to purchase it using an approved engineering specification that addresses all likely modes of failure, install it using quality work procedure that prevent deformation, and laser align shafts to precision standards. Do all these and the failure-free life of the coupling is greatly enhanced. The process map helps us to specify parallel tasks that will improve the step reliability.

Apply Series System Reliability Property 2

The second Series System Reliability Property – add 'k' more items into a series system of items, and the probability of failure of all items must fall an equal proportion to maintain original system reliability – requires us to ask if we can remove unnecessary components from the system. By removing items or steps the system is more reliable because there are fewer things to go wrong.

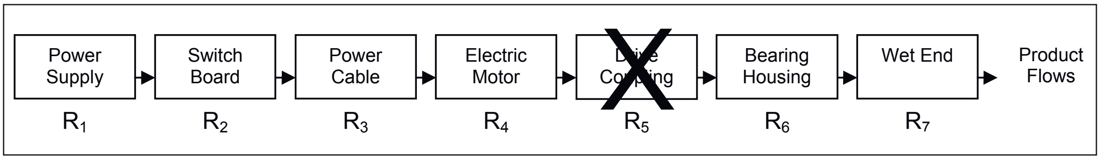


Figure 9.3 – Centrifugal Pump-set Reliability Improved by Removing Coupling.

Figure 9.3 asks what would happen if we remove the drive coupling, one of the highest risk assemblies, from the centrifugal pump-set. Is there technology to eliminate the need of a coupling? Figures 9.4 and 9.5 show two such technologies – canned motor pumps and magnetic drive pumps.

Figure 9.4 – Canned Motor Pump.

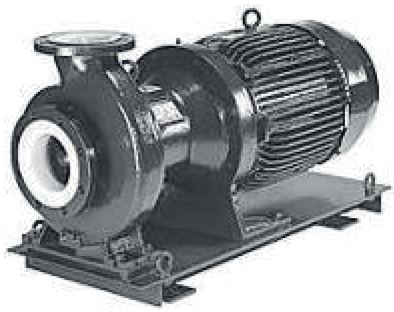


Figure 9.5 – Magnetic Drive Pump.

Both these pumps do not have a shaft drive coupling. With one assembly removed, the system reliability (assuming the other items keep the same individual reliability) becomes:

$$R_{pump\text{-}set} = R_1 \text{ x } R_2 \text{ x } R_3 \text{ x } R_4 \text{ x } \cancel{R_5} \text{ x } R_6 \text{ x } R_7 = R_n^{\,6} = 0.9999$$

This calculates to individual assembly reliability of 0.99998333, which equates to no more than 17 failures in every 1,000,000 opportunities for failure. It is a minor reduction in assembly reliability from the 14 failures in 1,000,000 opportunities of a coupled pump-set. What this small reliability reduction tells us is that equipment reliability is difficult to improve if good quality parts and assemblies are already used. To confirm that simplifying a system of good quality parts produces only small change in system reliability, let us remove the bearing house as well as the coupling. The system reliability then becomes:

$$R_{pump\text{-}set} = R_1 \text{ x } R_2 \text{ x } R_3 \text{ x } R_4 \text{ x } \cancel{R_5} \text{ x } \cancel{R_6} \text{ x } R_7 = R_n^{\,5} = 0.9999$$

The individual assembly reliabilities are 0.99998. We now only need assemblies with 20 failures in every 1,000,000 opportunities to give our imaginary 5-assembly pump-set a chance of one failure in three years. Even after simplifying from seven to five items, we achieve the same system reliability with only marginally lesser reliable assemblies. If you are already using quality components made with quality materials and quality manufacturing then you must look for improved equipment reliability in other ways. Unless your plant and equipment is full of poor quality parts and assemblies, the equipment is probably not the cause of your failures.

Apply Series System Reliability Property 3

The third Series System Reliability Property – a small rise in reliability of all items causes a larger rise in system reliability – is the final perspective to consider. Figure 9.6 shows the introduction of precision work procedures to exacting stress-reducing specifications for each assembly. These procedures do not involve changes to components; rather they are learned skills and practices used company-wide. Precision skills, where work is done to precise standards that prevent stress being introduced, causes the reliability of the equipment to lift. By paralleling precision skills with high work accuracy for every item in the system we get greater system reliability. Parallel system reliability is calculated with Equation 1.2, repeated below.

$$R_{para} = 1 - [(1\text{-}R_1) \text{ x } (1\text{-}R_2) \text{ x } \ldots.(1\text{-}R_n)]$$

Values for human error rates in a variety of work situations are available [51]. Task error rates of 1 in 100 are a reasonable estimate for work done with precision to quality standards, combined with proof-testing for confirmation. To retain system reliability of 0.9999, the reliability of each paralleled arrangement, assuming they are identical, is calculated from:

$$R_{pump\text{-}set} = 0.9999 = R_{1para} \text{ x } R_{2para} \text{ x } R_{3para} \text{ x } R_{4para} \text{ x } R_{5para} \text{ x } R_{6para} \text{ x } R_{7para} = 0.99998571^7$$

We can calculate the reliability of each parallel arrangement, assuming identical reliability:

$$R_{para1} = 1 - [(1\text{-}R_{1A}) \text{ x } (1\text{-}0.99)] = 0.99998571$$

$$R_{1A} = R_{2A} = R_{3A} = R_{4A} = R_{5A} = R_{6A} = R_{7A} = 0.9986$$

That is interesting: prior to precision workmanship we needed assembly reliabilities of 14 failures per 1,000,000 opportunities to get pump-set reliability of 1 failure in 10,000 opportunities. With precision work, proof-tested to meet stress-reducing quality standards, we can get the same system reliability by using equipment with 1400 failures per million opportunities.

In poorly skilled operations buy top quality machines. In operations practicing precision maintenance and operation you can use machines of lower quality because they will be improved. If you want the very best reliability results, use quality equipment maintained to precision quality standards.

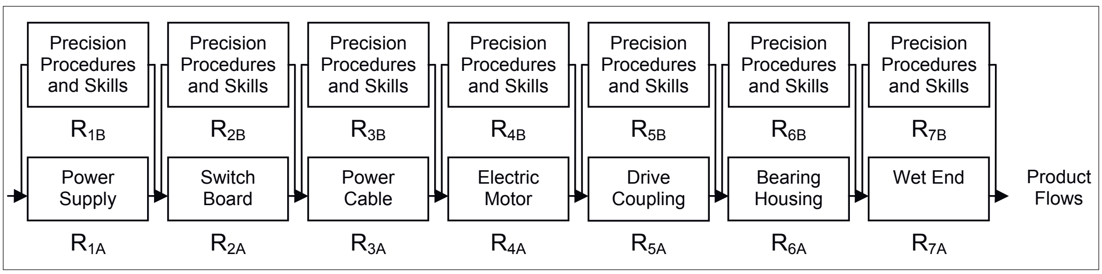


Figure 9.6 – Pump-set Reliability Improved by Parallel Precision ACE 3T Activities.

51 Smith, Dr, David J., Reliability, Maintainability and Risk, Seventh Edition, Appendix 6. Elsevier, 2005.

10. Failure Mode Effects and Criticality Analysis

Because parts fail first and then equipment stops, an effective equipment risk reduction strategy requires a detailed analysis of the causes of parts failure. This can be done with Failure Mode Effects and Criticality Analysis (FMECA) [52], or the deeply thorough Reliability Growth Cause Analysis. As a minimum, the simpler Failure Mode Effects Analysis (FMEA) is used when criticality is not required. In an FMECA the failures identified by the FMEA portion of the method are further classified by their risk severity.

Failure Mode Effects and Criticality Analysis is both a qualitative and quantitative technique providing indication of the nature of a risk and its size. The approach involves documenting the findings of a detailed design review on the failures inherent in the design of an equipment item. It permits identifying how equipment parts can fail and lets you recognise when to design-out a failure, or apply suitable maintenance and operating practices to prevent a failure. Table 10.1 lists the meaning of words and terms used in FMECA/FMEA.

Table 10.1 – FMECA/FMEA Terms and Definitions.

Term	Definition
Failure	Any unwanted or disappointing behaviour of an item
Failure Mode	How a part, or combination of parts, fails. Failure modes can be electrical (open or short circuit, stuck at high), physical (loss of speed, excessive noise), or functional (loss of power gain, communication loss, high error level)
Failure Mechanism or Cause	The processes by which the failure modes arose. It includes physical, mechanical, electrical, chemical, or other processes and their combinations. Knowledge of a failure mechanism provides insight into the conditions that cause failures
Failure Site	The physical location where the failure mechanism is observed to occur, and is often the location of the highest stresses and lowest strengths
Failure mode	Effect of the immediate consequence on the use of the item
Criticality	Combines Severity (a measure of cost and inconvenience of the failure) and Frequency (how often mode(s) that cause a failure arise) to indicate the risk caused by the item should it fail
Critical Item	Is a part or assembly where the failure mode(s) remains and has not been designed-out. These items require operating and maintenance strategies to ensure a long trouble-free life
FMECA Report	A document that explains why known modes of failure occur. It becomes the basis to decide the maintenance strategy for a part or assembly

There are two levels at which the FMECA/FMEA can be conducted. One is to look at the loss of the equipment to identify what failures would cause that to happen. This is the Functional Approach, and has some commonality with Reliability Centred Maintenance. The second method is to look at each part and identify what would happen if it failed and how the failure could be caused. This is the Hardware Approach. The second approach is the more thorough, though requiring more time. It is required by the Plant and Equipment Wellness methodology.

[52] Sherwin, David., Retired Maintenance and Reliability Professor, 'Introduction to the Uses and Methods of Reliability Engineering with particular reference to Enterprise Asset Management and Maintenance' Presentation, 2007.

The Criticality portion of FMECA is typically a mathematical calculation of the probability of the failure occurring [53, 54]. A concern in using formulaic criticality values is they are unlikely to be right. Both the chance of a situation arising exactly as imagined, and of producing the cost consequences expected, is highly variable. The actual risk depends on the circumstances present at the time and the nature of the situation. The Severity and Frequency used to calculate Criticality can only ever be guesses, which means the resultant is an even bigger guess. Because the probability calculations are difficult and the results may be misleading anyway, Plant and Equipment Wellness rates criticality with the risk matrix method of Chapter 8 – Operating Equipment Risk Assessment. It assumes certain failure, and the risk level (a measure of criticality) is determined using the resulting DAFT Cost and business consequences. Mitigation is then selected to reduce the frequency to a level unlikely to happen during the operating life of the equipment. An FMEA is used to determine the parts failures that stop equipment.

Failure Mode and Effects Analysis

When traditional Criticality is not included in the analysis it becomes a Failure Mode and Effects Analysis. A table is used to review each assembly and its parts for the many ways they can fail. Table 10.2 is a sample of the Plant Wellness FMEA worksheet layout.

The normal practice in an FMEA is for a team of specialist in the equipment's design, use and maintenance to conduct a design review. The team looks at each equipment asset to find and record all the ways in which it can fail. They assess the effect of each failure on the equipment's ability to continue in operation. For each failure mode the team suggests risk mitigation. These include redesign, preventive and predictive maintenance, improved work quality control or, in low consequence situations, to allow the failure to happen. Once the strategies to control or prevent the failure are selected, another review is made of how truly useful they will be in reducing stress levels significantly enough to stop failure. An important consideration during the FMEA is to identify when two or more parts could fail in association. The combined failures of multiple parts may lead to greater catastrophe than one part failing alone. These combined failures also need to be considered and controlled.

When used during design the principle is to consider each mode of failure of each part and determine the knock-on and system-wide effects in-turn. The learning from the FMEA is put back into the design and the equipment is improved. Specific risk management requirements can also be placed on operational and maintenance groups when the equipment is in service. It is an iterative process performed regularly during the design. When FMEA is used on existing operating plant and equipment many modes of failure are already known. Modes that are unlikely to occur in the operation are checked for their DAFT Costs and then a decision is made as to whether or not they will be pursued.

FMEA is also useful when doing root cause failure analysis to investigate how parts in equipment can fail. The evidence from the failure incident is used to confirm failure mode(s) and causes.

Performing a Failure Mode and Effects Analysis

1. Start by specifying the purpose of the FMEA. It can be for reasons of safety, reliability improvement, plant availability, repair cost, mission success, etc. to align attendees' viewpoints.

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53 MIL-STD 1629 , 'Procedures for Performing a Failure Mode, Effects and Criticality Analysis'.

54 BS5760 Part 5, Reliability of systems, equipment and components. Guide to failure modes, effects and criticality analysis (FMEA and FMECA).

Table 10.2 – Plant and Equipment Wellness Failure Mode and Effects Analysis Worksheet Layout.

System: ______ Equipment: ______ Drawing: ______				**FAILURE MODE and EFFECTS ANALYSIS WORKSHEET**						Date: ______ Sheet: ______ of ______ Complied By: ______ Approved: ______		
ID No.	Item Description	Function	Failure Modes	Failure Causes	At What Stage of Operation	Failure Effects			Symptoms prior Failure	Failure Detection Method	Rectification on Failure	Corrective Action to Prevent
						The Item	Neighbours	System				

2. Assemble a cross-functional team of people competent in the equipment to conduct the FMEA.
3. Provide all available design data and operating data to allow development of a full understanding of the equipment design and its service.
   a. Each equipment asset and its assemblies need to be identified down to the part numbers on the bill of materials (BOM).
   b. The equipment operation and design must be well understood by the people doing the FMEA.
   c. The process conditions impacting the equipment and its components must be well understood by the people doing the FMEA.
4. Develop a process map of how the equipment operates (known as a functional block diagram).
5. Prepare the FMEA worksheet listing assemblies and components.

Put the team into a quiet, spacious room to work. Record results directly into a computer spreadsheets, or a large sheet of paper at least A3 size. Use a reference number for each failure mode to differentiate it from others. Write plentiful and clear descriptions – words are more important than numbers. Record the decisions made and the follow-up actions to be taken. On the process maps use historic records of failure to show those items that have failed, the failure frequency and all known failure causes. Include a remarks column to pass-on advice and knowledge to others so they do not unnecessarily repeat the work.

Complete the FMEA for all parts/component in all equipment using the FMECA spreadsheet on the CD accompanying this book. Column by column in the spreadsheet the team enters the required information and develops a thorough understanding of how parts can fail in service. For those items with stresses that are not significantly reduced, consequence reduction strategies are used to limit loss and downtime. The review team selects appropriate condition monitoring to ensure initiated failures are caught before they cause unplanned downtime, wastage and loss. It is wise to confirm risk is reduced significantly for parts to ensure that there will be fewer failures.

Performing a parts hardware level FMEA may appear to be a lot of work. The driving premise of Plant Wellness is to achieve low-stress conditions that eliminate all part failures during equipment working life. Understanding how that can be done requires analysis of the causes of a part's stress and to identify practical measures to prevent failure. Fortunately, once a part has been through an FMEA review the results do not change greatly for other parts of that type. Once a roller bearing, or an alternating current electrical power supply, or a ball valve have been through an FMEA, the same analysis will likely apply to the next roller bearing, alternating current electrical power supply or a ball valve. The review team simply re-examines the previous FMEA to confirm its relevance and includes any changes and additions applicable to the risks in the situation being investigated.

Developing a Risk Control Plan

The FMEA process requires decisions on equipment design, maintenance and operation to reduce the level of risk a part carries. These decisions lead to actions that lower the frequency of an event and reduce its consequences. Each failure identified is addressed one-by-one until the risk control plan is complete. The risk control plan covers all that will be done, or not done, to remove or significantly reduce risk. It lists the mix of design, operating and maintenance activities that will lower equipment risk and deliver high operational reliability. Figure 10.1 shows where FMEA sits in the process of choosing risk management actions and the output it produces. Mitigation and prevention actions will fall to the Maintenance and Operations groups and design improvements will go to Engineering to do. Design-out is best done by a professional engineer or competent technical person who fully understands the equipment's purpose and design.

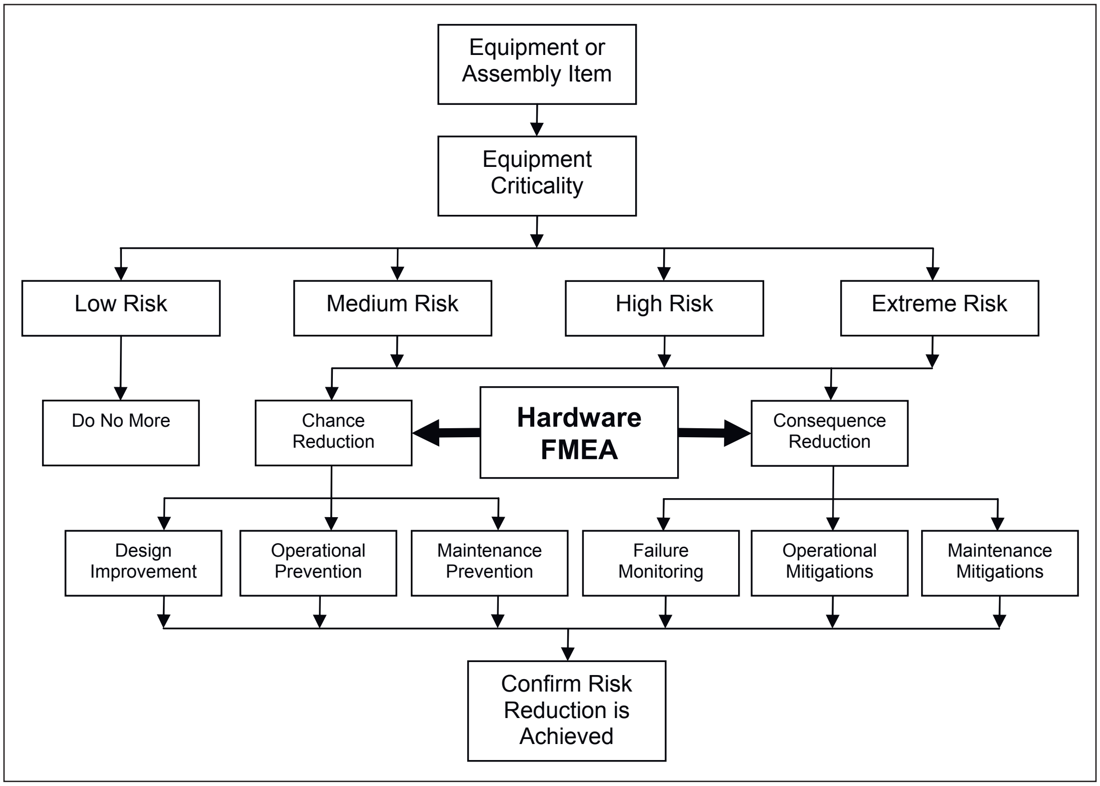

Figure 10.1 – Risk Management Strategy Selection Chart.

Maintenance Tasks, Condition Monitoring, Critical Spares

From the FMEA are developed the required operating and maintenance procedures, the specific spares holding needed, condition monitoring inspections, preventive maintenance, replacement policy (i.e. replace with new on failure, or at near end-of-life), or breakdown strategies to use for each part. Reliability can only be improved if parts are not allowed to fail and doing the FMEA at parts level identifies the engineering, operational and maintenance issues that should be addressed for maximum component reliability.

The choices available to prevent equipment failure are:

1. Placing operating limitations on distressed parts (e.g. De-rating, Over-sizing, Precision Operation)
2. Changing the design to prevent parts overstressing (Design Engineering, Design-out Maintenance)
3. Remove the situations that lead to the failure (e.g. Defect Elimination, Precision Maintenance)
4. Monitor for the failure mode to detect its onset (e.g. Predictive Maintenance, Condition Monitor)
5. Replace parts before failure (e.g. Preventive Maintenance, Age-based Renewal, Shutdown Maintenance, Overhaul)
6. Control the environmental conditions causing failure to arise (e.g. Failure Prevention, Accuracy Controlled Enterprise).

It is necessary to only hold equipment spares to the level of equipment that is replaced. For example, if a pump wet-end was to fail and the best economic decision is to replace the entire wet-end with a new one and get the old one overhauled, you would only carry spare wet-ends and not also the individual parts for the wet-end. To proactively prevent the wet-end failing you need to know how each of its parts can fail and act to prevent the failures from happening. That is where a parts-level FMEA helps you greatly.

Work Procedures and Resources Requirements

Risk reduction strategies are applied throughout the life cycle. The material selection and stress reduction choices made at design are the most effective in reducing risk. During manufacture, precision and work quality is crucial. On installation, again precision and work quality is vital to prevent distortion. During operation, low-stress operating practices are the best. When parts are stored, apply good stores management practices that retain their reliability. During maintenance, stipulate precision and quality workmanship with Accuracy Controlled Enterprise 3T procedures.

As a means to prevent parts' failures and control risk, numerous work activities involving condition monitoring, inspections, preventive maintenance and replacement of end-of-life parts will be identified in the FMEA and the equipment criticality risk analysis. Each of these operating and maintenance activities requires a documented Accuracy Controlled Enterprise 3T procedure (as explained in Chapter 14 – The Accuracy Controlled Enterprise) for performing the work to ensure the appropriate tasks are done correctly.

Included in the development of each procedure is an accurate estimate of the resources needed to do the work, the length of time they are needed, along with the parts to do the job. Once ACE 3T work procedures are written to cover a part's risk control activities, a job schedule for the year is developed. The schedule allows identification of the trade skills, the manning levels and materials needed to provide the risk management required. This information is also used for budgets and maintenance planning.

Turn the Plan into Procedures and Actions

Once developed, the plan needs approval by all key stakeholders affected. Typically, these people are the Operations and Maintenance Department Managers and Work Team Supervisors. They need to review the plan and include anything else they feel is necessary. Ideally the Team Supervisors are in the FMEA review team so they understand the purpose of the review, and support the efforts needed to instigate and perform the risk control activities that arise. It will be wise to also organise meetings with other relevant managers and workplace groups to explain and discuss the resulting plans and the roles each person plays in their achievement.

Providing avenues of communication and opportunity for discussion helps gather support from the people who will implement the necessary strategies. It is only by doing the plan that it delivers results. The plan is actioned by introducing the necessary changes and practices into the workplace. Maintenance procedures will detail the breakdown, preventive, predictive and precision maintenance activities that will control the level of risk in the operation. They ensure that the environment for the parts is healthy and the stress levels are low. The design activities incorporate the failure prevention, defect elimination and design-out tasks that prevent failures. The operations group procedures will contain activities that control variation in the use of operating equipment and deliver stable operation below parts threshold stress levels. In this way each business group limits and reduces equipment risk by respecting the Physics of Failure limits.

11. Chance Reduction Risk Management

For interrogating its secrets, it is better to write the risk equation as:

$$\text{Risk} = \text{Chance x Consequence}$$

The word 'chance' explains risk better than using 'frequency'. Chance are the odds of an outcome: a 25% chance the next card will be a spade in a pack of poker cards, a 30% chance of rain on a cloudy day. Chance has the connotation of uncertainty, of unpredictability. It implies that we do not know when an event occurs. It reflects the real world much more truthfully than does the word 'frequency'. Chance warns us that a once-in-five-year event can happen at any time; it provides a clearer connotation of risk.

Chance events require opportune occurrences to coincide. Accidents do not happen by accident. They need several enabling factors to exist together. A bad incident occurs when several unconnected factors align in such a way that the incident becomes possible. When the factors align there is opportunity for disaster. For a fire to start there must be fuel, air and an ignition source. All three must happen together. The Titanic Disaster (Example E11.1) is a famous case of consequent factors aligning to produce an accident.

Reduce the chance of an event occurring and you reduce the risk. Stop the necessary requirements for an incident to happen and the incident cannot occur. The use of 'chance reduction techniques' is the prime principle of risk control in the Plant Wellness Methodology. Risk can also be reduced by decreasing the consequences of an incident. That is the purpose of such things as emergency plans, fire brigades and ambulances. If we react quickly, correctly, and early enough, the consequences can be reduced. The use of consequence reduction techniques is a second level risk control principle in Plant Wellness.

In the risk equation the two factors, chance and consequence, are multiplied together. It would seem that the impact of either factor has equal effect on the risk. Halving the chance is equally as good as halving the consequences. Unfortunately most organisations fall into this trap. They think that it does not matter how they reduce their risk because either path produces the same result. It is not true. In reality the two 'paths' to reducing risk have totally different impacts on the prosperity of an organisation. The application of basic accountancy is sufficient to explain why the best path to take in risk management is to reduce the 'chance' of failure, and not its 'consequence'.

Impact of Risk Management Strategy

By individually applying chance reduction and consequence reduction to the basic business model we can identify their financial effect on the operation.

Figure 11.1 is the 'death of many cuts' production model encountered in Chapter 4. Each breakdown causes production time loss and a business-wide cost surge. Companies that use consequence reduction strategies minimise their losses by learning to fix breakdowns quickly. You do that by holding lots of spare parts in-store, setting-up a cache of parts by machines, training your repair people to fix things speedily or improving the equipment maintainability to do repairs faster. Figure 11.2 reflects the reduced production time loss when repairs are done rapidly. Comparing Figures 11.1 and 11.2 graphically shows that reducing the downtime produces profit improvement. Losses are less if the plant gets back into production quickly. Consequence reduction strategies do reduce risk.

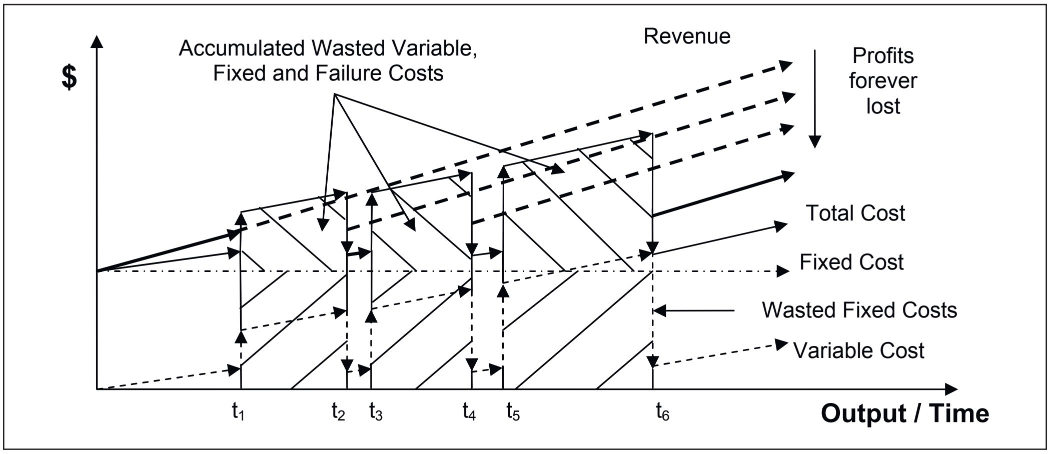

Figure 11.1 – Effects on Profitability of Repeated Failure Incidents (Death of Many Cuts).

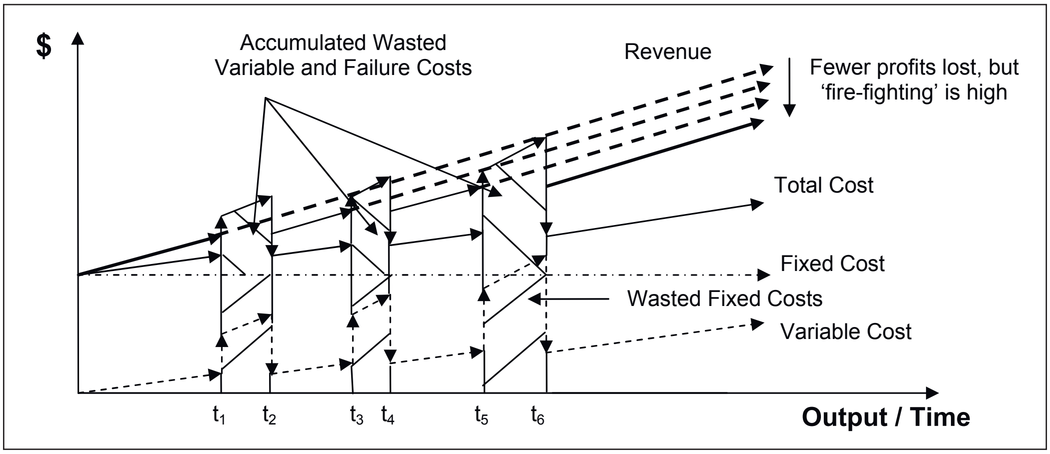

Figure 11.2 – Effects on Profit by Reducing Consequence Only.

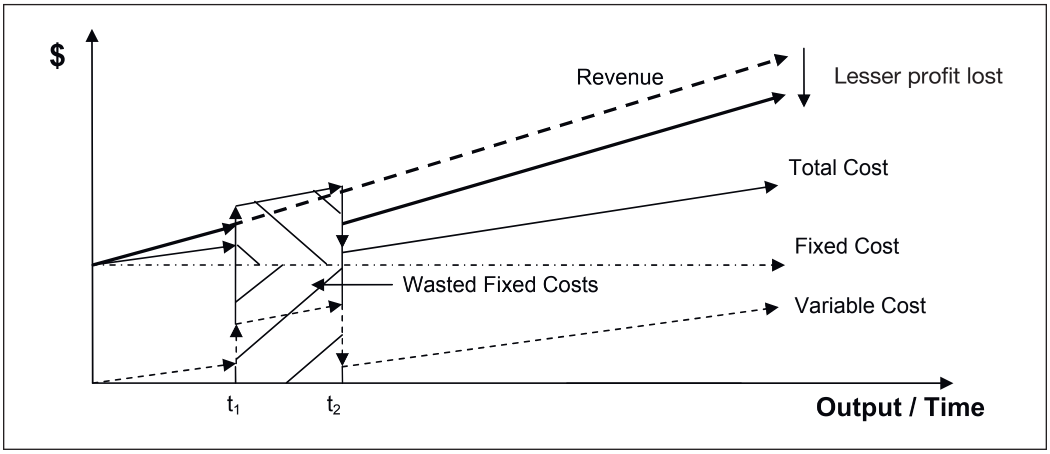

Figure 11.3 – Effects on Profit by Reducing Chance Only.

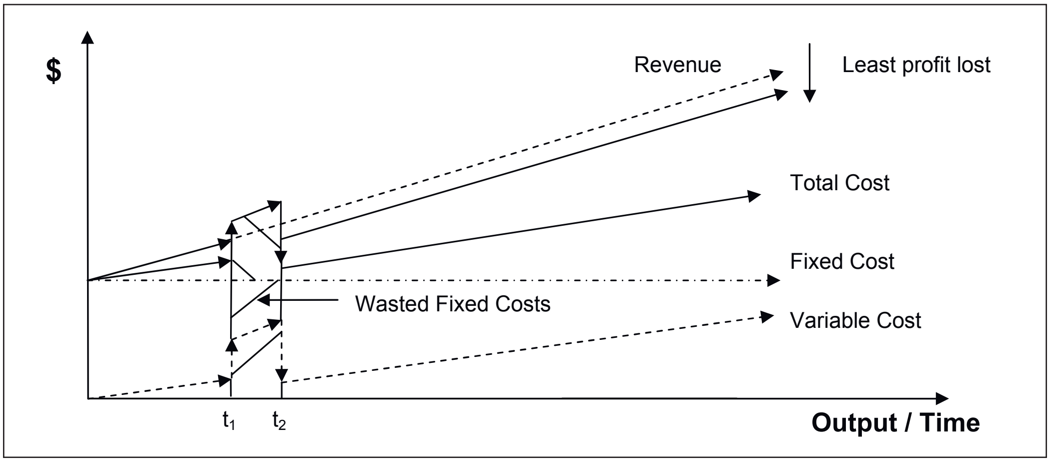

Figure 11.4 – Effects on Profit by Reducing Both Chance and Consequence.

What is interesting with the model in Figure 11.2 is that though costs reduce there will be much frantic activity and 'fire-fighting' happening in this operation. Minimising risk by reducing its consequences accepts failure incidents as a normal way of doing business. In organisations that use consequence failure management many things go wrong. Its people wait for the failures and then react to them. In this way the management instil a reactive culture in the organisation. Reducing only the consequences of risk makes work for everyone. This work is all wasted time, money and effort because people and resources spend their time fixing failures instead of improving the business. If you were to walk about in this company you would see that everyone is busy, but little of their time and efforts would add value to the operation; only more cost.

The alternate risk management strategy is to apply chance reduction techniques. In Figure 11.3 there is only one incident during the same period as there were three in Figure 11.1, while all else remains the same. Comparing the two models graphically it is evident that over the same period there is less profit lost with chance-reduction strategies than consequence-reduction strategies. Fewer failure incidents occur because chance reduction stops opportunities developing. Add-up the savings from failure surge costs not spent and you get a very profitable operation. The lower cost strategy is clear: chance reduction delivers less failures because fewer defects are present to rob resources and waste money.

A complete risk management strategy is to use both chance reduction and consequence reduction together to maximise profit. It is far better not to have a failure, but if it does happen you also need to quickly minimise its consequences. Your business processes need to be good at doing both well. The benefit of using combined strategies is evident in Figure 11.4 where both lost time and failure frequency are reduced. The business loses the least profits.

Figure 11.5 lists some of the methods available to address risk. The various methods are classified by the Author into chance reduction and consequence reduction strategies. Several observations are possible when viewing the two risk management philosophies. Consequence reduction strategies expect failure to happen and then they manage it so least time, money and effort is lost. The consequence reduction strategies tolerate failure and loss as normal. They accept that it is only a matter of time before problems severely affect the operation. They come into play late in the life cycle when few risk reduction options are left.

In comparison, the chance reduction strategies focus on identification of problems and making business system changes to prevent or remove the opportunity for failure. The chance reduction strategies view failure as avoidable and preventable. These methodologies rely heavily on improving business processes rather than improving failure detection methods. They expend time, money and effort early in the life cycle to identify and stop problems so the chance of failure is minimised.

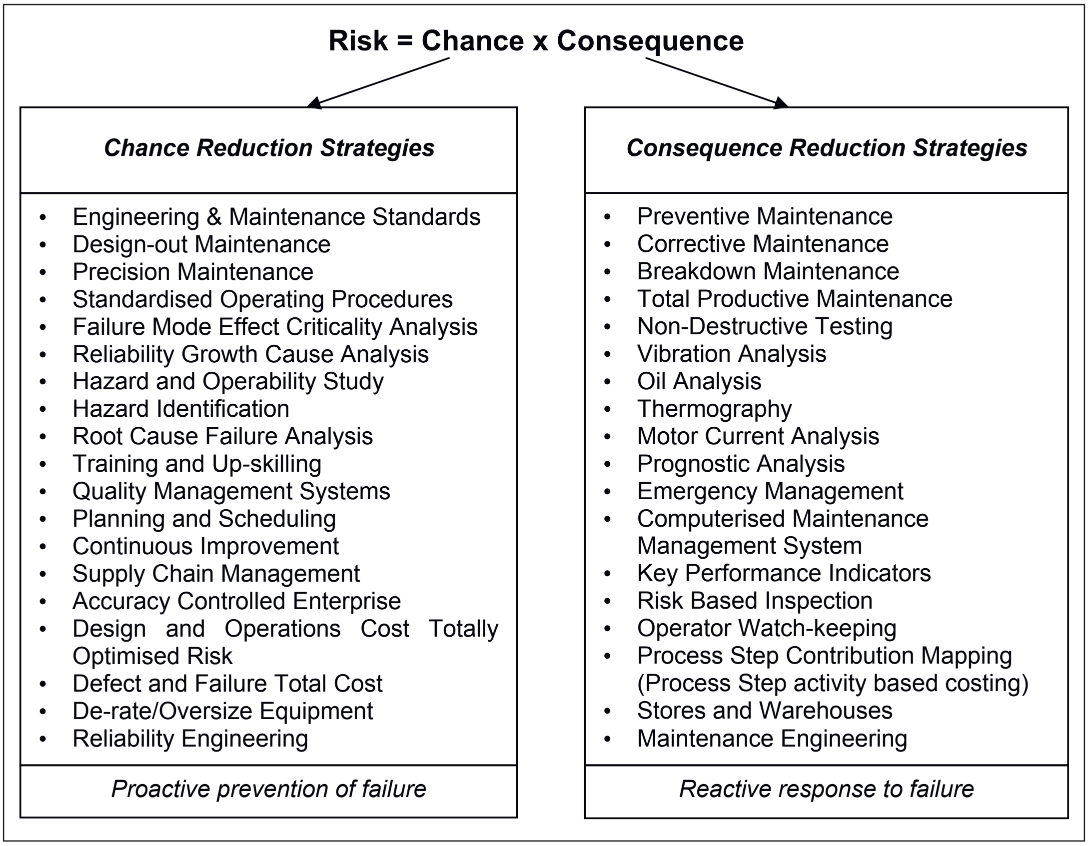

Figure 11.5 – Various Risk Management Processes and Methods.

Both risk reduction philosophies are necessary for optimal protection. But a business with chance reduction focus will proactively prevent defects, unlike one with consequence reduction focus which will remove defects. Those organisations that primarily apply chance reduction strategies truly have set-up their business to ensure decreasing numbers of failures. As a consequence they get high equipment reliability and reap all the wonderful business performance it brings.

Power Law Implications

Equations of the risk and loss type are special [55]. They are known as power laws and take the general form $x = z.y^n$. For the standard risk equation the exponent 'n' is assumed to equal 1. Power laws have particular properties. For example, they are 'scale-free'. In the case of risk it means the risk equation applies to every size of risk. It means that failure costs are not linear, and while one incident may lose a few dollars, another can total immense sums. They are "typically a signature of some process governed by strong interaction between the 'decision-making' agents in the system". This implies that risk does not arise entirely randomly; rather it is affected by the 'decision-makers' present in a system. Situations that follow power laws have a higher number of large events occurring than those of a normal distribution. For risk, this means that catastrophic events will occur more often than by pure chance. In power-law-mirrored events, a few factors have huge impacts while all the numerous rest have little effect. For risk, this means there are a few key factors that influence the likelihood of catastrophe. Control these and you increase the chance of success.

[55] Ball, P., 'Critical Mass – how one thing leads to another', Arrow Books, 2005.

Figure 11.6 shows plots of the risk equation on a normal linear-linear graph [56]. The risk plots as curves. You develop the risk curves by keeping the value of risk constant and then varying the frequency and the consequence through a range of numbers. Anywhere on a curve is the same risk. Figure 11.7 shows the log of the risk equation plotted on a log-log graph. The fact that the logarithm of the risk equation plots as straight lines has special significance. It is an example of how power laws have an uncannily ability to reflect the real world. The insurance industry uses such curves to set insurance premiums because they closely represent what actually happens in human endeavours.

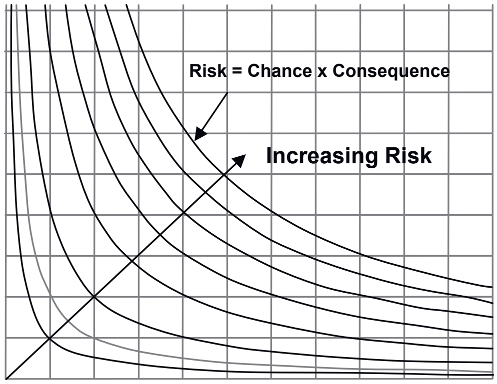

Figure 11.6 – Risk Curves on a Linear Graph.

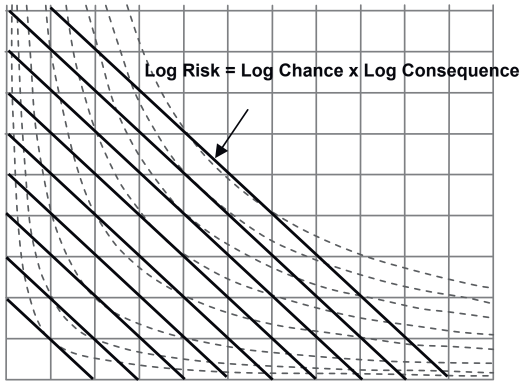

Figure 11.7 – Risk Lines on a Log-Log Graph.

Power laws that reflect the human world also tell us much about the situations from which they arise. Perhaps the most important understanding from the risk equation being a power law is the presence of 'decision-making agents' in a system. Philip Ball in his book, 'Critical Mass', points out that, "Physicists' long experience with power laws … leads them to believe that such laws are the universal signature of interdependence. A power law generally emerges from collective behaviour between entities through which local interactions can develop into long-range influences of one entity on another." Our simple risk and loss equations now take on far greater and menacing implications.

Risk reflects the presence of 'agents' working uncoordinatedly within a system. The effects of these 'independent agents' move through the system in unknown ways. The results of their uncoordinated, and most likely perfectly justifiable, efforts is to increase the risk. We now have another reason why chance reduction strategies are more successful than consequence reduction strategies in reducing long-term organisational risk – chance reduction strategies work on controlling the systems in a business. They align and coordinate masses of people and information, thereby removing the randomness of 'independent agent' influence which unwittingly acts to increase the causes of failure and loss. Gradually and continually the chance reduction strategies act to align and organize the efforts of the mysterious 'independent agents' playing unscripted parts. The randomness of their actions and effects are reduced, and finally removed. Chance reduction strategies are the total opposite to consequence reduction strategies, which live with risk and failure as normal. Instead, chance reduction strategies forever reduce risk. Because they strike at the random behaviour of the 'independent agents' within a company they align people, decisions, actions and behaviours into an over-arching system for achieving organisational outcomes. Chance-reduction strategies remove randomness and unplanned interactions from business systems by specifying an agreed approach.

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[56] Buckland, Peter, Extract from 'Boss, we need a new switchboard' Presentation, Australian Asset Management Council, 2005.

It is in your organisation's best interest, and it will generate the most profit consistently for the least amount of work, to focus strongly on the use of chance reduction strategies. Consequence reduction strategies are still important and necessary – once a failure sequence has initiated you must find it quickly, address it and minimise its effects so you lose the least amount of money. But consequence reduction will not take your organisation to world-class success and profit because it expends resources. Only chance reduction strategies reduce the need for resources because they proactively eliminate failure incidents through defect elimination and failure prevention.

Nothing is certain with risk; it changes with the circumstances. Controlling risk demands that an organisation has the culture and practices to guarantee continuous, rigorous compliance to risk reduction practices, else the chance of failure rises over time as systems degrade. Eventually the worst will happen.

Similarity between Safety Incidents and Failures

Some consequences of risk will be negligible, and perhaps only an inconvenience at worst, others will be severe, and some catastrophic.

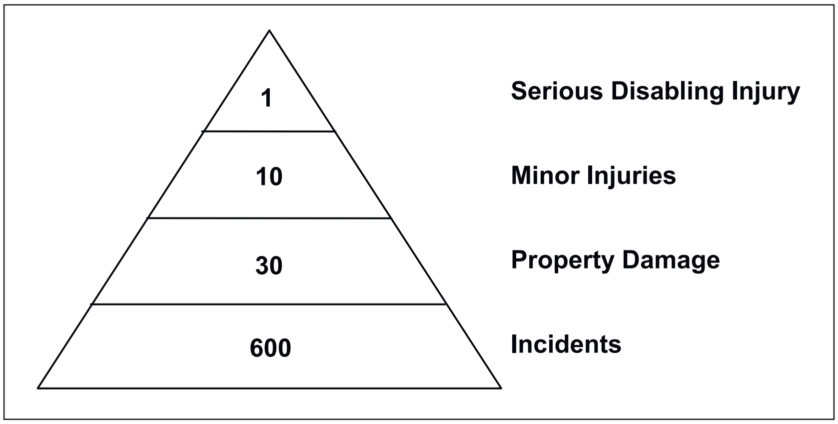

Figure 11.8 – The Updated Heinrich Accident Pyramid.

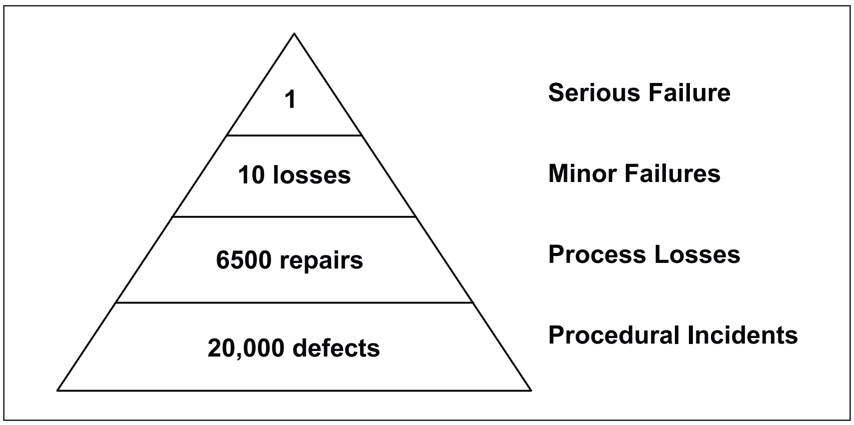

Figure 11.9 – The Failure Pyramid.

Figure 11.8 is the updated 1931 H.W. Heinrich accident pyramid that shows for every serious injury there are many minor incidents preceding it [57]. If there are sufficient numbers of incidents, probability means that one will progress to causing serious injury at some stage.

Analysis of historic industrial safety data not available in 1931 highlighted that the safety pyramid is not completely representative of the real workplace. It correctly represents the situation for minor injuries, where reducing the number of safety incidents leads to fewer injuries. But the new data indicated that reducing the number of incidents did not reduce a proportionate number of serious injuries. This is in-line with the realisation that risk is a power law and influenced by the 'decision-making elements' within a system. Serious injuries are not accidental but the result of systematic failure caused by unintentional outcomes of uncoordinated 'decision-makers' in the system. Current best practice in workplace safety is to actively seek serious injury causing situations before they happen and immediately act to stop them from ever leading to a real injury.

There is equivalent industrial data for the number of equipment failure opportunities needed before there is a serious production breakdown. The concept of a failure pyramid, with many small errors at the bottom leading to ever greater consequence levels above, applies [58]. Figure 11.9 is the failure pyramid for equipment failures.

As with the accident pyramid, the failure pyramid reflects a power law, and stopping minor failures does not prevent catastrophic failures. Catastrophic loss is not controllable until the 'decision making elements' in a system are controlled. Like minor safety injuries, minor equipment failures can be reduced by preventing the numerous and ever-occurring small errors that precede them. But to address catastrophic failures you must intentionally imagine the worst outcomes, then proactively put into place the necessary measures to prevent them from ever happening. The Plant Wellness Equipment Criticality process adopts that logic. The DAFT Cost can be immediately calculated for the full consequential costs of an event. Should the consequential costs be too high, additional protection measures are immediately included to lower the chance of occurrence. Frequency is an unimportant consideration in failure prevention because when catastrophe happens is unknowable. We must always be prepared. By first identifying the full cost of failure, our risk adverse natures prompt us to take wise precautions when the cost of being wrong is too extreme.

Even if the frequency of occurrence could be determined, the nature of risk, with its independent actors all playing unscripted parts, means the frequency will not stay the same. This implies that basing risky decisions on things not changing for long periods of time is fraught with danger. It is highly unlikely that frequency remains constant, because factors totally unknown and unknowable caused by the 'decision-making agents' are forever altering the future. What worked for us one day to prevent failure may not work the next day because failure has found a different route. Our only protection against risk is to be ever vigilant of its presence – look for its warnings, foresee and eliminate those that we can, and prepare yourself to fight back when it finds new ways to attack.

Example E11.1 – The Titanic Disaster – When Gaps in Protection Systems Align

There is one further concept about risk that is worth understanding, and adds to the justification of managing risk by chance reduction rather than consequence reduction. Catastrophic events, where life is lost and great costs result, do not often happen. For catastrophic loss to happen it requires the sequential failure of a number of overlapping protective systems.

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[57] Saldaña, Miguel A M et al., 'Assessing Definitions and Concepts Within the Safety Profession', International Electronic Journal of Health Education, 2003; 6:1-9.

[58] Ledet, Winston, The Manufacturing Game, Ledet Enterprises Inc., 2002.

The iceberg was not the only reason the Titanic sank and caused great loss of life. The captain ran the ship at high speed during fog conditions in iceberg prone seas. The rudder was too small. The ship was not fitted with sufficient safety boats for its entire complement of passengers and crew. The ship designers incorrectly deemed it as unsinkable through gross misunderstanding of the capability of the engineering design. The steel specified for use to build the vessel was crack-propagation prone.

On the night of the fateful disaster all these failures, errors and mistaken decisions aligned when the ship hit the iceberg and a great loss of life resulted. Like rubbing two palms together with outstretched fingers, when the fingers align a gap appears. So it was with the Titanic, the gaps in each layer of protection – operating procedures, safety practices, design assumptions, material selection – appeared and nothing was left to prevent a catastrophe.

The many small failures that happen in a business, such as misread numbers, incomplete information, wrong material selection, training not provided, poor procedures and documents, short-cutting tasks, and many other similar blunders, will at some future time allow the gaps in protection to align and cause unwanted problems to pour through and drown the business and its people.

Prevent failure incidents by providing numerous layers of various protections, and do properly the requirements for each layer. As with improving reliability, the more independent parallel proof-tests used for each activity, the fewer errors get through to later cause problems. Perhaps a minimum is to have three independent, unconnected layers of protection in place everywhere. For example, in a production environment start with well-documented, accuracy-controlled procedures, then add thorough training and retraining and finally a comprehensive testing and audit process of workplace practices. A second example is a capital project to increase plant capacity. Start the design with detailed and clear operational, equipment reliability and financial performance requirements written by the 'customer'. During the design phase, test and prove the proposals will deliver all requirements by prototyping, modelling or third-party review. The third layer is to conduct thorough and comprehensive reliability, availability, maintainability, safety and profitability studies and reviews with the 'customers' involvement prior to purchasing plant and equipment.

Before deciding the number of protective layers you need for a situation conduct a risk analysis and let the results of the analysis determine the final number of protective layers required to deliver the risk control certainty needed. Organisations that do not have multiple ways to prevent failure or problems, or do not demand and enforce the proper and full adherence of installed risk management practices, will always suffer losses, high costs and much waste – how can it be otherwise when they have not protected themselves properly.

Selecting Maintenance Strategy for Risk Management

Maintenance is a risk management strategy. When used as a chance reduction tool, maintenance is an investment spent proactively to prevent failure. As a result it delivers low-cost operation because few things go wrong. When maintenance is used as a consequence management tool it is applied after failure, and so it is wrongly seen as an expense to be minimised. Maintenance used to prevent failures is cheap; when used to repair failures it is expensive. The Figure 12.1 shows the process used in the Plant and Equipment Wellness Methodology to match maintenance strategy for an equipment asset to its business-wide risks.

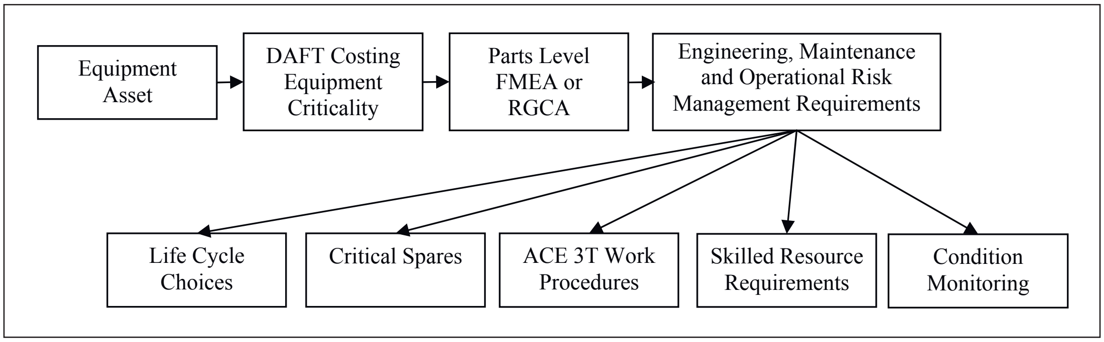

Figure 12.1 – Developing Maintenance Strategy for Risk Management.

Table 12.1 overlays engineering, maintenance and operations risk management activities onto a risk matrix to show how methodologies and activities can be selected and matched to business risk in order to protect a business from potential failures and catastrophe.

Table 12.1 – Maintenance Management Strategies Matched to Risk Levels.

Consequence		Insignificant	Minor	Moderate	Major	Catastrophic
Frequency		1	2	3	4	5
6	Certain	PM / Precision	CM / Precision	Precision / Design-out	Design-out	Design-out
5	Likely	PM / Precision	CM / Precision	Precision / Design-out	Precision / Design-out	Design-out
4	Possible	PM / Precision	PM / Precision	CM / Precision	Precision / Design-out	Precision / Design-out
3	Unlikely	BD	PM / Precision	CM / Precision	CM / Precision	Precision / Design-out
2	Rare	BD	PM / Precision	PM / Precision	CM / Precision	CM / Precision
1	Very Rare	BD	PM / Precision	PM / Precision	CM / Precision	CM / Precision

Equipment Criticality Assessment

The aim of assessing equipment criticality is to identify the severity of the business-wide impacts if an equipment asset fails. The process develops clear, justifiable strategies to reduce risk by applying the methods explained in Chapter 8 – Operating Equipment Risk Assessment.

Failure Mode and Effects Analysis or Reliability Growth Cause Analysis

Failure Mode Effects Analysis investigates the ways that the parts in a machine can fail when in use and identifies the actions to be taken to prevent the failure. The methodology uses a cross-functional team of experienced people to remove the various modes of failure for each part. They develop the corresponding plans and actions to prevent the failure and/or minimise the consequences. It can be applied to civil, structural, mechanical, electrical, communications or instrumentation assets, and the like.

Reliability Growth Cause Analysis considers all life-cycle risks an equipment part will face that can cause it to fail. Like FMEA, a competent, cross-functional team is needed for the analysis, but the focus is vastly different. An RGCA looks for ways to make equipment parts live outstandingly long lives. How to apply a Reliability Growth Cause Analysis is explained in Chapter 18 – Reliability Growth.

Plant Planned Maintenance and Operating Strategy

It is now time to summarise the contents of the book into a methodology for identifying the maintenance and operational strategies and activities that create plant and equipment wellness. The development of a strategy starts by stating the outcomes required. They may not be easily achievable, but you only have to continually improve your processes and they will be realised.

Set the Objective

Set measurable objectives based on the asset management and maintenance policies. For example:

a. To reduce the maintenance costs in the plant to 2.5% of replacement asset value.

b. To reduce breakdown maintenance costs below 10% of total maintenance cost for the plant by instigating defect elimination practices and conducting planned maintenance activities that renew plant and equipment before failures occur.

Methodology to Follow

The method to achieve the above objectives are summarised in the following steps;

1. First check what proportion of current maintenance effort is reactive work fixing things, versus pro-active work that stops them from failing in the first place. You want to be spending most of the maintenance time doing proactive work (defect elimination). Also identify what proportion of the maintenance effort is actually assisting project or production groups and not doing maintenance related work.

   Review the last two years of maintenance work history and separate into four categories of Proactive, Reactive, Improvement and Assistance work. Compile costs and man-hours per category to determine proportions of cost and effort spent for each. The Proactive category includes preventive maintenance, predictive condition monitoring, design-out maintenance, statutory maintenance, etc. Reactive includes corrective repairs, breakdown maintenance, emergency maintenance, safety or incident related maintenance, etc. Improvement includes equipment or process modifications to improve reliability. Assistance is maintenance resources used for capital projects, plant upgrades, production requests, etc.

2. Draw the process maps for each production line and for each equipment item in the line. Collate the equipment list from plant drawings, instrument and process diagrams and equipment asset lists. Be sure to capture all equipment in operation, as it will later be necessary to go to assembly and component levels of analysis. Ensure every equipment item required to run production is on a process map. This includes items used only at start-up or shutdown.
3. Logically divide the production process into definable sections. Put the full list of production line equipment used in each section of the process into the Risk Identification and Grading spreadsheet on the CD accompanying this book. For each section, list each item of equipment in the order encountered in the process, along with its assemblies and parts. List down to the lowest identified part number in the Bills of Material.
4. Determine the business-wide DAFT Costs for each equipment item. The DAFT Cost for equipment or assembly parts failures is used to make decisions on whether or not it is worth doing risk mitigation activities. Repeat this for all assemblies and components in the respective equipment. For each item of equipment, record what assemblies and parts are critical for the equipment to operate correctly and produce quality production. As a consequence risk reduction strategy, it may be necessary to keep some of these parts as spares if their failure jeopardises the business.

   For a parallel activity to check the DAFT Cost impacts, rate the most severe impact of individual equipment failure on a 5-point scale. 1 is immediate and total impact; major injury requiring hospitalisation or worst; permanent environmental damage. 2 is delayed total impact; medically treated injury; rehabilitatable environmental impact. 3 is reduced or hindered operation. 4 is inconvenience to operation. 5 is no impact. You have now determined the severity to the business for all its equipment and identified which assemblies and components are critical to its operational success.
5. From CMMS records and operating records identify failure frequency and annual maintenance costs per equipment. You need a representative period of time that reflects the effects of an operation's culture and management practices. Five or more years is ideal. If the plant was upgraded, or the process changed, then take the records from the date of commissioning the change. Where job costs are reliable and accurate, identify costs, man-hour and materials required for regularly recurring work to assist future estimating and planning purposes.
6. Using Pareto analysis, identify the high maintenance cost equipment recorded in the CMMS. Each of the top 20% most costly equipment can also be analysed using double-Pareto to identify their failure causes and pinpoint possible solutions.
7. For a double check, and as a parallel-test activity on work done so far, conduct an on-site tour and review of plant and equipment with experienced Operations and Maintenance personnel to identify operating problems not reflected in the maintenance records. Identify problem equipment, failure frequency, consequences and critical parts required for each plant asset. Confirm you recorded all issues from the site tour and the CMMS review in the Risk Identification and Grading spreadsheet.
8. Perform a Plant Wellness Equipment Criticality analysis.
9. In priority order of equipment criticality, conduct a parts hardware-level FMEA, or RGCA, with experienced engineers, operators and maintainers. Identify at-risk parts and select activities to address the risks. Mitigations can be chance and consequence reduction strategies payable by the DAFT Cost savings they deliver. In preference use chance reduction strategy ahead of consequence reduction.

   Using the Risk Management Plans spreadsheet, create planned maintenance activities to perform preventative maintenance, condition monitoring, renewal or refurbishment of equipment and components. Set the timing and the quality standards of each activity so that the activity prevents the failure. The quality standards to adopt are those world-class best practice requirements that significantly reduce stress in the parts.

Secondly, with the help of operations personnel develop operator inspection and check sheets so that operators can perform watch-keeping activities during their normal rounds.

Third, review if the current planned and preventative maintenance activities are still relevant, or need to change to suit the new planned maintenance requirements.

Fourthly, include maintenance activities for statutory compliance, quality control, safety hazard mitigations, and the like, not identified by the FMEA/RGCA.

10. Confirm planned activities significantly reduce risk by a minimum of two levels on the risk matrix for Extreme and High rating, and to low for Medium ratings. Ensure significant reductions in the Physics of Failure and parts environmental stress factors.
11. For each item of production equipment, financially model the new planned maintenance activities and compare the new cost to the current maintenance costs to provide economic justification for changing maintenance and operating strategies. Review the new balance of costs between expected Reactive and Proactive categories to confirm the majority of time is on proactive pursuits.
12. With help from maintenance planners, develop each planned maintenance activity into ACE 3T 'good, better, best' banded procedures. To help future job planning, include a scope of works with itemised tasks, materials list and cost estimation. Provide materials lead time indication, trade man-hours estimation and the total work order cost estimate.
13. Catalogue and cost the spares identified as critical requirements for plant and equipment from the FMEA/RGCA.

    Detail the spares required for planned maintenance activities each financial year for inclusion in the annual financial budget.

    Update critical spares list and order spares in a controlled and financial responsible manner.
14. Prepare the maintenance schedule and budget in advance for the next two years, including factoring the improvement effects on equipment reliability of the new planned work orders. Update the CMMS with the new planned work order details. Develop the resulting maintenance resource demand into an overall resource schedule.
15. Submit the plant maintenance budget into the corporate accounts
16. Track each production plant's equipment reliability performance to ensure it is improving.

Flow Chart of Planned Maintenance Strategy Process

Figure 12.2 is a summary flow chart of the methodology. Bullet-point comments on the requirements and aims of selective steps follow.

Collect Historical Information

- Gather Process Flow Diagrams, Process and Instrumentation Diagrams, Equipment Asset List
- List all equipment units and interconnecting processes in a spreadsheet.
- Insure all equipment has an asset number (tag number).
- Create a full and complete list of plant equipment assets.

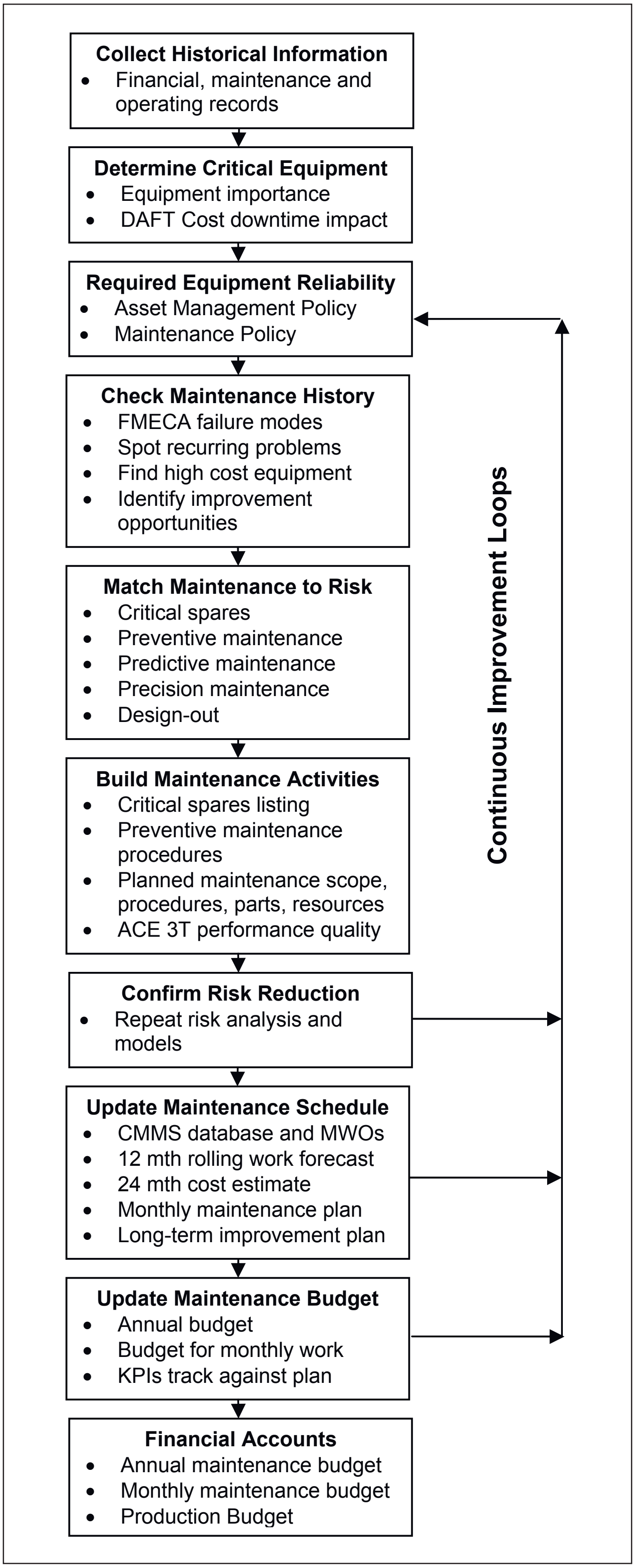

Figure 12.2 – Planned Maintenance Flow Chart.

- Group equipment assets into their process function, e.g. Bulk material handling, mixing, reaction, storage, filtration, filling, etc
- Draw the process maps

Criticality Assessment

- List all plant used for a process function into a spreadsheet. For individual plant, list each piece of equipment and its primary assemblies. Under each assembly, list components. Continue listing working components until all working items on the bill of materials for each assembly are recorded.
- From equipment maintenance history, identify the annualised number of failures for equipment, assemblies, sub-components, and parts.
- Taking a piece of equipment/assembly one at a time, use DAFT Cost of Failure to rate the worst impact of its failure on the business. Use the consequential cost to get a risk matrix rating for the item (E, H, M, L) and a risk number (add together the numeric values for 'likelihood' and 'consequence')
- Reduce the DAFT Cost and risk number value by deciding what operating activities and maintenance types an item requires to ensure stresses are significantly reduced to produce a long, low-stress service life.

Review, Categorise and Proportion Current Maintenance Efforts and Costs

- Differentiate all historical work orders into primary categories identifying the reason for the work order. Typical examples at 'Failure' related, 'Preventative' related, 'Improvement' related, 'Assistance' to Production related.
- Determine the total material costs, labour costs and labour hours for the period expended by in-house maintenance trade type and by contracted services/trade type in each primary category.
- Determine the proportion of hours and costs in each primary category to identify which are disproportionate to the risk reduction value they provide.

Identify High Maintenance Cost Equipment from CMMS

- Analyse past work orders and history to identify problem equipment with high costs, repetitive failures, and long downtime.
- Collect repair times and costs for work on high maintenance equipment to use in estimating future planned maintenance jobs.
- Identify those items of plant that require engineering review to design-out problems. An engineer or the like will need to address these.

Pareto Analysis of High Cost Equipment

- Review work order costs for last two financial years and categorise equipment in order of cost to the business.
- Review numbers of work orders against each item of equipment for the last two financial years to determine which equipment are a high drain on maintenance resources.

Plant Review with Operators and Maintenance Technicians

- Taking each equipment item one at a time, find out from an experienced operators and experienced mechanical and electrical maintainers, what goes wrong with the equipment and how often. Record any comments on necessary spares, causes and solutions to the failures.
- Compare back to the CMMS history review to confirm the degree of the problem. What operators and maintainers perceived may not be noted in the CMMS records.

Conduct an FMECA/FMEA or RGCA

- Gather a cross-functional team and do a parts-hardware level FMEA, or perform the life-cycle encompassing Reliability Growth Cause Analysis to identify the means for preventing parts failures.

Create Planned Maintenance Activities to Address Equipment Failure Frequencies

- Based on severity and frequency of failures develop planned operating and maintenance activities to reduce future occurrences. Select the activities and set quality standards that will stop parts failure from operational stresses.

  Include requirements for statutory compliance of equipment. Use 'roundtable' meetings of maintenance trades, operations personnel and experienced engineers to get consensus.
- Develop for each identified item of equipment a list of Preventive Maintenance (PM) parts replacement and Predictive Maintenance (PdM) condition monitoring tasks to be performed.
- Record estimates of trades, times, additional resources and materials to do each PM and PdM.
- If operators can do the maintenance activity well, identify it for discussion with the operations manager as the start of a Total Productive Maintenance (TPM) program.

Detail the Critical Spares Required

- Based in the criticality analysis, CMMS review and FMEA, compile the critical spares required, listing the model details, part number and supplier.

Develop Planned Maintenance Activities

- In order of equipment criticality, develop the specified planned activities.
- Include a full work scope, materials list, materials cost estimate, lead time for materials, trades requirement, trades time estimate, labour cost, ancillary items and costs.
- Produce ACE 3T precision procedures for all activities.

Confirm Risk Reductions

- The effect of activities to reduce parts' risk are assessed to ensure that they do deliver the needed risk reduction. Use the Risk Treatment Schedule and Action Plan Template, Table 8.5, to gauge that the total effect of proposed actions will reduce current risk level sufficiently. Alternately, a spreadsheet such as that for Risk Reduction in Table 8.6 can be extended to include the action plans and the confirmation that they will significantly reduce risk.

Model Revised Costs Based On Likely Results of New Maintenance

- Do a spreadsheet analysis to estimate the cost of using the proposed planned maintenance and frequency of tasks. Compare it against current costs and proportions of work effort.

Prepare a Planned Maintenance Schedule and Budget for the Coming Financial Year

- For each production plant develop a forecast maintenance budget based on the new planned activities. Include all statutory compliance requirements, any planned equipment replacements, along with any site specific work that is done on the maintenance budget.

Submit Revised Maintenance Budget to Corporate and Track Performance

- Role the new forecast maintenance costs for the plant into the company wide budget.
- Trend and monitor each plant's monthly breakdown performance with suitable Shewhart control charts using 3 sigma limits and/or with appropriate KPIs.
- Investigate special cause discrepancies and rectify them as appropriate.

Example of an Equipment Risk Reduction Strategy

Developing a maintenance strategy to prevent failure of a centrifugal pump-set would start by drawing the process map for the equipment. The pump-set could fail for many reasons, as could any of its parts. The wet end could fail, the shaft bearings, the shaft coupling, the motor internal parts, the power supply to the motor, and the mounting frame or foundation plinth may fail. Each of these assemblies must be analysed in detail to spot the risks they cause.

From the analysis a maintenance strategy that delivers high reliability for each assembly is developed. An example of an operational and maintenance risk reduction strategy for the pump bearings is shown in Table 12.2.

If the proposed operational and maintenance strategy in Table 12.2 is carried out properly it will ensure the pump bearings have a long, failure-free life. The precision maintenance laser alignment removes the chance of overstressing parts and the inspections remove the risk of unknown environmental and operational degradation. The likelihood of a bearing failure event on the risk matrix has gone from 'likely' to 'very rare' and the criticality from High to Low.

The development of the risk control strategy then continues for each piece of equipment, assembly by assembly, failure mode by failure mode. There is great effort and time required in doing this level of risk assessment and risk control. It is the only way to ensure that risk is understood thoroughly enough to protect the business by greatly reducing the chance of catastrophe for the operating lifetime of the equipment.

The Operating Risk Control Methodology only produces understanding and pieces of paper. What is now vital is to actually do the risk reducing activities. The Accuracy Controlled Enterprise methodology is used to ensure the correct work is done so well that the chance of a failure is greatly reduced.

Table 12.2 – Example Pump Bearings Reliability Strategy Development.

Equip Tag No	Current Failure Events	Failure Events Frequency	DAFT Cost of Failure	Risk Reduction Activity	Improvement Expected	Freq of Activity	Cost / Yr	Failure Event Reduction
Pump 1	Bearings fail	2 years	$35,000	Laser shaft alignment to precision practices every time the pump is installed	A precision alignment is expected to deliver 5 years between bearing failures	Every strip-down	$200	Failure interval now likely to be greater than 5 years
				Oil and wear particle analysis every 1,000 hours of operation	Oil and Wear Particle Analysis can indicate the start of failure several hundred hours prior the event	1,000 hrs or Six monthly	$600	Failure will be prevented by a predictive planned condition monitoring task
				Visual inspection by the Operator each shift of the oil level in the sight glass	Visual inspection of the oil level ensure the bearings are always lubricated	Every Dayshift	No cost	Failure will be prevented by operator condition monitoring
				Operator physically touches pump bearing housing each week to feel for changed temperature and vibration	Touching the bearing housing will identify impending problems before they cause failure	Wednesday Dayshift	No cost	Failure will be prevented by operator condition monitoring
				Motor load monitoring using process control system to count overloads	Monitoring the electrical load will identify how badly and how often the equipment is stressed by overload	Continuous with monthly report to Ops Manager	$100	Poor operating practices will be identified and personnel trained in correct methods
				Pump performance monitoring of discharge flow and pressure using process control system	Monitoring the pump performance will indicate gradual changes of pump internal clearances affecting service duty	Continuous with monthly report to Ops Manager	$100	No direct impact on reducing risk of pump failure, but identifies performance drop and allows planned maintenance to rectify internal wear.