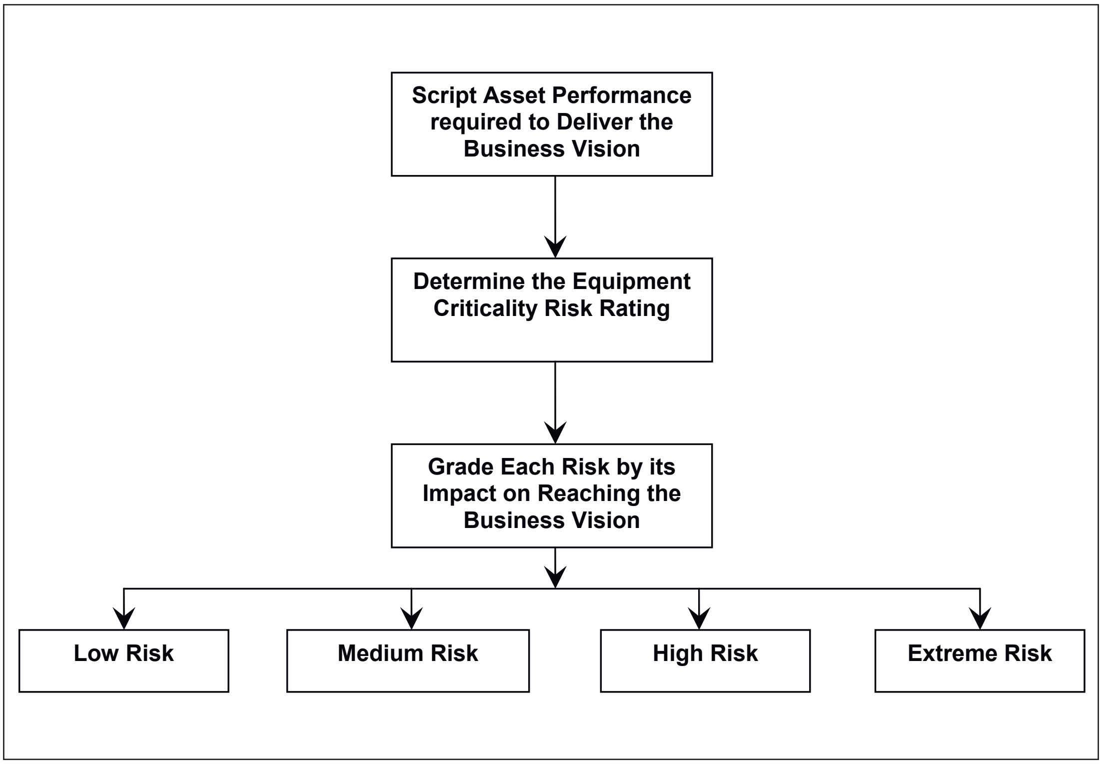
PROCESS 2 – Operating Risk Rating



Description of Process 2 – Risk Rating

Script Asset Performance that delivers the Business Vision:

Before going further with the risk analysis, identify why an asset is in your business and its purpose to the business. Describe in words how each asset benefits the business. Then describe how the asset must perform day after day in order to produce those benefits. Quantify that performance with measurable numbers. Use the process map in which the asset belongs to describe the impact on the operation and the knock-on effects across the business if the asset is not available for service.

For example, a pump used to move product from a vessel to a storage tank must deliver a desired flow at a specific pressure using a motor of sufficient power. The pump must perform its service a certain number of times a day for a certain period at a particular step in the process. This information is important in deciding how critical the equipment is to the business. If the pump cannot do its job, you must know what the impact is to the business. Do this for every item of equipment so its importance is made clear.

Not all assets are equally important and we need to match risk control to the effect the loss of the asset causes the business. The scale of those effects is what the DAFT Costs make clear.

It is also necessary to develop both an Asset Management Policy and a Maintenance Policy. These policies tell why Asset Management and Maintenance are important to the business and give legitimate reason for their existence and for the use of business resources to do them.

Determine the Equipment Criticality:

Equipment Criticality is a measure of the business-wide risk each asset causes a company, and not only to production. To grade the risk requires knowing the cost of the consequences to the business should the risk happen, along with the likelihood that it can happen. The consequential costs of failure are its DAFT Costs. What remains is to estimate the chance that an event will happen.

To quantify chance requires calculating probability of occurrence. This is a difficult requirement unless you trained in probability mathematics and methods. If you have, then calculate the likelihood of each identified failure cause and calculate the risk. If you have not trained in probability and statistics, use a risk matrix. Most organisations use risk matrix ratings to estimate the size of their risks.

Grade Each Risk by its Impact on Reaching the Business Vision:

Recalibrate the risk matrix to the values and consequences of risk your business is willing to carry. You need to know what a low risk, medium risk, high risk and extreme risk is worth in your business. Identify the risk boundary the operation is willing to pay and put into place strategies and actions that limit risk to within the boundary.

Once you determine the risk rating for each failure cause show it in the Equipment Criticality Spreadsheet on the CD accompanying this book.

6. Pathway to Plant and Equipment Wellness

The journey to world-class production and maintenance performance starts by charting a sure pathway to get there. It is not accidental to be a world-class operation. First, you chose to become world-class, even when at the start you are not. Then you develop a plan to become good at what you do. Once you reach 'good', you develop a plan to become better. At 'better', you develop a plan to become the best. When you are the best at what you do, you are world-class. You script the future of your operation with words and diagrams. Like making a movie, where first a script and storyboard is developed, you start with a written script and process maps of exactly how things will happen in your business.

Enterprise Asset Management

Enterprise Asset Management is a corporate-wide methodology for attaining the physical plant and equipment performance needed to meet business aims. Figure 6.1 is an Enterprise Asset Management process of how to deliver an organisation's objectives. Enterprise Asset Management is the "systematic and coordinated activities and practices through which an organisation optimally manages its assets, and their associated performance, risks, and expenditures over their lifecycle, for the purpose of achieving its organisational strategic plan" [32]. It derives from the Terotechnology [33] movement in Europe during the late 1980s. The drive for an international asset management specification arose because ISO 9001 did not specifically focus on the performance of physical assets [34]. In fact, had business adopted ISO 9001 as it was designed to be used there would be no need for an asset management specification. Businesses that correctly use ISO 9001 make the necessary businesses system developments to address their plant and equipment performance as part of improving their quality management system.

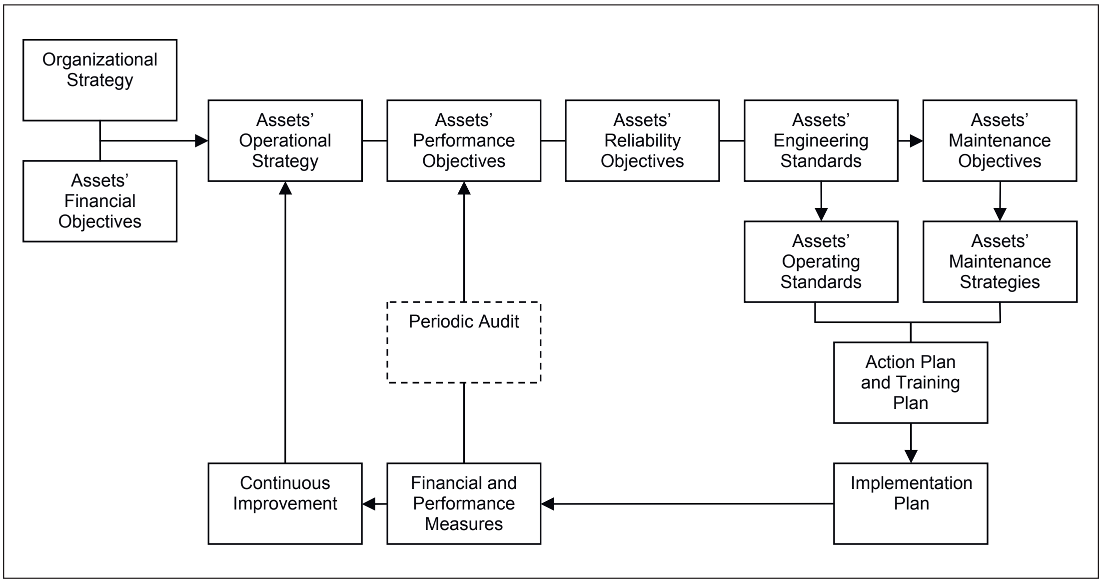


Figure 6.1 – Enterprise Asset Management Model.

32 PAS 55-1:2004 Asset management. Specification for the optimised management of physical assets, British Standards Institute.
33 The economic life-cycle management of physical assets.
34 ISO 9001:2008 Quality Management Systems – Requirements.

The appeal of Enterprise Asset Management is its ‘promise’ of maximum life-cycle profit (LCP), along with its converse, minimum life cycle cost (LCC). But in order to achieve ‘The Promise’ it is necessary to institute the required practices and systems of Enterprise Asset Management throughout the organisation. This is no easy matter in most organisations, especially those that are reactive or those that have become institutionalised over the years. Enterprise Asset Management proposes that businesses follow a path to desired equipment performance by using the foundation elements of systems engineering, reliability engineering, maintenance management, operational management, risk management and industrial engineering, guided by sound financial management. Historically, numerous internationally recognised industrial and the military standards form the documented database of best practices applied in organisations seeking to become world-class engineering asset managers. Practically, the intended achievements of asset management have proven very difficult to attain. The evidence being that extremely few industrial businesses around the world reach the world-class performance level Enterprise Asset Management is meant to deliver. There are important factors not yet recognised by current asset management models and methods that every business needs to deal with themselves. This book aims to provide assistance to industry in addressing the ‘missing links’ needed for enterprise asset management success.

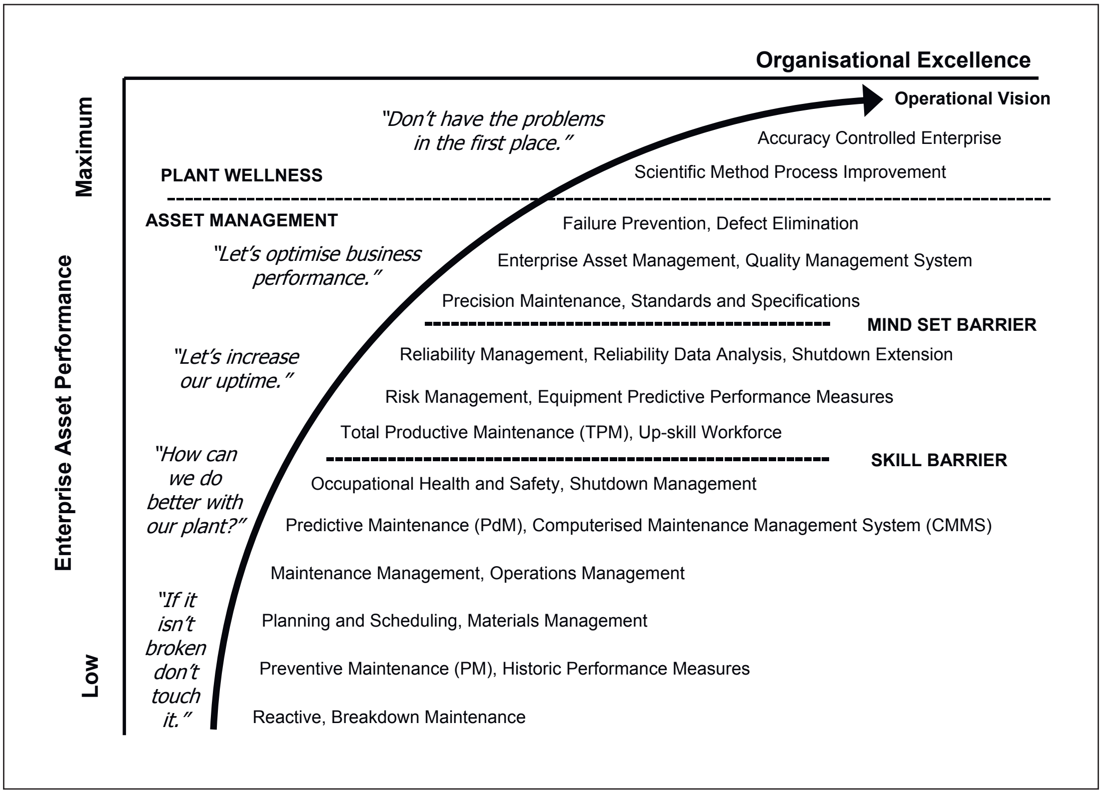


Figure 6.2 – Enterprise Asset Management Pathway with Plant and Equipment Wellness.

The Enterprise Asset Management methodology mix requires time for organisations to introduce them in a staged fashion. In large organisations that have successful introduced asset management, it has taken up to five years to build the necessary culture and skills [35, 36]. For smaller operations, the time is less. In all cases, committed, stable leadership and change

[35] Flynn, V J, ‘Maintenance Benchmarking and the Evolution of DuPont’s Corporate Maintenance Leadership Team’. E I Du Pont de Nemours & Co.

[36] Cumerford, Nigel, Crow/AMSAA Reliability Growth Plots And their use in Interpreting Meridian Energy Ltd’s, Main Unit Failure Data.

management is required in order to maximise the rate that benefits accrue to an organisation. The changes necessitated by Enterprise Asset Management usually require developing new knowledge and skills in the managers and personnel of the Executive, Finance, Engineering, Operations and Maintenance groups. A representation of the organisational practices and financial controls applied at various stages of a combined Enterprise Asset Management and Plant Wellness initiative is in Figures 6.2 and 6.3.

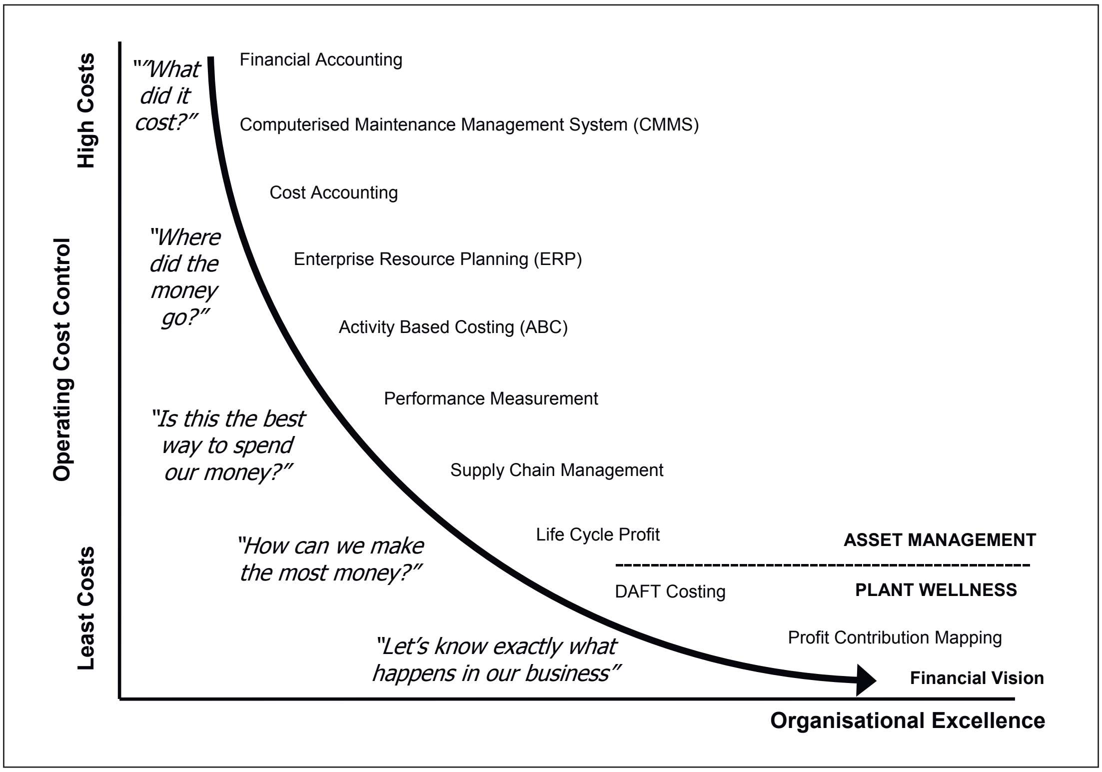


Figure 6.3 – Enterprise Asset Management with Plant and Equipment Wellness Cost Control.

Introducing Enterprise Asset Management and Equipment Wellness into Organisations

Enterprise Asset Management combined with Plant and Equipment Wellness collect together the key methods for plant and equipment integrity and performance excellence into a life cycle profit philosophy. Plant and Equipment Wellness provides Enterprise Asset Management with additional tools for the selection, use and care of plant and equipment assets to achieve the year-after-year production goals that help deliver the business goals. Plant Wellness helps achieve the desired business results by:

i. controlling the inherent variability in business, engineering, maintenance and operating processes to within those limits that produce excellence

ii. managing risk through eliminating the chance of adverse incidents, along with minimising the consequences of a risk

iii. preventing equipment failure by setting and adhering to high quality standards for parts health throughout their life, starting with sound capital equipment acquisition

iv. ensuring the accuracy and precision of human intervention and work activity

v. minimising total life-cycle costs with proactive, fact-based financial modelling of failure, waste and loss

vi. bringing management and workforce together to work cooperatively as a team of experts building a business that will secure their communal future.

Plant Wellness adds to Enterprise Asset Management the specific need and methods to sustain equipment working parts in perfect health for a lifetime of reliability. It gets management and the workforce working together cooperatively to improve their chance of business success. When you put a critical equipment part at risk of a bad outcome you put the equipment at risk of failure. When the equipment is at risk, the business is at risk. All bad risks become losses when the luck runs out. Those organisations and people that do not give priority to creating parts health and wellness in their operating equipment will struggle to be world-class. They will have too many failures and losses. Production success starts and ends with the individual health and well-being of the parts in your machines. Because when a part fails a machine stops, and then your business starts losing money.

The introduction of change into organisations and the success of a change program requires determined senior management commitment and leadership. The launch of a corporate-wide initiative as large as Plant and Equipment Wellness requires a solid appreciation by senior management of the principles and practices they need to apply if they are to reap the maximum benefits most quickly. To help senior managers grasp the needs and implications of Plant Wellness it is normal that they undergo five-day introductory training in the basic principles, concepts and practices required. With a detailed understanding of Plant and Equipment Wellness senior managers comprehend its impact and effects on the organisation; along with the benefits that result. They can develop a strategy and plan for its introduction. To prevent Plant Wellness from becoming a 'business fad' that is quickly dropped if improvements are not swiftly generated, companies undertake its introduction through a 'pilot program'. A representative portion of the business proves that the concepts and practices deliver improved operating performance and increased profits. Once the 'pilot program' is successful it is rolled it out progressively to the rest of the business.

Asset Management and Plant Wellness Policy

An Asset Management and Plant Wellness Policy is used to make sure that business efforts are made to support the wellbeing and long-term health of plant and equipment. The policy drives the engineering, projects, production, maintenance and finance groups to improve equipment part health and wellness. A successful business needs plant and equipment that makes on-time, low-cost, quality product customers willingly buy. Because an industrial operation's future depends on their equipment working accurately and reliably, the finance, engineering, operations and maintenance groups need to protect and improve the wellness of their machine's parts so they get high reliability and a trouble-free operating plant for their business.

It is important to ensure that an asset wellness policy meets all the requirements that make it a useful and valuable document for guiding plans and practices. A policy needs to be inspirational to the people it applies to. A policy needs to excite those people and get them out of bed each day motivated with positive expectation. A limp policy does nothing for its readers or the company. The final published policy may need to be written by a writer who can inject that sort of energy and life into it. Table 6.1, Asset Policy Content Comparison Table, is intended to help build into the asset management and wellness policy those things that are important in minimising risk and maximising plant and equipment health and wellness. It lists the quality, risk and asset management policy requirements of internationally recognised standards.

That does not mean an asset management policy must comply with every requirement in the table. The most important factor must be the amount of 'life' the policy breathes into the people and the business, along with its ability to produce good equipment parts' health decisions and actions. But the checklist will help to get useful content into the policy so that it focuses business efforts on the right things – those that actually reduce life-cycle operational risk. An example of an Asset Management and Equipment Wellness Policy might be:

"We recognise that our plant and equipment are the foundation on which our livelihoods, plans and dreams depend (Shareholders, Staff, Employees, Suppliers, Customers and Community). Without sure and certain, competitively-priced, quality products from our operation, we put our collective and individual futures at grave risk.

Because our business and personal success depends on the reliable and faithful production of 100% quality product that satisfy our customers' requirements, we will adopt and use those proactive asset management, engineering, project, operational, maintenance and financial practices, methods and business systems that minimise operating risks and prevent failure of our plant and equipment during its operating lifetime.

Starting from the conception of a business idea through to the decommissioning of a plant we will work together in cross-functional teams to seek ways that maximise the safety, productivity and value-added in every part of our operation, and its supply and distribution chains. Included is the need to constantly minimise, and eventually eliminate, our business losses, wastes, accidents and incidents so that we do no harm to our planet, our people and our community.

We want all our people to continually seek and learn better ways that improve our productivity and minimise our risks in every task. We encourage their learning with both formal methods and by controlled experimentation. Through the on-going drive of our people to seek excellence and mastery, we will become and remain a best-in-class performer."

A shorter asset management and equipment wellness policy example is:

"We support a well-planned and executed Asset Management and Plant Wellness strategy encompassing best operations and maintenance practices as a key risk management tool to assure plant performance, and positively contribute to the achievement of our business outcomes.

Maintenance is fundamental to successful production, and the reliability of our plant and equipment assets is dependent on doing the maintenance function effectively, in a timely manner.

We recognise that successful equipment performance is due to the cooperative contributions of its maintenance, operations, engineering and finance departments and to an operational culture of relentless risk management, responsible and controlled business risk taking, defect prevention and failure removal, continuous improvement and cross-functional staff involvement in decisions."

Maintenance Vision, Policy and Maintenance Strategy

Part of developing a maintenance strategy is to first develop a maintenance policy – what to achieve with equipment maintenance, why it is necessary for the business, and how to do it. With the importance of maintenance to production success firmly placed into a business context through the Asset Management and Equipment Wellness Policy, it becomes necessary to decide how to use maintenance to maximise production productivity. This is the role of the Equipment Maintenance Policy and Strategy. The maintenance policy explains how to use plant and equipment maintenance to ensure the necessary production performance from the plant and equipment.

Table 6.2 is a tool to help identify the maintenance vision and policy. Plot where the operation is in each column and then decide where you want to go over the next 2 to 3 years. Plotting on the chart helps the development of a maintenance vision to guide the drafting of the policy. With the policy decided then work can start on the strategy and actions, which when achieved will get the vision.

Listed below are the typical issues to address in a maintenance strategy document. There may be others specific to your operation. Its development is a substantial undertaking. But without it maintenance flies-by-the-seat-of-their-pants, everything becomes guess-work and the business is run by luck rather than good management. Without maintenance policy and strategy vast amounts of production time and money are wasted. With maintenance policy and strategy there is a far better chance of becoming a great company. Turning a company into a world-class leader is a job worth doing well.

Typical Contents of an Equipment Maintenance Strategy Document

Maintenance Vision (Why you do maintenance and how it helps the business)

Maintenance Policy (How your business does maintenance, who does it, what you expect from it)

Production Performance Envelope (what daily plant availability meets the production output? What is the daily average production rate to sustain that delivers the required output? What is the daily quality rate required to meet production plans? What is the equipment reliability needed for each piece of plant to deliver the total plant availability required to meet the production plan? How much can you afford to spend on maintenance and repairs?)

- Production Performance Required
- Process Reliability Analysis (reliability model your production process to identify its weaknesses and most likely performance)

Risk Assessment of Operational Assets (what can go wrong with your equipment, what will it cost, how often does it happen. The equation is: Risk = cost consequence [$] x no. of events in a period [/yr] x chance of event ('chance of event' is between 1, if it will definitely happen, to 0, if it definitely will never happen). This is done in a spreadsheet using the DAFT Costs as the consequences value.)

- Equipment Level (e.g. a complete pump-set)
- Financial and throughput impact on Production of failures on each equipment item
- Equipment Criticality (prioritise the importance of the equipment to sustaining production)
- Assembly Level (e.g. pump – coupling – motor – base frame – foundations – power supply)
- Failure Mode and Effects Analysis at part level (identify the parts in the assemblies that can fail and in which ways. Then identify the operating practices and maintenance each part requires to prevent production failure.)

Production Risk Management Plan (how maintenance is used at the parts and assembly level to reduce production risk at the equipment level)

<u>Precision Maintenance Standards</u> needed to meet plant and equipment operational performance (Mechanical, Electrical, Instrumentation, Structural, Civil – Safety, Environmental, etc)

<u>List Equipment on Preventive Maintenance</u> (make adjustments and/or replace wearing parts)

- List of equipment done as shutdown, or as opportunity-based PMs, or as time/usage scheduled PMs
- Precision standards to meet when performing PMs

<u>List Equipment on Predictive Maintenance</u> (to detect impending failure and repair/replace before failure)

- What condition monitoring will be used
- Where will the condition monitoring be done
- How will it be decided when it is time to maintain or replace
- Who will do the condition monitoring (i.e. subcontract, in-house maintainer, in-house operator)
- What will be done when condition is too far deteriorated

<u>List Equipment to Rebuild</u> (to identify which equipment to repair)

- Criteria to pass to justify repair instead of replacement
- How many times to rebuild before replacing with new
- Precision standards to meet on each rebuild
- Precision standards to meet on re-installation

<u>List Equipment to Replace</u> (identify which equipment is not to be repaired, but always replaced. The DAFT Cost of a breakdown often easily justifies installing new equipment, rather than take the chance of an unplanned production stoppage)

- Precision standards new equipment must meet
- Precision standards to meet on installation

<u>Critical Spares List</u> (to identify which parts you must have available)

- Equipment parts to be carried on-site
- Equipment parts to be carried by local supplier
- Stores management standards to protect integrity of spares

Records Management (to document maintenance history of equipment and parts usage in order to identify reliability improvement opportunities)

- Which engineering, operational and maintenance documents to keep
- How documents are to be kept current and safe
- What records are to be made and kept over each equipment life
- What analysis of records will be required and the information to be provided from the analysis
- How will all the records and documents be controlled

Maintenance Performance Monitoring (to ensure that maintenance is delivering the reliability, availability, quality and cost that the production plan requires)

- KPI definitions and calculations
- Plant level KPIs (e.g. availability, unit cost of production, quality rate)
- Equipment level KPIs (e.g. reliability, quality rate, production rate)

- Personnel KPIs (e.g. hours spent developing skills, employee satisfaction)
- Maintenance Process Performance KPIs (e.g. daily work order complete per trade type, backlog of work, percent planned work, percent scheduled achievement)
- Maintenance Improvement KPIs (e.g. no. of procedures written to ACE 3T standard, no. of design-out projects started, no. of design-out projects completed
- Reliability Prediction KPIs (e.g. no. of work orders spent improving reliability, reliability improvement graphs e.g. Crow-AMSAA plots)

Maintenance Resources Required (there will be a need to resource the production risk management activities known as 'maintenance')

- Necessary maintenance equipment and technologies
- Necessary stores capacity and stores internal operating methodologies
- Necessary engineering and maintenance knowledge
- Necessary trade skills and competence
- Necessary numbers of people by trade type/service
- Location of people for most efficient operation of maintenance activities
- Necessary Computerised Maintenance Management System (CMMS) capabilities

Cost and Benefit Analysis (to confirm that the cost of doing maintenance will return value to the business)

- Annual maintenance cost verses the cost of failures prevented (the risk analysis will provide the DAFT Costs that will be incurred by the business if equipment fails)
- Annual maintenance cost verses the cost of lost production output if plant availability does not meet production targets (your production and equipment history can be used to determine the numbers of production slowdowns and stoppages in an 'average' year that did not need to happen)

Rolling Two Year Maintenance Program (indicate exactly when and what is to be done with each item of plant to deliver maximum production productivity)

- Work orders by type performed on each equipment item and the benefits they provide
- Schedule of work orders for each equipment

Rolling Two Year Maintenance Budget (develop a believable budget that will deliver the risk control that production needs. Using a rolling two years forecast allows inclusion of the savings from improvement initiatives. Two years is a believable period for anticipating changes. A five years forecast becomes unrealistic in the later years because it cannot anticipate the impacts of a changing world.)

- Maintenance cost by equipment
- Maintenance cost by plant
- Maintenance cost by type
- Maintenance cost per time period
- Equipment improvement plans

Rolling Five Year Reliability Improvement Plan (the on-going list of sheduled activities, funds and resources that will be committed to continually improve the operation. The focus is on activities that improve equipment reliability)

The list is reasonably comprehensive but may need to be tailored to suit the situation and the requirements of a business and its management. Once the time and effort is put into developing such a detailed strategy there will be confidence that it can achieve its intention. Such a document is the result of many peoples' efforts and input. A team consisting of production, engineering, maintenance and finance working together is the best way to develop it. It can take three to six months to do the job fully. But a simpler document can be compiled within a couple of months and later refined as resources become available.

Table 6.1 – Asset Management Policy Content Comparison.

Policy Requirements	Quality Management System ISO 9001:2008	Physical Asset Management System PAS55-1:2004	Risk Management System AS4360:2004
Responsible to develop policy	Top Management (Board or Chief Executive Officer)	Top Management	Board or Executive
Obligatory policy content inclusion	• Commitment to comply with requirements of the Quality Management System • Commitment to continually improve effectiveness of Quality Management System	• The overall physical asset management objectives • That physical asset management is directed at achieving the Organisation's strategic plan • A commitment to continually improve the physical asset management process • A commitment to comply with current applicable legislation, regulatory and statutory requirements and with other requirements subscribed to by the Organisation	
Recommended policy content inclusions			• Objectives of risk management • A commitment to risk management
Possible policy content inclusions			• Objectives and rational for managing risk • Links between policy and strategic/corporate plans • Guidance on extent and type of acceptable risks taken and ways to balance threats and opportunities • Processes to be used to manage risk • Accountabilities for managing particular risks • Details of support and expertise available to assist those accountable for managing risk • Level of documentation required • Statement of how risk management performance will be measured • Commitment to periodic review of risk management system • Statement of commitment to the policy by directors and executives
Organisational context	• Appropriate to the purpose of the Organisation • Equal and consistent to Organisation's overall policies and strategy • Provides the framework for setting and reviewing measurable quality objectives	• Appropriate to nature and scale of Organisation's physical assets and operations • Be derived from how the management of physical assets will help achieve Organisation's strategic plan • Consistent with other Organisational policies • Provides the framework for setting physical asset management strategy, objectives, targets and plans • Be consistent with Organisation's risk management framework	• Create linkages to other corporate strategies
Showing commitment to policy	• Visibly endorsed by Top Management • Communicated across organisation • Understood by all persons within organisation • Reviewed for continuing suitability	• Visibly endorsed by Top Management • Documented in suitable media • Implemented into use to be standard practice • Maintained in condition to meet purpose • Communicate individual physical asset management obligations ▪ To relevant employees ▪ To relevant third-parties • Published to stakeholders where appropriate • Reviewed periodically for relevance and consistency to Organisation's strategic plan	• Publish Policy • Communicate Policy ▪ Establish management team to communicate and involve staff across organisation ▪ Raise awareness across organisation on risk management process ▪ Risk management is in the organisation's culture

Table 6.2 – The Journey to Reliability and Maintenance Mastery.

	Leadership and Capability					Systems and Processes				
	Maintenance Vision & Strategy	**Performance Measures**	**Organisation Structure**	**Human Resources**	**Knowledge Base**	**Maintenance Strategy**	**Materials Management**	**Planning & Scheduling**	**Contractor Management**	**Reliability Engineering**
Mastery	Quality System managed Accuracy Controlled Enterprise where everyone in every department works to 3T error prevention procedures; Lean philosophies improve processes	Business strategy focus; Maximising Life Cycle Profit; Defect And Failure True (DAFT) Cost database. Process Step Contribution monitoring across all processes	Integrated cross-functional teams incorporating financial, engineering, operations and maintenance	Empowered, flexible, cross-functional teams of experts working to scientific discipline	Continually learning, pushing-out the boundaries of human knowledge and understanding, Six Sigma discipline is normal	Precision Domain drives all engineering, installation, operations and maintenance work; Risk analysis and management normal	Materials problems designed-out, OEM monitors real-time information on critical parts' condition and carries necessary spares	Maintenance reducing as continual improvements extend time between outages; continually reducing time to repair with Lean philosophies	Small teams of experts servicing entire local industry delivering precision maintenance and design-out maintenance with profit sharing	'Design and Operations Cost Total Optimized of Risk' (DOCTOR) is used to minimise all operating risks throughout the facility's life. Reliability growth pervades thinking
Excellence	Personnel action plans; appraisals are clearly tied to the maintenance strategy	On-going benchmarking of metrics and processes; Full cost database	Total Productive Maintenance where operators drive reliability, fault-find and maintain equipment; root cause failure analysis by operators and maintainers	Empowered, flexible, world-class workers; self-managed teams	Expert systems used; fully integrated CMMS common database	Preventive & Predictive plans continuously optimized; the 'right' maintenance tactic is applied based on analysis	Stores system integrated to CMMS and accounting system; bar coding or radio frequency tags of all stores items; World-class Stores Management	>90% all maintenance is planned and >95% first-time schedule compliance; rolling schedule fixed for the week ahead	Small numbers of contractors on long term sharing partnership agreements with high innovativeness	Risk and unplanned failure reduced to best in industry by analysis and modelling
Competence	Reliability focused Maintenance improvement action plan is linked to the maintenance Management Strategy	Statistical process control applied to maintenance process measures; Equipment specific maintenance costs available	Established teams for achieving key objectives in the Maintenance Management Strategy	Multi-skilled trades with process capability analysis and basic operating skills	Easy access to knowledge bases available to all employees at all times	Preventive & Predictive plans exist for all maintainable items; emphasis on PdM. All tactics understood	Single source supplier partnerships established and effective; Area stores with visual controls; Reliability of spares maintained; Suppliers provide technical expertise	Long term asset planning established; Critical path analysis used for all rebuilds and shutdowns	Contractors are established based on principle of 'risk sharing'; Contractors provide technical expertise	Effective Root Cause Analysis (RCA) applied to equipment problems to extend life
Understanding	A clear Maintenance vision and strategy is documented and communicated to all employees	Input – Output process measures reviewed and displayed; Downtime by cause; Segregated maintenance costs reviewed	Decentralized with central support; Clearly written, mandates/roles for each maintenance function and group	Trades have problem identification and solving; team dynamics and training skills	Document control system established; CMMS installed and used to manage knowledge bases	Preventive & Predictive plans exist for key equipment; Compliance to scheduled plan is more than 95%	Spares classified with separate strategies; Spares linked to BOMs/Equipment Drawings; Standardisation polices exist; ABC spares management with 'A' spares protected	All but unexpected failures planned; All planned jobs specify safety, labour, materials, tools, technical details	All contractors repairing rotables are capable of Original Equipment Manufacturer's testing	Basic equipment conditions established; Good failure databases; All major failures investigated; PMs modified based on site experience
Awareness	No clearly documented role of maintenance; No Maintenance vision or strategy	Some downtime records; Maintenance costs regularly available, but not segregated into area/line	Centralized maintenance group with alignment to production; Team approach to technical problems	Trades have OH&S and maintenance support (inspection, reporting) skills	Plant register established and useful data collected; central technical library; All drawings and equipment information identified	System to identify all maintainable items exists; Emphasis on time-based overhauls and inspections	Stores catalogue established; Inventory accuracy >95%; Goods receiving practices in-place	Work Request/Work Order system established; Major rebuilds, shutdowns fully planned and programmed	Contractors used for peak loads and non-core maintenance work	Collect the failure data; Equipment histories occasionally reviewed for failure analysis
Innocence	The main role is to fix it when it breaks/fails	Incomplete or no maintenance downtime records; Maintenance costs not readily available	Centralized maintenance group with no alignment to production; Command and Control' approach	Trades have their basic trade skills, however little or no technical knowledge or support and training given	Ad-hoc records kept for purchasing; No plant register or control of drawings	"If it isn't broke don't fix it'; Annual shutdown and inspections only	Ad-hoc stores; No costing or control of spares	No planning function; planning done on-the-run; Short term focus	All maintenance carried out by in-house team, which may include individual contractors	No failure records

7. Defect Elimination and Failure Prevention

The following extracts are from three sources investigating industrial plant and equipment failures.

"Many managers and engineers believe most failures have a root cause in the equipment [37]. Data from nuclear power plants (which maintain a culture of confessing failures and the roots of failures – this is in opposition to most industries were the culture is to hide the roots of failures) show the following roots for failures:

Early in the life of nuclear power plants –

Design error	35%	[people induced problems, not calculation errors]
Random component failures	18%	[process/procedure problems]
Operator error	12%	[people/procedure problems]
Maintenance error	12%	[people/procedure problems]
Unknown	12%	
Procedure error & (procedure) unknowns	10%	
Fabrication error	1%	[people/procedure problems]
	100%	

Mature nuclear power plants –

People	38%
Procedures & Processes	34%
Equipment	28%
	100%"

"ASME (2002 report) shows a similar root for failures. For 10 years, from 1992-2001, 127 people died from boiler and pressure vessel accidents and 720 people were injured. In the 23,338 accident reports, 83% were a direct result of human oversight or lack of knowledge. The same reasons were listed for 69% of the injuries and 60% of recorded deaths. Data shows that if you concentrate only on the equipment you miss the best opportunities for making improvements. Another point to seriously consider is little or no capital expenditures are required for improving people, procedures and processes which can reduce failures. In case you believe that equipment is the biggest root of problems it will be instructive to download (http://www.bpresponse.com) the Final Report of BP's Texas City Refinery explosion and tick off the reasons behind the explosion which took the lives of 15 people and maimed more than 200 addition people—you will see objective evidence for people, procedures and processes as the major roots for failures. The #1 problem was not equipment! [38]"

"… the major challenge to reliability theory was recognised when the theoretical probabilities of failure were compared with actual rates of failure [and the] actual rates exceed the theoretical values by a factor of 10 or 100 or even more. They identified the main reason for the discrepancy to be that the theory of reliability employed did not consider the effect of human error … Human error in anticipating failure continues to be the single most important factor in keeping the reliability of engineering designs from achieving the theoretically high

37 Barringer, H. Paul, P.E. 'Use Crow-AMSAA Reliability Growth Plots To Forecast Future System Failures', www.barringer1.com.

38 Barringer, H. Paul, P.E. 'Use Crow-AMSAA Reliability Growth Plots To Forecast Future System Failures', www.barringer1.com.

levels made possible by modern methods of analysis and materials … nine out of ten recent failures [in dams] occurred not because of inadequacies in the state of the art, but because of oversights that could and should have been avoided … the problems are essentially non-quantitative and the solutions are essentially non-numerical. [39]"

The above quotes are evidence that the problems we have with our plant and equipment are not machine problems. Our machines are fine. The problems of poor equipment reliability, poor maintenance and poor production performance are in the minds and hearts of the people that control our companies, design and manage our business processes, and run and maintain our machines. The reason companies have so many equipment and production failures is that their people and business processes cause them. That is the conclusion from the evidence in the three extracts. Human beings let happen all equipment failures that are not 'Acts of God'. If you want to make serious improvements to your plant and equipment reliability you need to first focus all your efforts and resources on changing attitudes and beliefs. You need to change the way people think about, and value, quality and reliability.

Remember always the famous advice of quality guru, the late W. Edwards Deming, "Your system is perfectly design to give you the results that you get!" His quote truthfully explains why you get the results that you do; you designed them into your business systems because you neglected to design them out! If you don't want reliable equipment, simply don't tell your operators and maintainers how to deliver reliability. The 'human factor' will make sure you get a matching level of equipment performance. To move from a repair-focused organisation, where failure is seen as inevitable, where maintenance is a servant to failure and reliability is the responsibility of an 'elite', to a reliability-focused organisation with a culture of failure elimination that permeates staff at all levels, requires a mindset change. It is driven by a passionate management over a long time [40].

You start changing to a reliability culture by first installing the right processes and systems into your business. Then you teach the people to follow them. Read this quote about causing change in organisations – "Changing collective values of adult people in an intended direction is extremely difficult, if not impossible. Values do change, but not according to someone's master plan. Collective practices, however, depend on organisational characteristics like structures and systems, and can be influenced in more or less predictable ways by changing these. [41]"

You cannot change people's internal values, but what you can change is the practices they must follow so that their cognitive dissonance brings about change in their values. Cognitive dissonance is the uncertainty and unhappiness that happens in your mind if you believe one thing, but are forced to do something else. For example, if you want people to do high quality work, provide a high quality procedure that they must follow along with a report sheet to complete and hand-up at the end of every job, so that you can encourage and train them to do masterly work. If, when the procedures are exactly followed users produce better results than they ever achieved without them, they will start to change their belief. Their old internal values change because the external evidence does not support them. This is cognitive dissonance in action. In this way the quality requirements built into the procedures brings about the necessary change in the value people put-on careful observation, quality workmanship and accurate recording. You use your standard operating procedures to describe and create the 'role model' you want your people to follow.

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[39] Petroski, Henry, 'Design Paradigms: Case Histories of Error and Judgment in Engineering', Cambridge Press, New York, 1994. Remarks on Pages 7 and 8 about the role of humans in failures.

[40] Wardhaugh, Jim. Extract from 2004 Singapore IQPC Reliability and Maintenance Congress presentation 'Maintenance – the best practices'.

[41] Hofstede, G. J., Cultures and Organisations – Software of the Mind, Second Edition, McGraw-Hill.

Unwanted variation causes defects and failure is the message in Chapter 3. The challenge for a business is to control variation to within those limits that produce good outcomes. If too many of its outputs are unacceptable a process produces excessive losses. Such a situation is terribly wasteful and needs to be investigated to understand the causes of the problems. A successful resolution will alter the output spread so that all products are within the specification. The output spread will change from a volatile distribution to one more stable, as shown in Figure 7.1. Now the vast majority of process output meets specification.

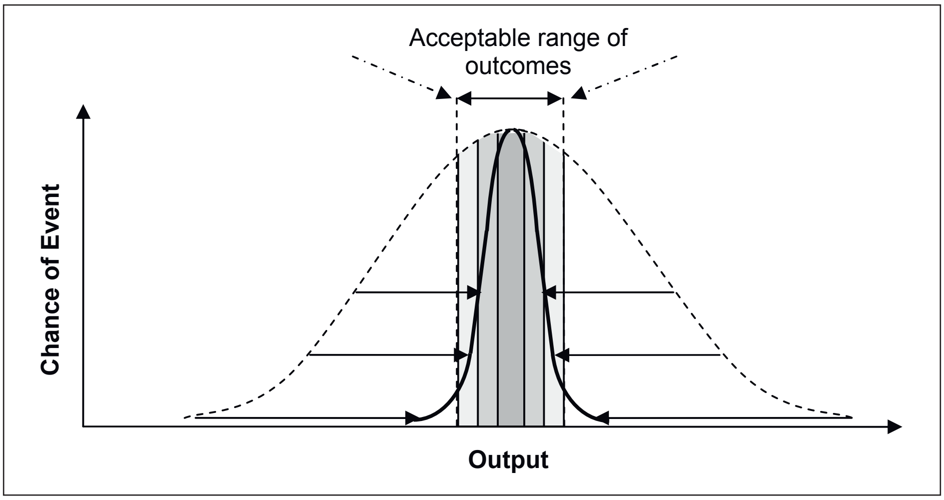

Figure 7.1 – The Effect of Removing Volatility from Processes.

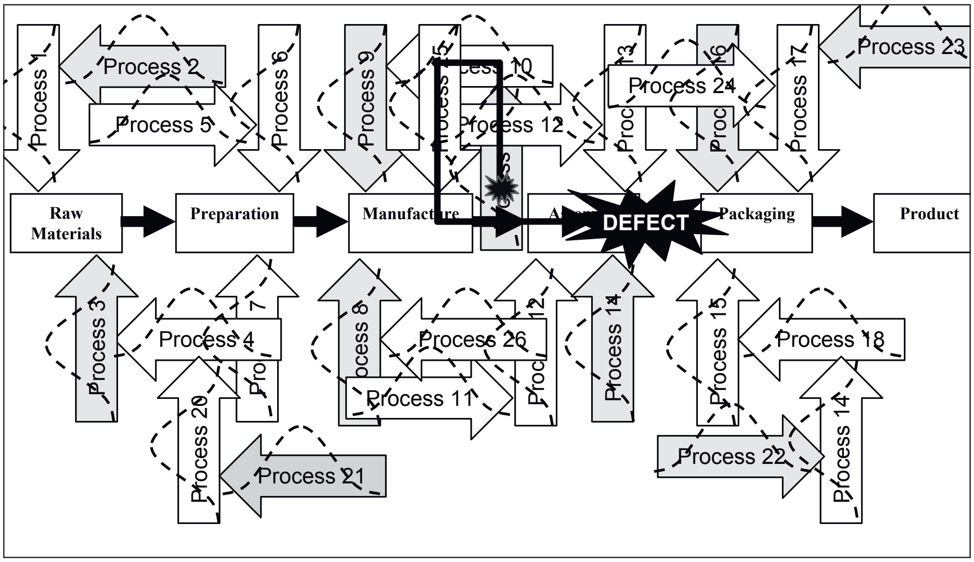

Figure 7.2 – Processes which Allow Wide Variation Produce many Defects.

A business with poor process controls provides many chances for producing scrap and waste. Having poor controls causes continual opportunities for unwanted variations to arise and encourages great loss by not preventing their transmission through the business. Figure 7.2 indicates that each process in a business produces variable outcomes which feed into downstream business processes. Any quality problem created in a process travels through the business to eventually become a defect that has to be rejected in another process. Once rejected, all the work, money and time spent on it is wasted. The business loses money and customers get annoyed.

The Need and Purpose of Standardisation

In his books, the late was concerned about the impacts of variability on business because he knew from industrial experience that it caused great waste, inefficiency and loss. Starting in 1950 he taught industrial statistics to the Japanese. Including the use of process control charts to identify changes in processes so that corrections could be made before product quality deteriorated out-of-control. The Japanese managers, engineers and supervisors learned well and by the 1960s Japanese product quality was renowned world-wide. The Japanese were gracious and willing told the world what they had learned. During trade visits to high-quality Japanese companies the Japanese hosts explained to visitors the factors they believed had made the greatest difference [42]. One factor in particular was regularly identified as the most important to start with. It was to standardise a process so that there was one way, and only one way, that it was done.

What had the Japanese learnt about variation that western business managers have not? The Japanese saw that output variation was either the natural result of using a particular process (called common cause variation because it was inherent, common, to a process) or caused by factors external of the process changing its performance (special cause variation because they were identifiable as a particular problem special to a situation). They also noticed that the extent of the output spread was dependent on the amount of volatility permitted in a process. If many methods of work were allowed, each introduced its own effects. Each new method caused the final process output to be slightly different to that of the other methods. But when one standard method was used the outputs were less variable. The difference in output distribution between a standardised method and the use of any method is shown in Figure 7.3. Standardisation reduced variation. Once a method is standardised the use of any other method is an external special cause factor, easily identified and corrected by training if it produces volatility, and gladly accepted into standardised practice if it reduces volatility.

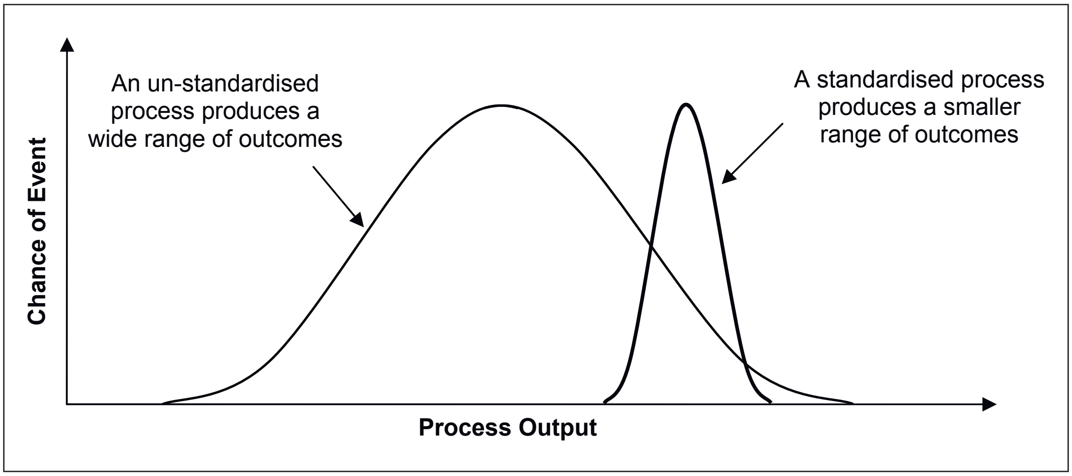

Figure 7.3 – The Effect of Applying Standardisation on Process Results.

However, standardising did not ensure that it was the best method for achieving the requirements. In Figure 7.4 the process produces fewer variations, but its output is not to specification.

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[42] Bodek, Norman., 'Kaikaku – the Power and Magic of Lean – A Study of Knowledge Transfer, PCS Press, 2004.

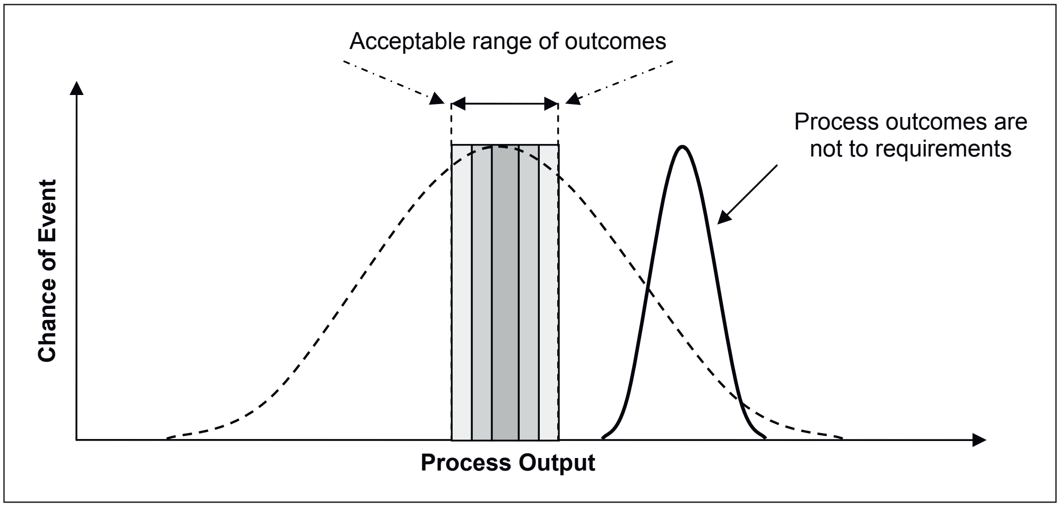

Figure 7.4 – Low Variation but Output is not to Specification.

In such cases the Japanese repetitively applied the Deming Cycle (Plan-Do-Check-Act) to trail new methods and learn which produced better results. Through experimentation, testing and learning they continually improved a process until the outputs met the requirements. The approach used by the Japanese to build high-quality processes is shown in Figure 7.5.

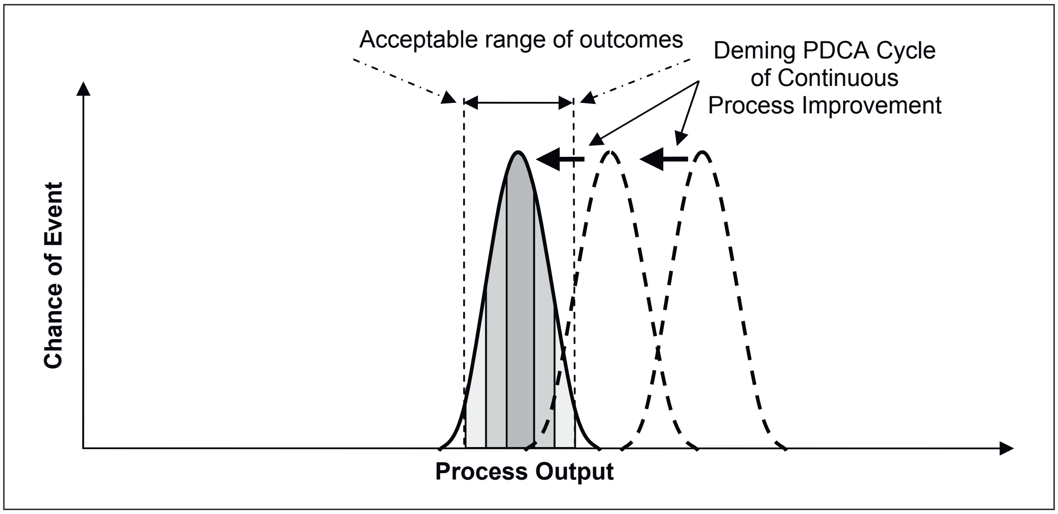

Figure 7.5 – Altering Process Performance to get Desired Results.

How to Use This Knowledge in Your Business

The Japanese learnt that they could change their business processes to produce the results they wanted. It did not matter how much variation existed because if it was due to the process they changed and improved the process. If variation was due to external special causes they found and removed them. Figure 7.6 reflects what to do to create a process with excellent outcomes, no matter where you start.

First identify what is excellent performance and set the limits on its allowable variation. If the current process cannot deliver the required results; redesign it and standardise on one way, and one way only, for the process to be done. Use process control charts to monitor the process and its variables. The process control charts help to find those special causes that prevent excellence and remove them. Make the changes and run the new process. If the new standardised process does not meet requirements after all special causes are removed, the process is not capable of doing so. Because it is a process problem preventing achievement, the process needs to be redesigned and changed to one that can deliver the necessary quality. With each running of the process a great deal of learning is gained. This learning is used to decide how to change the process to deliver improved performance. The process is again modified and run. This 'scientific method' of process development and improvement is repeated until the process produces the required quality results. This is how the Japanese moved their businesses up to world-class quality and cost performance.

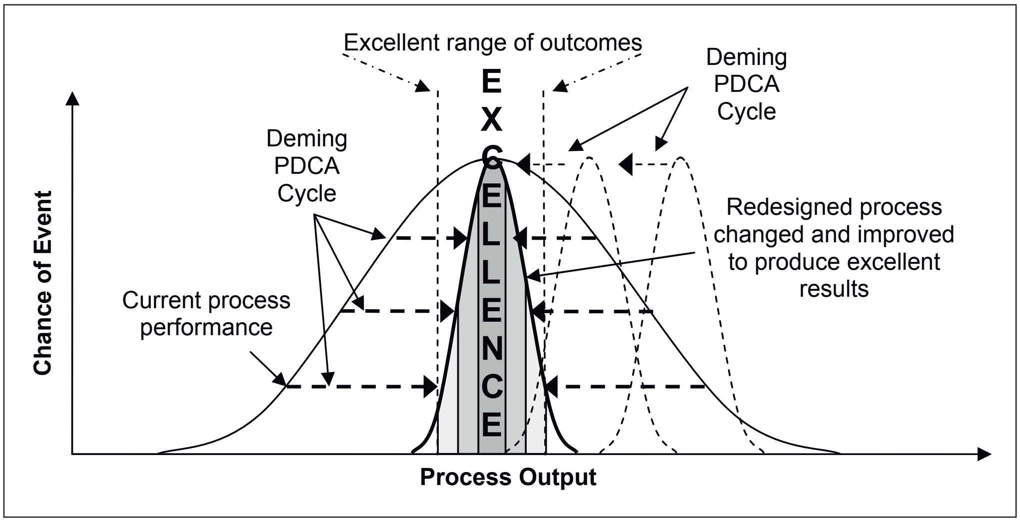

Figure 7.6 – Processes can be changed to Deliver Excellence.

If a business process produces excessive errors, for example there is too much rework from poor quality, it is vital to investigate if it failed to meet the standard because of a process problem or a special cause problem. In his book 'Out of the Crisis' Deming provided an example of analysing the error rate per 5000 welds from eleven welders [43]. Figure 7.7 shows his analysis on a Shewhart control chart. Deming calculated the process error limits and put the upper control limit at 19; implying the process error naturally lie between 0 and 19 errors per 5000 welds. Any results less than 19 errors per 5,000 welds were within the process variation and were normal results from the process. Nothing could be done about it because that was how the process was designed – it could make anything from 0 to 19 errors due to its natural volatility. Those results outside of the process limits were special-cause related and needed to be corrected.

Deming used the control chart to get the process to talk to us. He was showing us how to understand our businesses and its performance. Error in a process is a random event and the probability of errors forms a normal distribution. By showing error on a control chart and defining the 3-sigma limits of the normal distribution the data belongs to, you can immediately see if the error is likely caused by the system volatility or by something outside the system. If it was a system cause then the data falls within the natural normal distribution of errors produced by the system – it is within the number of errors you would expect from running the process normally. If it is a system error it is no one's fault – it is just how the system works due to its design. Only the performance of Welder 6 is unexplainable, all the other welders have made no more errors than the system was designed to make. Special causes are affecting the performance of Welder 6 that need correction.

[43] Deming, W Edwards., 'Out of the Crisis', MIT Press, 2000 edition, Pg 256.

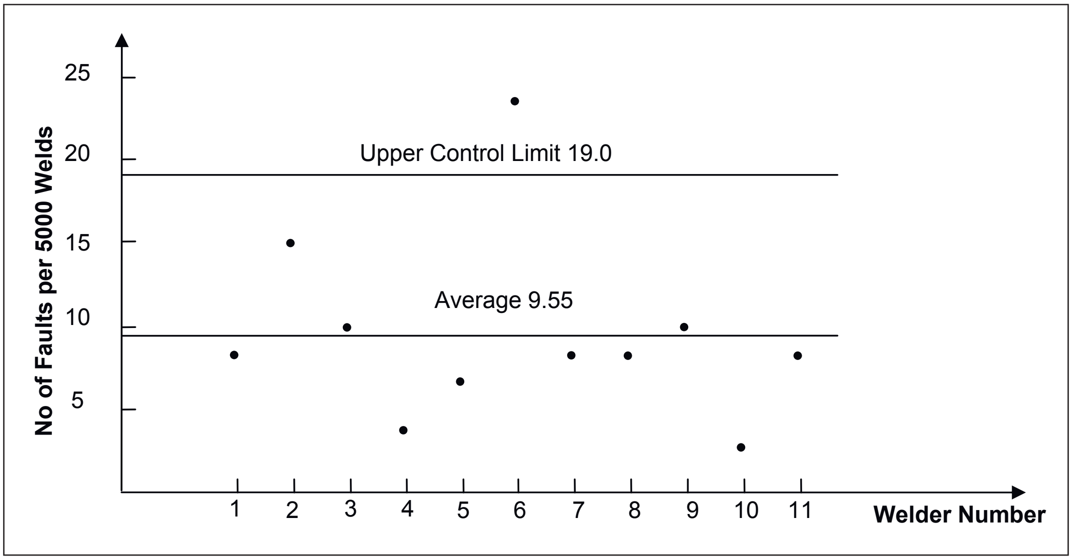

Figure 7.7 – Welding Process Control Chart.

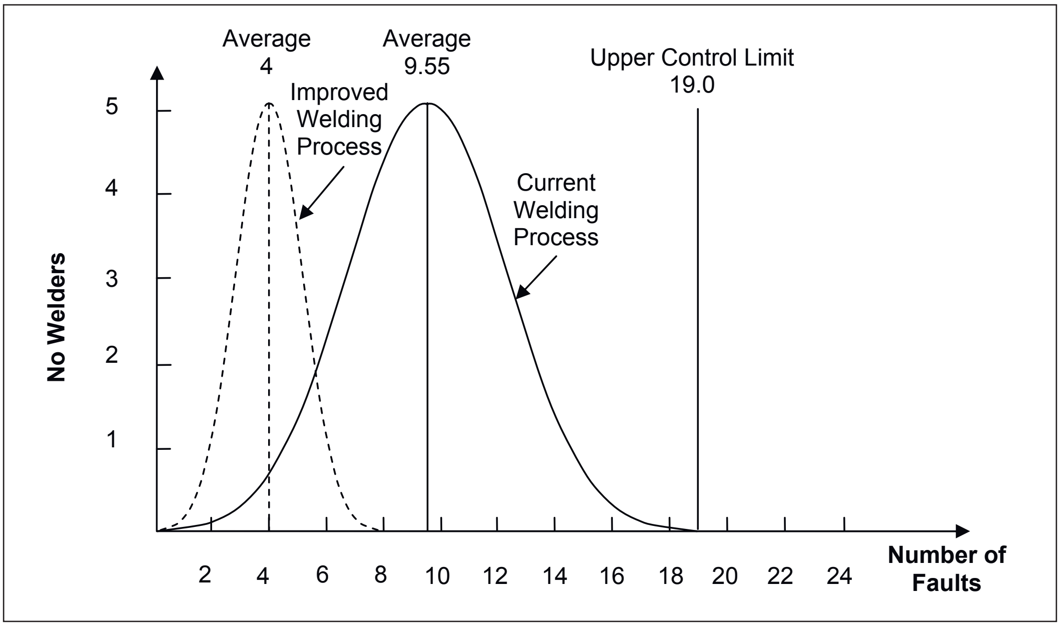

Figure 7.8 – Welding Fault Distribution.

Deming never blamed people for poor performance, he knew that the vast majority of faults lay with the system design in which they worked (by his estimate 94% of errors were system caused). Deming suggested the investigation consider two issues. The first was to look at the work stream to see if it was exceptionally difficult material to weld or the welds were in difficult locations. If the job difficulty was the problem then no more needed to be done because the problem was not with the person and as soon as the job returned to normal the welder's performance would too. The second factors to examine were such things as the condition of the equipment being used, the quality of his eyesight, and other handicaps, like problems at home or his health. To get fewer weld failures from the group of welders it would be necessary to change the design of the process to one with lower average number of faults.

Figure 7.8 shows the measured welding results assuming the frequency of failures matched a normal distribution. It also shows the new distribution if the process was redesigned to produce an average of four faults per 5000 welds. To move from the current average of 9.55 faults per 5000 welds to an average of 4 would require an improved process with much less variation than the existing one. Deming said "overall improvement … will depend entirely on changes in the system, such as equipment, materials, training." He listed possible factors to consider, including getting the eyesight of all welders tested, reducing the variation in material quality, changing to material that was easier to weld, providing improved welding equipment, developing better welding techniques and retraining poor performers.

To have an operation where good results are natural and excellence abounds it is necessary to ensure variation in a process is controlled to within the limits that deliver excellence. It requires that a standardised system of producing excellence is developed and then followed. In a series process this means accuracy in every step, without which one cannot get excellent process outputs. World-class operations recognise the interconnectivity amongst processes and work hard to ensure everything is right at every stage in every process. This was Deming's purpose – to help businesses learn to control variation so they always produced top quality products that customers love. This too is our job – to help our business learn to control variation and deliver the quality performance that our customers love.

Script and Write the Future You Want

To attack unwanted variation specify exactly what is required and how to get it; script the desired performance. Variation starts to be controlled when management set clear and precise standards. The best practices to achieve the required outcomes are then developed by management and workers in collaboration and taught to people. Those best practices are the one agreed way to do a job so special cause variations are not introduced. The script is the start of delivering supreme performance. Achieving success is almost certain once you know what it looks like and how to get there.

Scripting the future of an operation begins by setting the required engineering quality, production quality and maintenance quality standards you will meet. Quite literally, decide what standards that people, plant and processes need to achieve and write them down so everyone knows what they are. They become the level of quality that everyone works to. To go below those quality standards will result in additional and increased risk to the operation from equipment failure, from wasted production processing and from poor work task performance. By scripting the quality standards for an operation you increase the reliability of every business process. You apply Series Reliability Property 3 to a business – the series reliability property that delivers the greatest benefits – because once a standard is set it drives improvements right across an operation. Without touching a piece of plant, the setting of a higher quality standard decrees better reliability performance of all equipment and processes. Anything that is not up to that standard is changed and improved to meet it.

Set the Risk Management and Quality Standards Required

In the end, a library of procedures and standards for every job and activity in every department is needed – from boardroom to shopfloor. Everyone works to procedures and standards. Nothing is left to chance – even the dress standard. If variation is acceptable in a job, the procedure will tell the amount of variation permitted. Where accuracy and precision are required, the procedure documents it. How will people know what great performance and a world-class result looks like unless it is described for them exactly as it needs to be? Once there is a script of what is a great result, people put plans and actions into place to get there. Without knowing what top class performance looks like, anything happens.

Table 7.1 – Sample List of Documented Standards in a World-Class Industrial Process Plant.

Technology and Facilities Safety System	Electrical	Fire and Explosion	Environmental	Product Stewardship	Distribution	Occupational Safety, Health and Industrial Hygiene	Asset Productivity Standards	Capital Effectiveness Standards
• *Process Hazards Analysis* • *Standards and Guidelines* • *Process Safety Management Implementation* • *Continuous Improvement Process* • *Management Commitment and Responsibility* • *Facility Positioning Studies* • *Inherently Safer Processes* • *Emergency response Planning* • *Integrated SHE Organization*	• *Electrical Safety Training and Consultation* • *Incident Investigations* • *Audits Using Best Practice Protocols* • *Electrical Safety Standards/ Guidelines* • *Short Circuit Studies* • *Time/Current Coordination* • *Arc Flash Hazards*	• *Fire and Explosion Incident Investigation* • *Fire and Explosion Modeling, Detection, and Suppression* • *Fire Safety Audits* • *Fire Safety Training* • *Life Safety* • *Occupant Notification and Egress* • *Emergency Preparedness and Response* • *Fire Safety Management Systems*	• *Environmental Permitting* • *Environmental Solutions* • *Environmental Management System Assessment* • *Air Dispersion Modeling* • *Exposure/Risk Assessments* • *Water Quality Treatment* • *Ground Contamination Remediation Planning* • *Solid Waste Management*	• *Senior Management Support* • *Internal Communications* • *Product Review Systems* • *Risk Characterizations and Risk Management* • *Systems for Training and Refreshing* • *R & D Systems* • *Joint Ventures* • *Sustainable Growth Initiatives* • *Standards and Guidelines*	• *Regulatory Training* • *Standards and Guidelines* • *Risk Assessments* • *Transport Safety* • *Emergency Preparedness*	• *OSH Injury and Illness Reporting, Classification, Investigation, and Documentation* • *OSH Roles, Responsibilities, and Accountabilities* • *Metrics of OSH Management* • *OSH Audit Protocols* • *Medical Programs for Fitness Duty, Surveillance, and Emergency Care* • *OSH Records and Communications* • *Effective Wellness Programs*	**Maintenance and Reliability System** • *Work Management Processes* • *Managing Storeroom Supplies Effectively* • *Reliability-Focused Maintenance* • *Uptime Measurements* • *Preventive/Predictive Maintenance Strategies* • *Reliability Growth* **Manufacturing Capacity** • *Material and Product Flow Analysis* • *Continuous Flow Manufacturing and LEAN Manufacturing* • *Industrial ergonomics* • *Warehouse/Distribution Analysis* • *Manufacturing Systems Simulation / Visualization* **Energy Optimization** • *Steam Generation* • *Electrical Power Distribution* • *Refrigeration* • *Cooling Towers* • *Heating, Ventilating, & Air Conditioning (HVAC)* **Facilities Infrastructure** • *Groundwater Protection: trenches / sumps / dikes; tank foundations; sewers* • *Structural Integrity and Architectural Components* • *Transportation Systems: roads/pavements; railroads* • *Power/General Services: PG&S equipment & systems; electrical power equip & systems; HVAC equipment & systems;*	**Business Planning** • *Business Objectives* **Facility Planning** • *Project Objectives* • *Project Capital Budget.* **Project Planning** • *Production Design Basis* • *Authorization Estimate* **Project Implementation** • *Production Design* • *Procurement* • *Construction.* **Start-up and Initial Operations** • *Plant Commissioning, Operations, and Maintenance* **Value Improving Guidelines** • *Technology Selection* • *Process Simplification* • *Classes of Facility Quality* • *Waste Minimization* • *Constructability Reviews* • *Process Reliability Modeling* • *Minimum Standards & Specifications* • *Predictive Maintenance* • *Design-to-capacity* • *Energy Optimisation* • *3D CAD Modeling* • *Value Engineering* **Contractor Effectiveness** **Shutdown/Turnaround Practices**

							service piping • *Materials: coatings & linings; plastics & elastomers; insulation; fireproofing* • *Life Safety Systems* **Mechanical Integrity** • *Materials of Construction Selection, Specification, and Fabrication* • *Equipment and Piping Nondestructive Testing and Condition Assessment* • *Maintenance and Reliability Predictive/Preventive Maintenance* • *Process Safety Management* **Product Quality and Process Control** • *Dynamic Process Simulation* • *Product Performance* • *Proportional Integral Controllers* • *Process Operability Analysis* • *Statistical Process Estimation and Control tools* • *Six Sigma and Applied Statistics* • *Quality Management*	

You need to document and explain exactly how all your business processes will be run to get the required business outputs. They must be scripted precisely as things need to happen. Find the right people to compose these documents and give them the time to sit down, research and write the standards, procedures and checksheets you need. Once the documents are drafted, test them in the workplace and correct them from the experience. Re-write them and re-test them until they produce the correct results. Once the standards are set and the procedures are proven they provide the training strategy for the business. Anyone that cannot meet the quality standards undergoes training to achieve the level of mastery they need to do their work excellently. With certain repeatability in meeting standards you know your business processes are in-control and capable.

Table 7.1 lists the types of procedures and documents to write for an industrial operation. [44] There are 105 document types listed. Without such documents, and the procedures that stem from them, there will be numerous interpretations of what is acceptable performance. Lack of clarity breeds wide variation and causes defects, problems and 'fire-fighting', as one thing goes wrong after another. With standardised, high quality procedures variation is controlled. Better methods can be developed to stop deviation and prevent failures. The lists in Table 7.1 represents a great deal of work. But such documents introduce and apply defect elimination and failure prevention throughout a business, and you cannot do without them. World-class operations will do the work, 'also-rans' won't bother because they mistakenly think it is not a prequisite to becoming world-class. They are wrong of course, and their thinking explains why they are where they are. They will remain 'also-rans' until their values and beliefs change and they do the work that is necessary.

Another mistaken belief is to see detailed documented procedures as the death of human creativity. Many people think they know all they need to know about their job and the best way to do it. They may be right. They do know a way to do their jobs. Whether it is the best way will depend if they have kept up with growing knowledge in the fields of research and technology that apply to the job, and then regularly introduced appropriate changes. A world-class company challenges its people to find even better ways to do their work. They know that the people doing a job are their resident experts and they want them to use their creativity to discover ever superior methods and procedures. Creativity does not die once procedures are introduced; rather it is funnelled into continually improving them toward yet better quality, for lower cost and at faster rates.

You now know what makes world-class businesses. They use sure methods and systems that deliver the performance standards their customers want. Then they keep lifting the standards and improving the systems. World-class operations use the scientific method, and not accidents of good fortune, to get lower-cost, on-time, quality production.

[44] Maximising Operational Efficiency Presentation, E. I. Du Pont de Nemours and Co, 2004.

The Enterprise Asset Management Toolkit

Managers use Plant Wellness, Asset Management and Quality Management methods and systems to get outstanding plant and equipment reliability. Figure 7.9 lists the main tools and when in the life cycle to use them. They let you set the standards that deliver world-class performance and build the business processes and skills to achieve it.

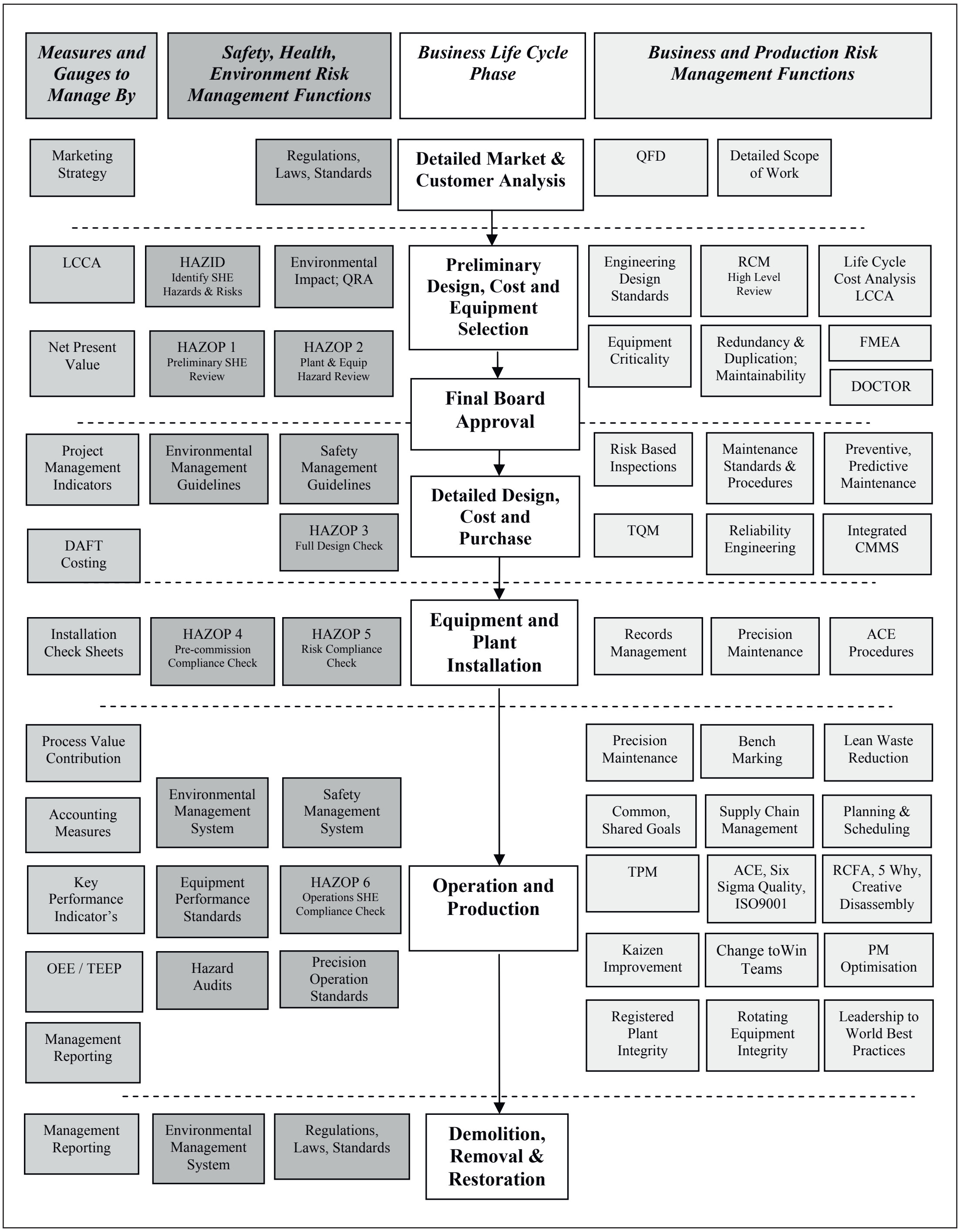

Figure 7.9 – Enterprise Asset Management Tool Kit.

On the left-hand side of Figure 7.9 are feedback and feedforward measures to gauge and manage a business. To the right are techniques and practices that produce compliance to the safety, health and environmental (SHE) requirements. Further to the right is a simplified life-cycle of an industrial business. It starts with the concept and financial justification for a project, through its design, commissioning, operation, and finally its de-commissioning. On the far right-hand are the methods, practices and systems that reduce business risks and deliver outstanding equipment reliability and plant performance. Short descriptions of 'tool kit' items not explained elsewhere in this book are in the Glossary.

Detailed Market and Customer Requirements Analysis

Designers of products and designers of production plants need to be sure that what they build will meet customer and legal requirements. This is achieved by asking the customer what they want and documenting it. Once the requirements are specified in writing the designer has clear indication of the characteristics and attributes they must deliver in the product or the plant. The legal, safety and community issues are addressed in applicable legislation and international engineering standards.

Figure 7.10 – Know the Needs of Your Customer by Asking and Listening to Them.

Quality Characteristics – The Determinants of Quality [45]

Customers decide if a product or service has quality. Table 7.2 lists some of the attributes they seek and use to confirm to themselves that it is a quality product or service. If the attributes are not there the product or service is poor.

Table 7.2 – Some Quality Attributes Customers Want from Designers.

Product Quality Characteristics			
Accessibility	Emittance	Producibility	Strength
Availability	Flexibility	Reliability	Taste
Appearance	Functionality	Reparability	Testability
Adaptability	Interchangeability	Safety	Traceability
Cleanliness	Maintainability	Security	Toxicity
Consumption	Odour	Size	Transportability
Durability	Operability	Susceptibility	Vulnerability
Disposability	Portability	Storability	Weight
Service Quality Characteristics			
Accessibility	Competence	Effectiveness	Responsiveness
Accuracy	Credibility	Flexibility	Reliability
Courtesy	Dependability	Honesty	Security
Comfort	Efficiency	Promptness	

45 Hoyle, D., 'ISO Quality Systems Handbook', Butterworth-Heinemann, 5th Edition.

Available techniques that attempt to get the 'voice of the customer' echoed into the design and manufacture of the product include writing detailed scopes of work that specify required outcomes, and applying the structured method of Quality Function Deployment (QFD). It is critical that designers know what the customer wants and that sufficient effort is put into clarifying and recording their needs before time and effort is put into develping a solution. If the designer is not sure what a client wants they can waste a lot of time doing the wrong thing. Delivering the quality that a customer wants is a process. Specify the attributes needed of products and work. Define how to control, assure, improve, manage and demonstrate their achievement. Script what is required and how to deliver it and then do it. Figure 7.11 overviews the factors that need to be considered in designing a process to satisfy customers.

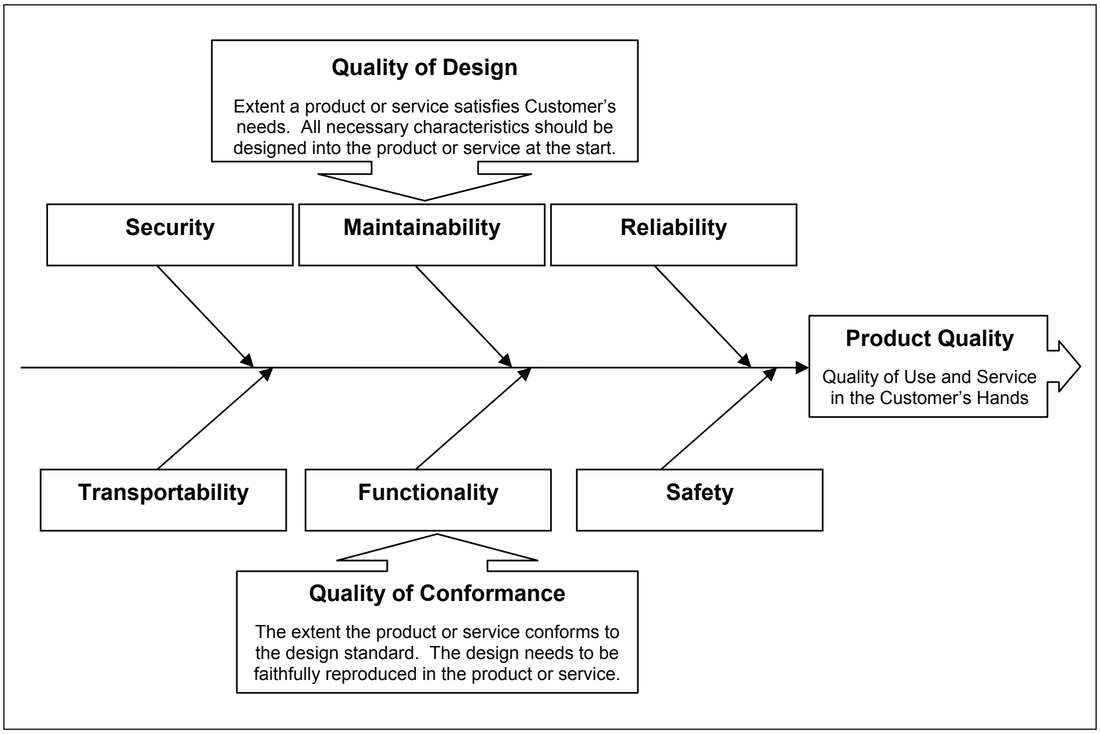

Figure 7.11 – Customers Determine Quality.

Preliminary Design, Costing and Equipment Selection

The design and selection phase is a most critical period in the long-term success of a business. This is the stage that will determine its future operating costs and profitability. The choice of technologies, the choice of production processes, the choice of location, the choice of equipment to make the product mix will fix the facility's cost structure. It is at this point that the facility's future profits, and its future options to adapt in response to changing market forces, are set. If the equipment chosen for the facility requires major up-keep, or if the equipment cannot maintain quality production for great lengths of time, then the facility will produce high cost product and much waste. Production will produce less operating profit since part of their profit margin must pay for the up-keep of the facility and its equipment. There will be less cash available to make future business and plant improvements and so make products more competitively. In time, the products will disappear from the market because competitor items are cheaper and of better quality.

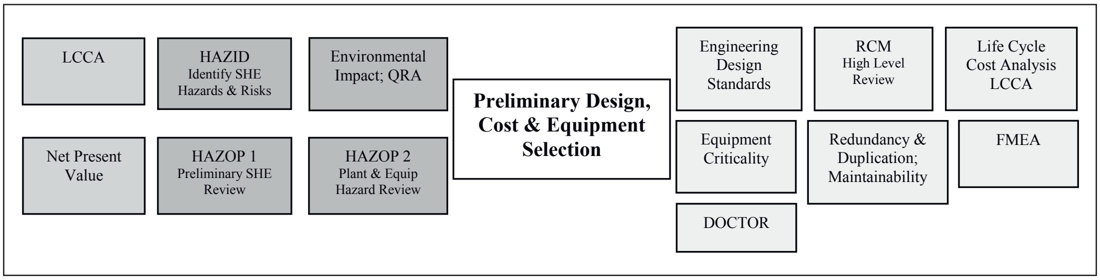

Figure 7.12 – Preliminary Design, Costing and Equipment Selection.

Business Risk Reduction Strategies

The odds of making the right business choices at the Preliminary Design, Cost and Equipment Selection stage improve by using proven successful risk reduction strategies.

1. Apply Engineering Design Standards to permit standardisation throughout the facility,
2. Establish Equipment Criticality using DAFT Costing to highlight bottlenecks and equipment critical to success. Include the necessary production risk controls in the project justification.
3. Apply Failure Mode and Effects Criticality Analysis (FMECA) reviews on process and equipment and design-out problems or allow funds to maintain equipment at the level that will produce the production rates and quality required for project profitability.
4. Ensure the original equipment manufacturer (OEM) uses Failure Mode and Effects Analysis (FMEA) right down to the individual equipment component level to remove all foreseeable modes of equipment failure and their associated cost. By having the OEM perform the FMEA and getting their designs right, you will know that you are buying highly reliable equipment that will have low operating costs.
5. Model Life Cycle Cost Analysis (LCCA) by people experienced in using and maintaining the equipment to make the best life-long profitable equipment choices for the business.
6. Use Duplication and Redundancy wisely where functional failure is unacceptable to the financial return for the project. Use the process maps to find opportunity to apply parallel reliability strategies. For example, include tie-in points to use mobile equipment during breakdowns and preventive maintenance servicing. Design the plant and process so there are duplicated systems and circuits that keep production going even if one circuit is lost.
7. Optimise operating costs with the DOCTOR. Maximise maintainability of plant and equipment to speed-up maintenance actions and reduce outage times. Simplify repairs so that operators can do them. Remove costly special access requirements. Ensure the plant is maintainable without shutting down large portions of it.

Controlling Safety, Health and Environment Risk

The likelihood of future Safety, Health and Environment (SHE) problems are controlled and mitigated by:

1. Performing Environmental Impact Studies and Qualitative Risk Assessments (QRA) to highlight potential risk to the community and environment.

2. Conducting Hazard Investigation (HAZID) risk management analysis of potential dangers with the proposed design.
3. Applying Hazard and Operability (HAZOP) reviews of proposed plant and operating practices to insure safe outcomes in event of upset situations occurring during operation.

Measures and Gauges

Selecting good long-term production, process and equipment decisions depends on finding the least expensive life cycle cost that meets product quality and throughput requirements. The financial benefits and effects on the viability of a project from addressing SHE and business risks can be estimated and optimised by using the DOCTOR and modelling the Net Present Value of future profits from each option.

Detailed Design, Costing and Purchasing

Once the Board accepts the marketing analysis and cost justification of the preliminary engineering design, the project goes into the detailed design and procurement phase. The complete engineering is finalised so materials and equipment can be purchased and sent to site for construction and installation. The detailed design, costing and purchasing phase produces all the final drawings, construction specifications, equipment specifications, purchasing and supply contracts, operating standards and procedures, maintenance standards and procedures. This ensures that from the first day the operation reliably produces quality product to meet the cash flow expectations of the business.

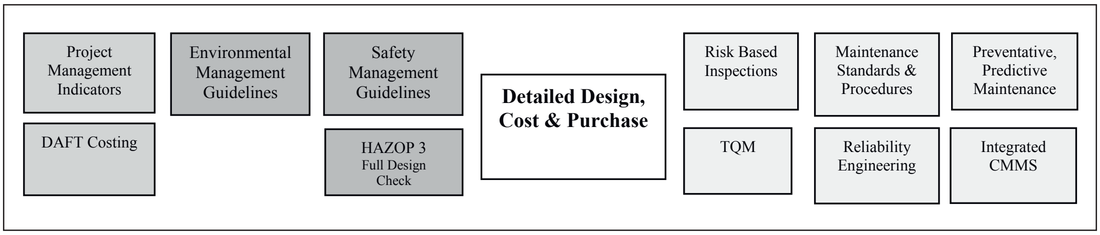

Figure 7.13 – Detailed Design, Costing and Purchase.

Business Risk Reduction Strategies

At this point in the project it is necessary to go into detail and specifics with care, and a desire to build a world best operation and facility. The tools available to manage business risk include:

1. Maintenance Standards and Procedures defining and specifying the operating tolerance of plant and equipment. They establish the benchmark requirements to keep the facility in a condition to meet its community, safety, environmental and business obligations.
2. Risk Based Inspections (RBI) that quantifies the likelihood of catastrophic plant and equipment failure so you can set into place suitable inspection periods and procedures.
3. Using Total Quality Management (TQM) to set and control quality requirements for the equipment, processes and systems in the facility.
4. Developing Preventative Maintenance (PM) routines to prevent ageing and usage failure through vigilant equipment care and observation.

5. Instigating proactive Predictive Maintenance (PdM) inspections to forewarn of future process, plant and equipment problems.
6. Installing an integrated Computerised Maintenance Management System (CMMS), as part of an Enterprise Asset Management (EAM) System, to manage and track the facility's production and maintenance requirements and associated costs.

Controlling Safety, Health and Environment Risk

To manage SHE risk it is necessary to have both safety and environmental guidelines to meet during detailed design. Once a process design is firm it is time to conduct an in-depth and detailed Hazard And Operability Study (HAZOP) of each process item to check it will perform to its design requirements during operation, and insure the protection of people and environment if it does not. The HAZOP risk review methodology is a well-used and successful risk identification and management tool applied at the drawing board level of a facility's design.

Measures and Gauges

The whole process of designing, specifying and purchasing project infrastructure, goods and services is project managed.

Plant and Equipment Installation

The project has now progressed to the field work stage. The site is prepared, buildings constructed and plant and equipment installed in place. Poor workmanship and quality control during construction and installation will produce excessive maintenance and production downtime in future.

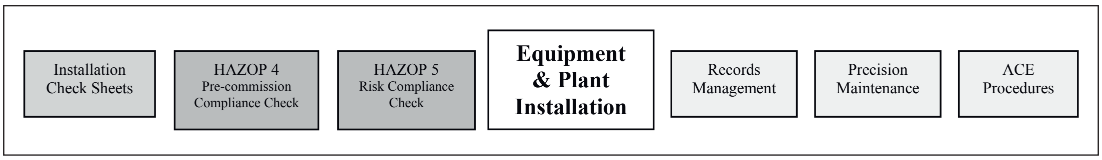

Figure 7.14 – Plant and Equipment Installation.

Business Risk Reduction Strategies

At this point, it is critical to ensure the equipment goes into place to world class installation and maintenance practices and standards. This level of professionalism will guarantee that the equipment operates within its design requirements all its working life.

Accuracy Controlled Enterprise

Document the procedures that, if followed, will deliver highly reliable equipment operation. From commissioning ACE quality practices must be in use. Train people to the 3T – Target, Tolerance Test – procedures so they always deliver the required quality performance.

Precision Maintenance

The installation standards needed are those of Precision Maintenance. They cover the requirements for fastener tension, shaft alignment, rotating equipment balancing, equipment operating vibration limits, lubrication and equipment frame stresses and distortion. It is necessary to specify these requirements to both the original equipment manufacturer and the equipment installation contractor. Internationally recognised standards are available.

Records Management

Protect the engineering, operating and maintenance knowledge base developed during the design process by the use of sound records management practices. Correct information will be the lifeblood of the facility management's future ability to make good, timely decisions. It is terribly important to preserve all the facility's design and equipment selection information for the facility's entire existence. Similarly, all the operating and maintenance standards and procedures established during the design phase must be readily available during commissioning and in later operation.

The best record management practice is to centralise the storage and care of the master documents but make all necessary information (project, engineering, operating, process and maintenance) easily available and widely distributed electronically. When questions arise and decisions are to be made in future, complete and accurate information must be quickly on-hand.

Controlling Safety, Health and Environment Risk

At the end of construction and installation, it is necessary to confirm and prove that hazards identified previously are under control. Further HAZOP studies and check tests conducted during commissioning to prove compliance.

Measures and Gauges

Because this is part of the project construction phase, the existing project management measures and controls monitor compliance to the project plan.

Maintain control of the precision and quality of installation with check sheets. On the check sheets, record the previously set standards and equipment design requirements. Take site measurements and compare them to the standard to ensure the work meets precision maintenance and engineering standards. If site results do not meet the standard, correct the problem until compliance.

In Operation and Production

At this point, the plant is fully operational and making product. This is when profits are generated to payback the capital used to create the business and make a return on the investment. Typically, a manufacturing or processing plant operates for several decades. The equipment always needs to be in suitable operating condition when it has to perform its function. To prevent equipment failures, production outages and product quality problems the business processes in use must control variation to within specification. If that is not possible then the business processes must be redesigned until the outputs comply with requirements.

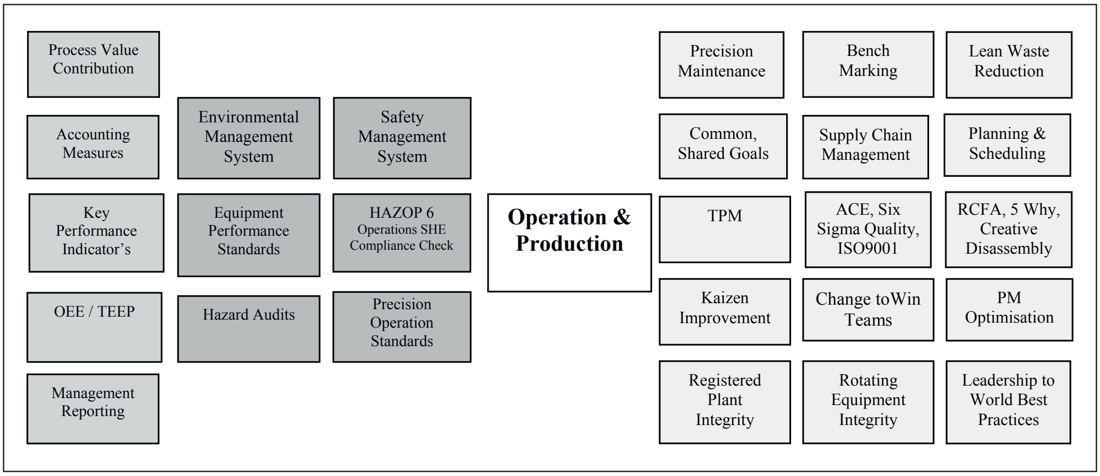

Figure 7.15 – During Operation and Production.

Business Risk Reduction Strategies

A large range of methodologies and practices are available to Operations and Maintenance to manage, control and adjust processes and equipment to produce product within specification [46].

The business risk controls available include:

1. Leadership and guidance to maintain a world class effort;
2. Common, shared goals across all departments so all strive for the same result;
3. Lean Manufacturing practices and methods to reduce waste in all its forms;
4. Total Productive Manufacturing (TPM) loss minimisation through worker empowerment;
5. Six Sigma Quality control that targets well above average compliance to specification;
6. Kaizen continuous improvement projects in the workplace. The workplace is where the problems exist, where they can be seen, and where the people are most likely to come up with workable answers;
7. Root Cause Analysis (RCA) fault removal to find and break the causal trails that occur in all failures and faults;
8. Preventative Maintenance Optimisation to focus on preserving the key functions of the equipment;
9. Benchmarking against others in the industry to check the right things are being done and that performance is at a high standard;
10. Supply Chain Management of raw materials and processes to deliver the best finish product to the client;
11. Planning and scheduling to ensure up-keep of plant and equipment.
12. Challenge paradigms and create a learning organisation with the 'Change To Win' process explained in the workbook on the CD accompanying this book.

[46] Moore, Ron., 'Making Common Sense Common Practice', Butterworth-Heinemann, 2002.

Controlling Safety, Health and Environment Risk

SHE risk management requires religiously following the specified operating procedures, and by measuring and auditing the process, plant and equipment performance to prove they meet the set safe operating specifications and corporate standards.

Precision Operation Standards for Degradation Management

Establishing Precision Operating Standards and Procedures to run the facility, plant and equipment in ways to meet its legal, community, environmental and business obligations is critical. Precision operation involves specifying and setting limits within which the process, plant and equipment is operated. This protects the assets from abuse and misuse and insures the viability of the operation for its lifetime. With the use of precision operation standards, the equipment runs in a condition that keeps it within the design envelope it was constructed and built to perform reliably.

Equipment Performance

This includes making information on the equipment and process available in a visual form such as graphs and Pareto Charts (bar charts). An even more useful form of presenting important information is to trend a process variable against another affected by it. For example trending pump power usage against pump flow to indicate loss in performance as the internals of the pump wear. When the loss in performance is unacceptably far from the standard precision operating specification the equipment is rebuilt and brought back to as new again, or replaced.

Hazard Audits

Systems degrade over time. New people come in and new ideas and methods develop. The importance of past decisions becomes less relevant as time passes. This is a natural process of evolution and learning. The danger is that the original requirements designed into the plant and its production systems, which were meant to manage business risk and control hazards to protect the business, its people and its assets, are lost. Businesses have lost entire production facilities and people have died because the organisation did not do key hazard control requirements [47]. It is critical that management knows the status of the risk management practices and the risk control methods used by its employees.

Regular auditing is the only way to prove that the important aspects of business and safety risk management requirements are in common use in your operation. When auditing look for proof of non-compliance, not proof of compliance! It is easy to show a record of a system working as designed. But it's more important to look for evidence that it is not working to specification and correct the problems causing it.

Measures and Gauges

The importance of maintaining continual vigilant control over the operation reflects in the range of measures used to monitor and address variability of the operation. The measures to use include:

1. Key Performance Indicator (KPI) trends showing whether processes and systems are in or out of control,

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[47] Hopkins, Andrew, 'Safety, Culture and Risk – The Organisational Causes of Disasters', CCH Australia, 2005.

2. Overall Equipment Effectiveness (OEE) measure to quantify the whole operation's ability to have the plant availability, product quality and production performance necessary to make what the customer wants.
3. Accounting measures such as profit, cash flow, return on assets, cost control, inventory control and many more.
4. Management reporting, which becomes a critical factor in monitoring and maintaining compliance to set and agreed procedures and policies.

Demolition, Removal and Restoration

At this stage in the life of a facility the equipment is old, but if properly maintained and used during its service life it is still in good condition and able to deliver production at the same throughput, quality and specification as if new. There is no reason that old equipment properly maintained, replaced when fatigued, and run as designed without overdue stress to its materials of construction, should not retain the same capacity and abilities as it had at the start of its life.

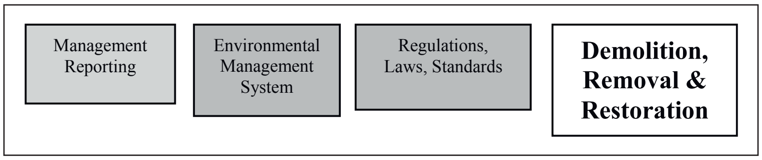

Figure 7.16 – Demolition and Rehabilitation.

8. Operating Equipment Risk Assessment

Risk is an amount of loss or gain. The presence of risk does not imply certain loss. The risk of having money invested in the stock market brings with it the possibility of great reward as well as the possibility of serious loss. The challenge is to develop methods to increase the likelihood of good outcomes while controlling and removing the bad. Because risk has such profound impact in everything to do with business and commerce it is critical to understand it. Once you have a good perspective on risk you are better able to identify the risk management strategies that provide the greatest financial, production and safety benefits to your organisation.

Risk is virtually impossible to reckon exactly because it is probabilistic – a situation might happen, or it might not. People will model and quantify risk to give it a firm value, but the results are notoriously misleading because real situations are unlikely to behave in the way they are imagined, unless they follow a well rehearsed script. The mathematics for gauging risk is straightforward and can be calculated in a spreadsheet or rated with the help of a risk matrix. Identifying the inherent risk profile present is the first step in matching mitigation strategies to the risk.

The Risk Equation

The most commonly used form of the risk equation is:

Risk = Frequency of Occurrence (/yr) **x Consequence of Occurrence** ($) *Eq. 8.1*

Risk is equal to the frequency of an event occurring multiplied by its cost, should it occur. Frequency is the number of times an event actually happens during a period. Usually a year is used. An event that happens every five years has a frequency of 0.2 times a year. The consequence of an occurrence is the total financial impact of the event – its DAFT Costs. By calculating the frequency of an event per year, and counting consequence of the occurrence in monetary value, the equation measures the annual cost of risk. It is a means to quantify the yearly cost to the organisation of every event it suffers, good or bad. It provides a figure to gauge one risk against another and so allows the setting of priorities for addressing risk.

The 'Frequency of Occurrence' divides further so the risk equation becomes:

Risk = [No. of Opportunities (/yr) **x Chance of Occurrence] x Consequence** ($) *Eq. 8.2*

The 'Number of Opportunities' is how many times a year the situation arises that could lead to a failure. The 'Chance of Occurrence' (or Probability) is the odds that a situation will go through to failure. It is one (1) if it will definitely fail every time the situation arises, and zero (0) if there will never be a failure when the situation arises. It normally takes values between 1 and 0 because the chance of a thing happening is usually possible to some degree.

There are great benefits available to businesses that reduce their risk of failure. If the chance of a failure is reduced so it happens less often it saves money because there are fewer events to spend it on. Using a simple example of a failure event that happens twice a year and costs $10,000 each time it occurs, the standard risk equation gives:

Cost of Risk = 2 events per year x $10,000 per event = $20,000 per year

By introducing risk reduction strategies that reduce the chance of the event to every two years, the risk becomes:

Cost of Risk = 0.5 events per year x $10,000 per event = $5,000 per year

The mitigation has delivered a saving of $15,000 per year, year after year. This is how businesses can minimise their cost of operation and make a lot of money. If they can reduce the numbers of failure events, or lower the cost of those events, then the risk to the operation reduces. If in the example the cost of reducing the risk to once every two years is less than $15,000 a year, then the company has made money by saving it. Controlling failure and controlling risk have identical implications to a business – reduce the numbers of failures and cost falls; reduce the amount of risk and cost falls. The challenge is to select those strategies that cost the least but realise the greatest risk reduction.

When a normal risk analysis is conducted the values for each part of the risk equation are developed using information available about the situation under review. Table 8.1 shows the typical column headings of a risk assessment spreadsheet used to gauge risk for operating equipment.

Table 8.1 – Risk Calculation Spreadsheet Layout.

Ref No	Equip Tag No	Equip Desc	Failure Event or Causes	Cost Consequence of Failure ($)	Years Equip in Service or Expected	No of Historic Failure Events at this Site or Expected	No of Annualised Failure Events due to Cause (/ Yr)	Likelihood of Failure Event (Between 1 – 0)	Estimated Inherent Risk ($/Yr)
1	2	3	4	5	6	7	8	9	10

The ‘Equipment Tag Number’ (Column 2) is the equipment number given to each item of equipment at that site. Every Tag No. is included – machinery, electrical equipment, instrumentation, piping, even the buildings and each functional area in a building.

The ‘Equipment Description’ is the official descriptive name used to identify the equipment.

The ‘Failure Event or Causes’ is the separate ways in which an item of equipment has failed, or could fail, in the situation it is in. For example, a two-wheel bicycle can fail due to a tyre puncture, a road accident, a chain drive failure, and so on.

The ‘Consequence of Failure’ is the cost impact when the equipment fails due to the cause.

The ‘Years Equipment in Service or Expected’ is the count of years the equipment has been in use. For new equipment items the expected years in service is used. Work in whole numbers and round any part-year to the nearest full year.

The ‘Number of Historic Failure Events at the Site or Expected Due to Cause’ is determined for each failure event cause by interrogating the equipment history (e.g. from a Computerised Maintenance Management System – CMMS) or from industry failure databases adjusted for the quality culture prevalent in the operation.

The ‘Number of Failure Events per Year’ is from dividing the ‘Number of Historic Failure Events at the Site’ by ‘Years Equipment in Service’ values.

The ‘Likelihood of Failure’ is a determination from tables such as Table 8.2, developed using risk analysis methodology from international risk management standards and industry guides [48, 49].

48 Australian Risk Management Standard AS4360:2004.

49 Robinson, Richard M., et al, ‘Risk and Reliability: An Introductory Text’, R2A Pty Ltd, 7th Edition.

Table 8.2 – Determining the Likelihood of Equipment Failure on a Site.

Risk Level	Descriptor	Description	Indicative Frequency (expected to occur)	Actual Failures per Year (historic evidence basis)	Likelihood of Failure per Year (opportunity for failure basis)	
					Opportunities (No. of Times a Situation Arises)	Probability of Failure
6	Certain	Failure event will occur at this site annually or more often	Once a year or more often	1 or more	Count every time the situation for an event occurs	1 if failure results every time the situation arises
5	Likely	Failure event regularly occurs at this site	Once every 2 to 3 years	1 in 2 = 0.5 1 in 3 = 0.33	Count every time the situation for an event occurs	0.1 if failure results 1 in 10 times the situation arises
4	Possible	Failure event is expected to occur on this site	Once every 4 to 6 years	1 in 4 = 0.25 1 in 6 = 0.17	Count every time the situation for an event occurs	0.01 if failure results 1 in 100 times the situation arises
3	Unlikely	Failure event occurs from time to time on this site or in the industry	Once every 7 to 10 years	1 in 7 = 0.14 1 in 10 = 0.1	Count every time the situation for an event occurs	0.001 if failure results 1 in 1,000 times the situation arises
2	Rare	Failure event could occur on this site or in the industry but doubtful	Once every 11 to 15 years	1 in 11 = 0.09 1 in 15 =0.07	Count every time the situation for an event occurs	0.0001 if failure results 1 in 10,000 times the situation arises
1	Very Rare	Failure event hardly heard of in the industry. May occur but in exceptional circumstances	Once every 16 to 20 years	1 in 16 = 0.06 1 in 20 = 0.05	Count every time the situation for an event occurs	0.00001 if failure results 1 in 100,000 times the situation arises

Determining the likelihood of failure is fraught with uncertainty. The opportunity for failure may rise often but never go to conclusion. Counting historic failure is easy because there are records. But counting an opportunity for failure that does not progress to a failure is open to speculation. An example of counting opportunities for failure is those known to be due to overload on equipment start-up. The likelihood of failure of a part known to fail from a high-stress overload during start-up can be calculated with Eq. 8.3. The opportunity for failure is the count of the average numbers of starts between failures. The likelihood of failure is:

$$\text{Likelihood of failure} = \frac{\text{No of failures}}{\text{Average number of starts between failures}} \qquad \textit{Eq. 8.3}$$

For an operation running continuously with 10 starts a day and failures averaging every 6 months, or twice a year, the likelihood of failure is:

$$= \frac{1\text{ failure}}{1800\text{ starts}} = 0.00056$$

With DAFT Cost of failure at $25,000, the risk calculated by using Eq. 8.2 is:

Risk = [No. of Opportunities (/yr) x Probability of Failure] x Consequence ($)

= 3600 x 0.00056 x $25,000 = $50,000/yr

The $50,000 annual risk estimated by first finding the probability is the same as that estimated by using the number of failures a year of Eq. 8.1 (i.e. 2/yr x $25,000). Where failures have happened, it is easier to count the average ‘Failures per Year’ from historic evidence and use the number in the risk equation. Historic failures are used because they already reflect the risk present. Future failure rates will remain the same as in the past until better risk management strategies are put into use. Use the opportunity for failure approach of Eq. 8.2 if it is known how often a failure situation truly arises. But if the count of opportunities is uncertain then use the historic average failures per year for the site in Eq.8.1. If actual site failures are not available, the industry average adjusted for the on-site culture can be used. If there is a good reliability culture and industry best practices are applied well, use the industry average; in a poor reliability culture assume a substantially worse outcome.

The 'Estimated Inherent Risk' is the annualised cost to the business of carrying the risk calculated by multiplying the values: 'Number of Annualised Failure Events due to Cause' x 'Likelihood of Failure'. It is the yearly cost for the risk carried by the business, and is used for gauging the size of a risk and comparing it with others. Those risks that a business does not want to carry can now be identified and mitigation plans put into place to reduce them.

The Risk Matrix

Knowing the 'consequence' and 'frequency' allows development of a risk ranking table for an operation. Table 8.3 is a risk matrix used to gauge the level of risk in a business. It is developed using the recommendations of international risk management standards. The business-wide consequences for people, reputation, business processes and systems, and financially are explained and scaled to reflect the organisation under review.

Table 8.3 – Risk Identification and Assessment.

RISK MANAGEMENT PHILOSOPHY **E – Extreme risk – detailed action plan approved by CEO** **H – High risk – specify responsibility to senior manager** **M – Medium risk – specify responsibility to department manager** **L- Low risk – manage by routine procedures** **Extreme** or **High** risk must be reported to Senior Management and require detailed treatment plans to reduce the risk to **Low** or **Medium**		**Business-Wide Consequence**					
		People	Injuries or ailments not requiring medical treatment.	Minor injury or First Aid Treatment Case.	Serious injury causing hospitalisation or multiple medical treatment cases.	Life threatening injury or multiple serious injuries causing hospitalisation.	Death or multiple life threatening injuries.
		Reputation	Internal Review	Scrutiny required by internal committees or internal audit to prevent escalation.	Scrutiny required by clients or third parties etc.	Intense public, political and media scrutiny. E.g. front page headlines, TV, etc.	Legal action or Commission of inquiry or adverse national media.
		Business Process & Systems	Minor errors in systems or processes requiring corrective action, or minor delay without impact on overall schedule.	Policy procedural rule occasionally not met or services do not fully meet needs.	One or more key accountability requirements not met. Inconvenient but not client welfare threatening.	Strategies not consistent with business objectives. Trends show service is degraded.	Critical system failure, bad policy advice or ongoing non-compliance. Business severely affected.
		Financial	**$5K**	**$50K**	**$100K**	**$250K**	**$500K**
			Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
Historical Frequency:			**1**	**2**	**3**	**4**	**5**
Event will occur at this site annually or more often	**6**	**Certain**	**M**	**H**	**H**	**E**	**E**
Event regularly occurs at this site	**5**	**Likely**	**M**	**M**	**H**	**H**	**E**
Event is expected to occur on this site	**4**	**Possible**	**L**	**M**	**M**	**H**	**E**
Event occurs from time to time on this site	**3**	**Unlikely**	**L**	**M**	**M**	**H**	**H**
Event occurs in the industry, and could on this site, but doubtful	**2**	**Rare**	**L**	**L**	**M**	**M**	**H**
Event hardly heard of in the industry. May occur but in exceptional circumstances	**1**	**Very Rare**	**L**	**L**	**L**	**M**	**H**

The methods and principles to apply in addressing risk can be advised in the Risk Management Philosophy box to the left of the matrix. The risk matrix is used to gauge whether an item or situation is at low, medium, high or extreme risk. Extreme and high risk are reduced to medium and low respectively, and medium level risk is reduced to low. The numbers corresponding to each level of likelihood and consequence can be added together to provide a numerical indicator of risk. This is often useful for comparing dissimilar risks to set priorities. It is a simple means not involving mathematical calculation to give each risk a representative value.

Identifying events and grading their risks is done using Table 8.4.

Table 8.4 – Risk Identification and Assessment.

EQUIPMENT OR ASSEMBLY	THE EVENT OR FAILURE *What can happen?*	SOURCE *How can this Happen?*	IMPACT *from event happening*	CURRENT CONTROL STRATEGIES *and their effectiveness* (A) –Adequate (M) – Moderate (I) – Inadequate	CURRENT RISK LEVEL			ACCEPTABILITY (A/U)
					LIKELIHOOD	CONSEQUENCE	CURRENT RISK LEVEL	
1	2	3	4	5	6	7	8	9

Table 8.5 is used to find strategies and actions to mitigate the risk and to judge their effectiveness. At the end of the review the risks and the mitigation actions are transferred into a Risk Management Plan spreadsheet, such as that for plant and equipment on the CD accompanying this book.

Table 8.5 – Risk Treatment Schedule and Action Plan.

EQUIPMENT OR ASSEMBLY RISK	POTENTIAL TREATMENT OPTIONS	COSTS & BENEFITS	TREATMENT TO BE IMPLEMENTED (Y/N) *and their effectiveness* (A) – Adequate (M) – Moderate (I) – Inadequate	RISK LEVEL AFTER IMPLEMENTED			RESPONSIBLE PERSON	TIMETABLE *to implement*	MONITORING *strategies to measure effectiveness of risk treatments*
				LIKELIHOOD	CONSEQUENCE	TARGET LEVEL			
1	2	3	4	5	6	7	8	9	10
		FINAL Cumulative Risk Level after Treatment							

A Practical Way to Use the Risk Equation

When risk is under-priced wrong decisions can result and insufficient protective measures are taken against the real likelihood of failure. Making decisions involving risk without understanding both the likelihood of an incident occurring and the full cost of its consequences have ominous implications to a business. In situations involving risk it becomes necessary to identify the various scenarios that may happen and estimate their individual cost and probability of occurring.

The risk equation requires its users to know the chance and the consequence before a risk can be determined. The cost consequence is the worst financial impact of the incident and found by assuming worst case scenarios and tallying costs using DAFT Costing. What is not easy to determine is the 'chance' factor for an incident. Because an incident requires several permitting causes to occur in sequence or together, and each has its own degree of chance, then the probability of all factors coming together is never more than a hopeful estimate, a guess. Few businesses want to operate on guess-work as their strategy for being profitable.

Typically, you look at the history of an incident and use recorded evidence to determine a frequency. Alternately, you can use industry databases if available and they are reflective of the situation under consideration. Where there is insufficient or no historic data for an incident, then laboratory and controlled trails and tests can estimate the conditions for a failure incident to occur. From the test you conduct a scientific analysis and engineering review to estimate a probabilistic frequency of the event. This is better than guess work, but no-one knows how much better because of the many assumptions needed to arrive at the estimated frequency figure.

We can be sure the consequence value is reasonably accurate if DAFT Costing is used to calculate the total cost. But we can never be certain that the frequency figure is correct, or even close to correct, unless there is a long, unchanged history of the incident occurring. If historic records are complete and accurate, you can use them as evidence of event frequency. For those loss incidents that hardly-ever happen, or happen infrequently, the estimated risk could be very wrong. The situation is further complicated by the fact that when the chance of the incident happening is altered by improvement projects, or by totally unknown events stemming from unrecognised causes, then the frequency figure changes too. It requires but one change to the factors influencing an incident and the event frequency can alter completely. This uncertainty raises the questions, "If the frequency figure in a risk equation is so uncertain why try and estimate it? Why base your decisions on something so unpredictable?" When the frequency is chancy then there is another way to use the risk equation to get value from it.

By simple mathematical manipulation of the risk equation:

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

With the equation written in this form we are in better command of risk. No longer do we need to wait in stressful expectation of a failure, wondering when it will happen. Instead, we decide the risk to carry in our business and then act to implement the risk control methods needed to produce that outcome. With the equation in the form above, we can decide what we want to pay for risk. We can set a risk boundary beyond which we will not tolerate. We become proactive against failure.

If we have a risk where the DAFT Cost consequence is \$100,000 but the frequency is uncertain, we can accept a guess for the frequency and hope it is right. Or we can decide that we do not want to carry a risk greater than \$10,000 per year and use the re-formatted the risk equation to identify the frequency we are prepared to accept.

$$\begin{aligned}\text{Chance} &= \text{Risk} \div \text{Consequence}\\ &= \$10{,}000 \text{ per year} \div \$100{,}000 \text{ per event}\\ &= 0.1 \text{ events per year (i.e. Once in ten years)}\end{aligned}$$

The frequency is no longer guesswork. Knowing we need ten years between events lets us develop and action risk mitigations that reduce the change of the event to the required period. Resources and money can be devoted to accomplishing it with greater certainty of achievement. It is a more useful way to use the risk equation than hoping an estimate for frequency is close to being right, and wondering if the current business systems and practices will provide that level of protection. A second benefit of using the risk equation in this way is knowing how much to pay for risk control. For an event that costs $100,000 to happen no more than once in ten years, you can afford to pay up to an equivalent $10,000 a year, or $20,000 every two years, or $50,000 every five years to prevent it. If it costs more than $10,000 annually to prevent the once-in-a-decade $100,000 risk, it is necessary to identify and address the causes of the higher cost. If reducing the annual cost to mitigate the risk is not possible, then the risk is greater than was envisioned. As a risk rises, more money can be justified to reduce the likelihood of its occurrence.

Risk Boundary

A DAFT Costs based risk analysis establishes the risk boundary that an organisation is willing to carry. If the risk is acceptable nothing is done to stop it and, should it happen, the business then knowingly pays for the rectification. But if the cost of failure is unacceptable, then mitigation is put into place to reduce it sufficiently, since mitigation to prevent the problem is seen as a better investment than paying to fix its consequences later. Figure 8.1 shows the risk boundary concept of investment to prevent failures. This company will not accept annual DAFT Costs on an item of equipment of more than $20,000, and is willing to invest to reduce greater risks.

A business makes money if a risk can be prevented for less than the risk's equivalent annualised cost. The greatest opportunity for business to manage risk for much less cost is by identify those methods, systems and practices that reduce the chance of a risk arising, and then implement them with great energy and vigour across the organisation. Maintenance is only one of the methodologies available to reduce the risk of equipment failure. But it is a consequence reduction strategy and comes after failure has started. Also available are numerous engineering and operational choices that are more cost effective over the equipment life-cycle than maintenance because they use chance reduction strategies that stop failure from starting. (Chance Reduction Risk Management is explained in Chapter 11.)

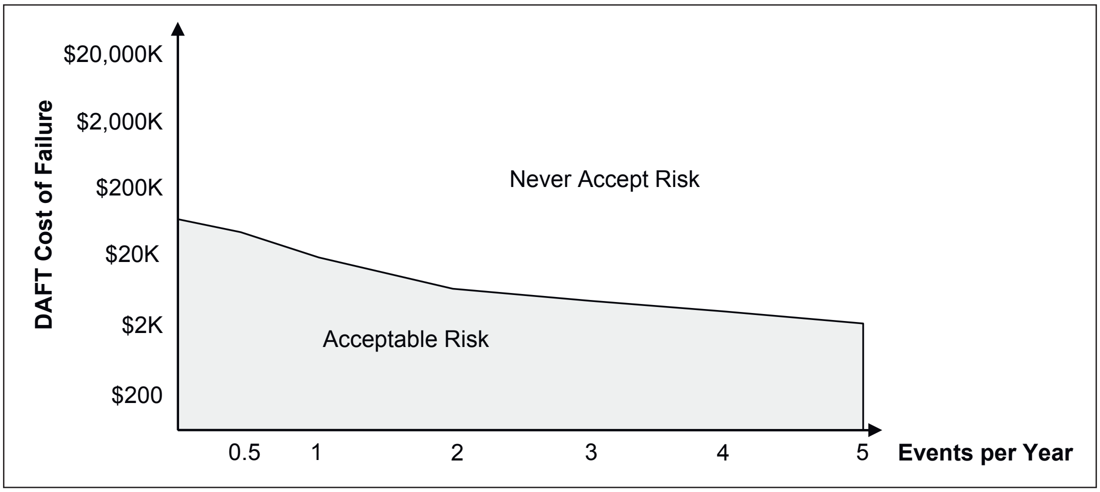

Figure 8.1 – The Risk Boundary Concept.

Equipment Criticality

Developing an equipment risk profile is known as Equipment Criticality. It uses the risk formula to identify the financial impact if an equipment failure was to happen – it is a risk rating indicator.

Equipment Criticality = Failure Frequency (/yr) x Cost Consequence ($) = Risk ($/yr)

The 'cost consequence' is the DAFT Costs. The 'failure frequency' is from the company's maintenance history, or industry norms for a similar situation.

Standard equipment criticality is also used to rate equipment in priority order of importance to the continued operation of a facility. The equipment that stops production, or that causes major production costs when failed is considered most critical. Once the criticality is known the facility's resources, engineering effort, operations practices, maintenance and training are matched to the priority and importance of the item's continued operation. The Plant and Equipment Wellness approach to equipment criticality differs from the standard approach in that it uses DAFT Costs, and not production impact, to gauge the business risk of equipment failure. A key premise of Plant and Equipment Wellness is that we are building a world-class business. To make the right business decision it is necessary to know the business-wide losses and not simply the production losses of a failure. Unless the true and total business-wide costs are included in determining equipment criticality, the full risk of an equipment failure to the business is not recognised. Using DAFT Costing gives a more accurate value of consequential loss to the whole business and so a truer business risk is determined.

A competent team of people is drawn together to identify the equipment criticality for a facility. Normally a database of DAFT Costs is first developed. The database is used to populate calculation spreadsheets and makes the analysis quicker and easier. Typically the review group consists of the operators, maintainers and designers of the plant who contribute their knowledge and experience. The group reviews drawings of the facility's processes and its equipment. Equipment by equipment they analyse the consequences of failure to the operation and develop a table showing each equipments criticality rating. It is the practice that the final arbiters of a choice are the Operations or Production Group, since they must live with the consequences and costs of a failure.

Risk Matrix Calibration

The persons involved with the risk assessment need to –

a. Understand the equipment operation and design – operator manuals, maintenance manuals and design drawings contain this information.

b. Understand the impact on production of losing the equipment. The information is in plant drawings, Process Flow Diagrams (PFD), Process and Instrumentation Diagrams (P&ID).

c. Know the business-wide financial loss from a forced outage. The DAFT Cost losses for a typical downtime period must be quantified.

d. Know the effects on business reputation and the impact on Clients of forced outages.

e. Review and adopt the risk control methodology in international risk management standards, such as Australian Standard 4360 – Risk Management, and its international equivalents.

f. Calibrate the consequences on the Risk Matrix using the information developed from the above and the advice of experienced and senior persons in the operation under review.

Asset Assemblies and Components

In order to understand the knock-on consequences of failed assemblies in individual equipment, each asset is subdivided into its major assemblies for separate risk analysis. If major assemblies contain substantial numbers of individual equipment, then these are further divided into sub-assemblies.

Risk Assessment

The Risk Identification and Assessment Template of Table 8.4 is used to list the operating risks to each equipment, assembly and sub-assembly. Alternately, a spreadsheet is developed to replace the template. For equipment and assemblies under assessment use a calibrated Risk Matrix to categorise Consequence (1-5), Likelihood (1-6) and Risk Level (L, M, H, E) from each risk.

Risk Management

For High and Extreme Risk Levels use the Risk Treatment Schedule and Action Plan Template of Table 8.5 to list actionable activities that will reduce risk by at least two levels. For Medium Risk Levels identify actions that will reduce them to Low. A Failure Mode and Effects Analysis or Reliability Growth Cause Analysis is used to identify required risk management activities to sufficiently lower the risk levels of individual parts.

Performing a Plant Wellness Equipment Criticality Analysis

In keeping with the premise that we are building a world-class business, Plant Wellness requires that the chance of failure be prevented during the operating life of plant and equipment. To achieve that outcome, the Plant Wellness method again diverges from the standard method in its rating for equipment criticality. Plant Wellness equipment criticality envisions the worst outcomes (including plausible 'acts of God' like lightening and serious bad weather damage), death of employees, destruction of the environment and major plant and equipment loss if such consequences are plausible, especially if known to happen in the industry. The assumption of sure catastrophe makes the DAFT Cost the initial equipment criticality rating because the chance of failure is taken to be certain. The DAFT Cost and the catastrophic outcomes of the incident are the consequences used in the risk matrix to determine a risk level. Risk is then reduced by selecting mitigations that lower the frequency of an event to levels not expected to happen during the equipment's working life. The frequency of failure is an outcome of a Plant Wellness equipment criticality analysis, not an input. Selecting responses that limit the consequences from a risk event is the secondary line of defence in Plant and Equipment Wellness. To do anything less than control the frequency of failure means a business is running on luck, and not on good judgement and sure risk management.

In many cases a failure event will not be acceptable under any circumstances (for example, if there was risk to human life, total or substantial production plant destruction, loss of a customer, or a catastrophic environmental incident). It is then unnecessary to ponder the frequency of the event because it is so horrific that everything justifiable to stop it is employed in its prevention. Even if such a failure were to happen once in one-hundred years, it would cause such severe effects that it must never happen.

It is impossible to predict when a one-in-ten year, or a one-in-twenty year, or a one-in-one-hundred year failure will occur. It could be tomorrow. Beware when standard risk analysis multiplies consequential cost by a low chance of the event occurring. The true devastating impact on the business is hidden by the low risk value. Catastrophic incidents do eventually happen if not prevented. By first discounting major events because their frequency is low you are guaranteeing that, from time to time, catastrophes will happen in your operation. This is another example of misunderstanding the capability of a process that leads to decisions which destroy equipment and businesses. Failures are controlled by use of appropriate engineering design, construction controls, operational practices and maintenance methods, systems and practices, not by hoping they will not happen.

If an operation lives with many disastrous risks, the odds worsen with time that one or more will happen. As the years go by and a possible failure has not yet occurred, the chance of the event rises because protective systems degrade, uncontrolled modifications are made, management focus changes, experienced people are replaced by those less experienced, people become complacent, along with numerous other reasons that become the root causes of failure. Unless preventive precautions are vigilantly maintained the worst failure event will eventually occur. In an operation carrying many unaddressed low-chance, high-cost opportunities there will be a steady stream of catastrophes. The next one is just around the corner. By identifying equipment criticality as the worst DAFT Cost it highlights risks that would be considered minor by traditional rating methods and forces adoption of the necessary precautions to prevent them.

The full range of possible equipment failure scenarios is costed in order to provide complete understanding of all operational risks. Knowing the full risk profile for the equipment allows better design, operating and maintenance decisions to be made to manage those risks. The same method of analysis is also applied to rate the criticality of each assembly in the equipment, and can be continued to sub-assembly and parts failures if required; though the failure of parts is best analysed with Failure Mode Effect Analysis or Reliability Growth Cause Analysis.

Estimate the Size of Risk Reduction

Many ideas to reduce risk have little real effect. The prevention strategies to limit chance of failure and the actions chosen to minimise the consequence of failure need to actually reduce risk to the required lesser levels. Estimating the extent of risk reduction can be done in a table, such as Table 8.6, or with a risk matrix. Provided mitigation significantly removes the stresses from equipment parts it is considered effective [50]. When parts are much less stressed and fatigued the frequency of failure falls and there are far fewer failure events. In order to accept that a suggested improvement is effective, it must be unquestionable in its ability to reduce stress levels and stress accumulation by a good margin from what would have been without it. Proof trials, such as reduced electrical power use, lowered equipment vibration levels, lesser operating temperatures, or other appropriate factors for monitoring, can be conducted on the equipment to confirm the stress reduction gained by a suggested mitigation. Team agreement is best when revising event frequency or likelihood, as a group decision that is well debated and discussed uses the 'wisdom of crowds' effect for arriving at consensus.

Gradually you build a documented engineering, maintenance and operational strategy to deliver highly reliable equipment. No longer is there mystery as to why maintenance is done, why plant is operated to reduce stress or why particular engineered solutions are required. The amount and type of engineering, operating and maintenance is matched the levels of risk willing to be carried by the operation.

The Problem with Standard Equipment Criticality Decision Methods

The rating of an equipment item at a certain criticality is the result of subject matter experts making informed decisions about the frequency and consequences of a failure. These opinion-

[50] 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.

based choices are open to misunderstanding and favoured choosing. Because mitigations involve subjective decisions based on past experience and the knowledge of consequences, it is possible that a person's knowledge is not deep and broad enough to make the better choice. They may be overly conservative and make an item a high criticality when it is not, thereby causing the maintenance costs to rise from unnecessary use of resources. Worst would be a choice that is a low criticality when it should be high and so chancing future failure.

In the Author's field experience, standard criticality rating is done too superficially to appreciate the real risk equipment failures cause a business. Important equipment gets mistakenly rated at a lesser risk than it should and so does not get sufficient and adequate maintenance and operator care. When a poor analysis is done the risk is not controlled well enough and the equipment continues to fail, much to people's wonder. But using DAFT Costing reduces the problem of subjective opinion, as knowing the full financial impact of failure encourages sound, fact-based decisions to be made.

In Table 8.7 is an example of a normal equipment criticality rating for a family car. It uses the traditional operational impact approach. Keeping the car in operation is important, but no consideration is given to the total effect on the family of a failure.

The standard methodology has produced maintenance and operating recommendations to address the perceived risks in use of the car. But there is no evidence that mitigations are correctly matched to the risk, or that they are adequate to control the risk to the family, because the real risks have not been quantified as a cost the family must suffer.

Table 8.8 shows a criticality rating for the family car which uses the Plant Wellness equipment criticality method. The analysis starts by identifying the DAFT Costs for a total failure of each major assembly and its main sub-assemblies. It is also useful to note the length of time taken to recover from an incident. Often the opportunity loss caused by the downtime is a more critical factor than the cost of repair. For this example the risk matrix of Table 8.3 is recalibrated at $20 for 'Insignificant' and increasing in multiples of ten. The risk matrix is used to determine the risk rank and a total risk number. For example, the fuel system has a moderate cost of $1,500 if it fails (nearest consequence value is 3), with a rare chance of failure (frequency value 2).

In the table there is a DAFT cost of $20,000 for damage to the car body that is a substantial cost to its owner. It is also the highest risk number because road accidents are possible (frequency value 4). Damage to the chassis from road accidents or running over curbs comes next at $15,000 to repair. Broken suspension cost of $8,000 is third. The engine at $6,000 is not the most expensive failure, but there is an annoying time delay in getting the car back on the road if key engine components are damaged. The standard equipment criticality rating would not have produced such a thorough understand of the failure consequences to the organisation (a family in this example). Having a real cost of failure provides greater insight into the full impact of a risk. The biggest risks are from car accidents and uncaring drivers who do not respect the vehicle. The best strategy to minimise risk is to ensure drivers have high driving skills, along with good road sense and attitudes. They could be sent to a defensive driving school to learn accident evasion techniques. The mechanical and electrical equipment in the car is best protected from failure by good driver education of how a car and its parts work, along with regular servicing and inspection. The service organisation will need to do a wide range of inspections and the selection of the service provider is based first on how comprehensive and competent is the service they offer, followed by their cost.

Using DAFT Cost shows that the failure cost of parts not considered important by the standard equipment criticality rating methods is actually very high. These parts received little attention in the standard criticality rating method because a low frequency implies few failures. People consider them a lower importance because of their supposedly low risk. The

Table 8.6 – Equipment Risk Reduction Spreadsheet Layout.

Ref No	Equip Tag No	Equip Desc	Failure Event or Causes	Original Estimated Inherent Risk ($/Yr)	Engineering, Maintenance and Operational Activities to Reduce Risk	Years Equip Remaining in Service or Expected to be in Service	Current No of Historic Failure Events due to Cause (/ Yr)	No of Failure Events or Expected due to Cause after Risk Reduction	Annualised Likelihood of Failure Event after Risk Reduced (/ Yr)	DAFT Cost of Failure Event ($)	Revised Inherent Risk ($/Yr)
1	2	3	4	5	6	7	8	9	10	11	12

Table 8.7 – A Traditional Equipment Priority Analysis for a Motor Car.

Priority Rating for a Rear Drive Family Motor Car						
Component	**Sub-Components**	**Failure Effects**			**Criticality by Risk**	**Maintenance & Care Required**
		Unusable	Causes Difficulty	No Concern		
Engine						
	Fuel system	Y			High	Regular service
	Crank and pistons	Y			High	Regular service
	Engine block	Y			High	Regular service
	Cooling system	Y			High	Regular service
	Oil system	Y			High	Regular service
	Ignition system	Y			High	Regular service
Gearbox						
	Input shaft	Y			High	Regular service
	Internal gears	Y			High	Regular service
	Output shaft	Y			High	Regular service
	Casing	Y			High	Regular Inspection
Drive Train						
	Drive shaft	Y			High	Regular Inspection
	Differential	Y			High	Regular service
	Axels	Y			High	Regular Inspection
	Wheels		Y		Medium	Regular Inspection and rotation
Body						
	Dash display		Y		Medium	Regular Inspection
	Indicator lights		Y		Medium	Regular Inspection
	Lights		Y		Medium	Regular Inspection
	Windows		Y		Medium	Regular Inspection
	Doors		Y		Medium	Regular Inspection
	Panels			Y	Low	
	Chassis		Y		Medium	Regular Inspection
Suspension						
	Shock absorbers	Y			High	Replace at end of life
	Springs	Y			High	Replace at end of life
	Frame		Y		Medium	Regular Inspection

Table 8.8 – Plant and Equipment Wellness Criticality Analysis for a Motor Car.

Component	**Sub-Component**	**DAFT Cost Rating**			**Criticality By Risk**		**Criticality by DAFT Cost**	**Required Operating Practice**	**Required Maintenance**
		System Loss Cost $	Assembly Loss Cost $	Time to Recover Days	Rank	Number			
Engine		6000		21	Medium	6	6000		
	Fuel system		1500	3	Medium	5	1500	Monitor operation	Regular service of parts
	Crank and pistons		3000	21	Medium	5	3000	Monitor operation	Replace at end of life
	Engine block		3500	21	Medium	5	3500	Monitor operation	Replace at end of life
	Cooling system		1500	5	Low	5	1500	Monitor operation	Regular service of parts
	Oil system		1000	5	Low	5	1000	Monitor operation	Regular service of parts
	Ignition system		1500	5	Low	6	1500	Monitor operation	Regular service of parts
Gearbox		5000		28	Medium	5	5000		
	Input shaft		1000	5	Low	4	1000		Regular service of parts
	Internal gears		2500	28	Low	4	2500		Regular service of parts
	Output shaft		1500	5	Low	4	1500		Regular service of parts
	Casing		3000	28	Low	4	3000	Monitor operation	Regular Inspection
Drive Train		2500		28	Medium	7	2500		
	Drive shaft		1000	14	Low	4	1000	Monitor operation	Regular Inspection
	Differential		2500	28	Medium	5	2500		Regular service of parts
	Axel x 1		1500	14	Low	4	1000		Regular Inspection
	Wheel x 1		1000	3	Medium	5	1000	Monitor operation	Regular Inspection
Car Body		20000		54	High	8	20000		
	Dash display		4000	28	Medium	5	4000	Monitor operation	Regular Inspection of condition
	Electrical system		4000	14	Medium	6	4000	Monitor operation	Regular Inspection
	Lights		1000	5	Medium	6	1000	Monitor operation	Regular Test
	Window x 1		1000	5	Medium	6	1000	High driving skills	Regular Inspection
	Door x 1		2000	14	Medium	6	2000	High driving skills	Regular Inspection for corrosion
	Panel x 1		3000	14	Medium	6	3000	High driving skills	
	Chassis		15000	54	High	7	15000	High driving skills	Regular Inspection for corrosion
Suspension		8000		28	Medium	5	8000		
	Shock absorbers		1000	3	Medium	4	1000	Monitor operation	Replace at end of life
	Springs		1000	5	Medium	3	1000	Monitor operation	Replace at end of life
	Assembly x 2		5000	28	Medium	5	5000	High driving skills	Regular Inspection for damage

DAFT Cost approach warns that though the equipment may not fail often, when it does it will be expensive and have destructive consequences for the owner. By reviewing the cost of failure independently of the chance of the failure, the DAFT Cost equipment criticality approach makes clear how bad each failure would be unless prevented from happening.

The Plant Wellness equipment criticality process also determines where responsibility lays for protecting equipment from harm. From the type of failure it is clear if the operator or maintainer needs to conduct mitigation. Management of the risk by proper operation, or by proper maintenance, or by re-engineering becomes self-evident. For the car only the driver (the operator) can prevent an accident. Only the driver can steer the car so it does not go over a curb and destroy the suspension. The maintainer cannot prevent such failures. Only for preventive maintenance or after equipment damage is the maintainer involved. The family car risk management plan involves having a skilled operator (the driver) who knows how to drive well and does not put the car into situations risking damage. Regular servicing of the car and its systems are important, as is the driver noticing when things are not working properly and reporting them for rectification before failure.

Knowing the full and real cost of a failure can help validate additional training, the purchase of new test equipment and changes to procedures not justifiable with traditional equipment criticality rating methods that under value risk.