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Plant and Equipment Wellness Asset Management Principles

5 Critical Understandings for Higher Productivity and Lower Maintenance Costs

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Preface

This book is not about maintenance, the word is hardly mentioned in it. Rather, the book provides understanding of five important issues - variability in outcomes, prevention of failure, risk control, work accuracy control and process step value contribution - that drive everything related to the use and care of physical assets. It is not a rehash of current physical asset management practice. Since current physical asset management and maintenance practices do not work well in most companies, there is no point in promoting their virtues. The concepts in this book provide better vehicles for implementing and sustaining physical assets simply and more successfully than today's failed methods.

It is clear from the poor results achieved by companies using physical asset management and operational improvement programs that something is missing with current methodologies and makes them so spectacularly unsuccessful when implemented in all but a very few organisations. For the few organisations where physical asset management stewardship reaps tremendous rewards it is because they understand and address the implications of the five concepts in this book. In mid-2009 these concepts were turned into a book also titled the 'Plant and Equipment Wellness Methodology' available from Engineers Australia.

This book aims to lift the success rate for users of physical asset management so that every company can enjoy the great and wonderful benefits that accrue to the successful ones. The book provides its readers with an insight into simple methods and practices that quickly and successfully introduce physical asset management and sustain it for the long-term to deliver continuous well-being to the organisation. The book ends with a simple formulaic approach to physical asset management and operational excellence that is easily adoptable by any organisation in all situations.

The future of physical asset management and operational excellence needs to focus on what really produces world-class equipment reliability, clear understanding of what causes it and the right tools for its successful rapid introduction and use. Because of its novel and innovative approach, it is proper to call the combination of practices promoted in this book by another name, rather than seeing it as an extension of existing physical asset management history. The name that best describes the new values that this book offers to industry, business and commerce is ***Plant and Equipment Wellness***.

Plant and Equipment Wellness is a more meaningful and clearer description of what is wanted for the future of business and commerce than is provided by the words ‘physical asset management’ or even ‘operational excellence’. It reflects the strong focus on defect and loss prevention that is the future of physical asset management and operational excellence and which this book promotes.

Like human wellness, which is the process of developing and combining the physical, mental, emotional, and spiritual parts of a person to create a sustainable, healthy, invigorating and satisfying life. Plant and Equipment Wellness is the process of developing and combining capital (the physical factor), business processes (the mental factor), organisation culture (the emotional factor) and human resources (the spiritual factor) to produce sustainable, healthy, invigorating and satisfying equipment performance.

My thanks go to Peter Brown of Industrial Training Associates for his perceptive understanding of industry’s needs by suggesting the concept of ‘Plant and Equipment Wellness’ to me. Thanks also to Don Fitchett of www.BIN95.com for first introducing me to the deep insights provided by True Downtime Cost.

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Introduction

Physical asset management, which also goes under the names of industrial asset management, engineering asset management, enterprise asset management and operational excellence, has three purposes –

- to prevent and eliminate the failure of facilities, plant and equipment,
- to minimise and eliminate risk in the use of facilities, plant and equipment,
- to optimise value from the use of facilities, plant and equipment.

Five important issues prevent the achievement of these three purposes - variability in processes, prevention of failure, risk control, accuracy control and process value contribution – which unless their effects and impacts are understood and completely controlled will continually prevent organisations achieving success in Engineering Asset Management and Operational Excellence.

The concept of Engineering Asset Management (EAM) and Operational Excellence (OE) has a short history. Its roots can be traced back to the same period in time as the start of quality management systems, around 1980. It is not a surprise to learn that the two are interconnected. It was soon realised after quality management systems were formalised, that they could not work without reliable plant and equipment which operated as they were designed to operate to produce products they were designed to make. Production success was found to be totally dependent on the quality of the business systems and processes in use, the reliability of the production machinery, and the beliefs and values of the management and personnel who worked in the organisation

Engineering Asset Management and Operational Excellence (EAMOE) were born of the need to have reliable, safe plant and equipment that behaved predictably and produced quality product. It included under in its umbrella all the business systems and resources needed to provide that safety, reliability, predictability and quality. But most unexpectedly, and most serendipitously, EAMOE also delivered lower production costs and more production throughput with less people.

Though EAMOE methodology is a fledgling it has been adopted internationally because when done well it is truly effective in reducing costs, reducing risk and boosting productivity. With all these benefits available to business it is not surprising that the rate of take-up by industry, commerce and government is accelerating. With rapid growth comes growth pains and EAMOE suffers from them. The record of its successful introduction is abysmal. Debates are ongoing as to what is the best asset management model to adopt. Investigations are conducted widely in universities and research organisations to find the variables that have the greatest payback for industry. Industry bodies have even developed international standards for asset management, such as PAS55 in Europe. Discovery and growth in knowledge of EAMOE is continuous and will carry on for some decades more.

From the early 1990s the large multinationals were beginning to suffer competition driven by globalisation. To stay competitive with the leading global players it was necessary for them to reduce their operating costs. Successful implementers of EAMOE gained the profit growth and the market advantage that came with greatly lower costs. At the turn of the twenty-first century the forces of globalisation were stronger still and had extended to affecting large national companies. If these local companies wanted to remain viable they had to match the costs of the best imports. The first decade of the new century also saw many companies growing by acquisition instead of natural growth and it was necessary for their investments to return money quickly. EAMOE was seen as a proven way to produce a good return. The acquiring investors needed to quickly make the purchased companies operationally excellent so they could generate rapid profit increases and quickly turn the investment positive.

With the demand to get the benefits of EAMOE the pace of operational change is quickening. When EAMOE was introduced into companies in the early 1990's the change process was expected to take four to five years to complete. Ten years on the adopters of EAMOE programs expected the change to be done within three years. In 2006 the time expected to make the change to a world-class operation has reduced to two years. By the start of the second decade of the century the same changes will be required within a year. Eventually a six month operational change period will be normal. The reason for the increasing speed of take-up is driven by shareholders wanting fast returns and market fragmentation due to the continual creation of niche products.

The markets of the early twenty-first century are more niche-focused and segmented than those of the previous century. The impact on business of many small markets means that new business opportunities can rise, mature and disappear within three to five years. Manufacturing and production operations must respond to the shortening of product life cycles by ensuring their plant and equipment is run effectively and efficiently from the start of product life. With machinery, equipment and plant only operating perhaps for three to five years before the changing market makes them obsolete, there is no time to go through a three-year cycle of developing operational excellence. From the start of production the manufacturers of products for segmented markets need to make a good business profit.

Since 1990 EAMOE has moved from being a program so costly and time consuming that it was the realm of the large multi-nationals, to becoming a necessary expectation for successful operation in the smallest of manufacturing and production operations. With the changing requirements of global competition and market fragmentation the vision that now drives EAMOE is clearly focused on rapid profit generation rather than simply to be the low-cost operator that it was in the 1990's. EAMOE is a must-have requirement for maximum profit generation. The only variable is how quickly an organisation adopts it to generate the great productivity benefits it can produce.

The ever shortening EAMOE implementation cycle has been made possible by the development and introduction of new operational management and maintenance management tools and practices. New methodologies, technologies and software to identify and remove causes of operating disruption have been developed, refined and applied as EAMOE developed. Such methodologies as Total Productive Manufacture (TPM), Root Cause Failure Analysis (RCFA), Failure Mode, Effects and Criticality Analysis (FMECA), and Risk Based Inspection (RBI) were developed specifically in response to the need to remove the causes and costs of defects and failure demanded by the practice of operational excellence. New technologies in predictive maintenance and condition monitoring have allowed machinery condition to be monitor to determine how they can most optimally be used and maintained, and to tell their operators of impending problems before production is affected. These technologies are being imbedded into the machines themselves so that, in time, machinery will self-regulate its operation and be able to care for itself. Software tools, such as Monte Carlo simulation modelling, Crow/AMSAA failure projection and Weibull reliability modelling were refined from being research tools of professors and academics to becoming standard applications used by industry to target efforts for rapid improvement.

Today's pace of EAMOE change is becoming faster and requiring ever quicker organisational change methods to be developed to match and drive that pace. The vision for Engineering Asset Management and Operational Excellence in future must incorporate the need to grow organizational productivity; for speed in addressing rapid market, community and environmental changes; it will need to ensure a relentless drive to remove causes of failures and boost equipment reliability; it will demand the introduction of new methods, technologies and tools to remove the need for specialists and superfluous management so that every operator has the skills and the access to the knowledge needed to optimise the use and performance of their plant and equipment.

But these 'future musts' of EAMOE will not be sufficient for the truly great companies. The best companies will have fast, accurate means of identifying cost saving and waste reduction opportunities. They will deliver massive savings in reduced waste of all resources and achieve extreme efficiency and effectiveness in all business and operating processes. The outstanding businesses of the future will not have many operational problems to solve because their operating methods and business systems will identify risks early and act quickly enough to prevent them.

The progress in the development of industrial and enterprise asset management methods, technology and tools can be seen as the progress toward enlightenment and understanding of the requirements that deliver excellence in equipment design, use and care. The future of EAMOE is to make business decisions self-evident by providing the knowledge and deep understanding needed to be outstandingly efficient and effective. The EAMOE of the future will make it obvious to plant and equipment designers, operators and owners what are the excellent practices that deliver great performance and results.

What has been learnt in the few decades since EAMOE became a business philosophy is that to achieve its full beneficial potential requires strong commitment across the entire organisation to becoming more professional, more educated, more scientific and more master-craftsman-like (highly skilled and accurate). No more can anything be done without a clear understanding of exactly what to do and how to do it to world-class standards. The future for organisations that adopt EAMOE is changing to one where its people know the outcomes and consequences of their decisions and actions before they are made and where everyone is continually seeking mastery over their work.

The Plant and Equipment Wellness concepts explained and explored in this book will move organisations rapidly and securely into a future where organisational change programs are done in six months and the drive for continuous improvement is imbedded into the organisation as a natural personal value. Plant and Equipment Wellness is the simplest, least cost, least time consuming methodology of all those currently available to quickly achieve physical engineering asset management and operational excellence that delivers high productivity and low operating costs.

1. Variability in Outcomes

Variability causes most operating and business problems. Any business with an aim of providing a product or service with consistent specifications and properties does not want its processes producing out-of-specification merchandise. Out-of-specification results are a waste of money, time and effort. A large amount of a modern organisation's resources are devoted to controlling variability within their business and operating processes. The people involved in this duty carry the word Manager, Supervisor, Superintendent, or the like within their position title. Their role is to ensure that business is done within prescribed limits. Anything outside the limits must be brought back under control urgently.

Variability, in the context being discussed, is 'the range of possible outcomes'. A more scientific definition is 'the characteristic of a product or process where parameters fluctuate significantly but do not typically trend in an identifiable direction'. A business process with high variability means outcomes can range from good, to mediocre, to disastrous. This volatility is the exact opposite of what is required in business. Getting the right result every time is what is needed.

1.1. Observing Variability

To understand variability and why it is a problem there is a simple tabletop game called the 'cross-hair game' to play that is a great introduction to the variability within processes.

In Figure 1.1 two lines are drawn crossing at 90^o with a 2mm circle drawn around their intersection. The game is to sit at a table and drop a pen into the two millimetre diameter circle from a height of around 300 mm (one foot). Getting a hit within the circle is the outcome required from this 'process'. Repeat the targeting and drop process at least thirty times. After each drop measure the position of the new mark to an accuracy of half a millimetre. Record the horizontal distance from the vertical line (the 'x' distance) and the vertical distance from the horizontal line (the 'y' distance) in a table like that of Table 1.1.

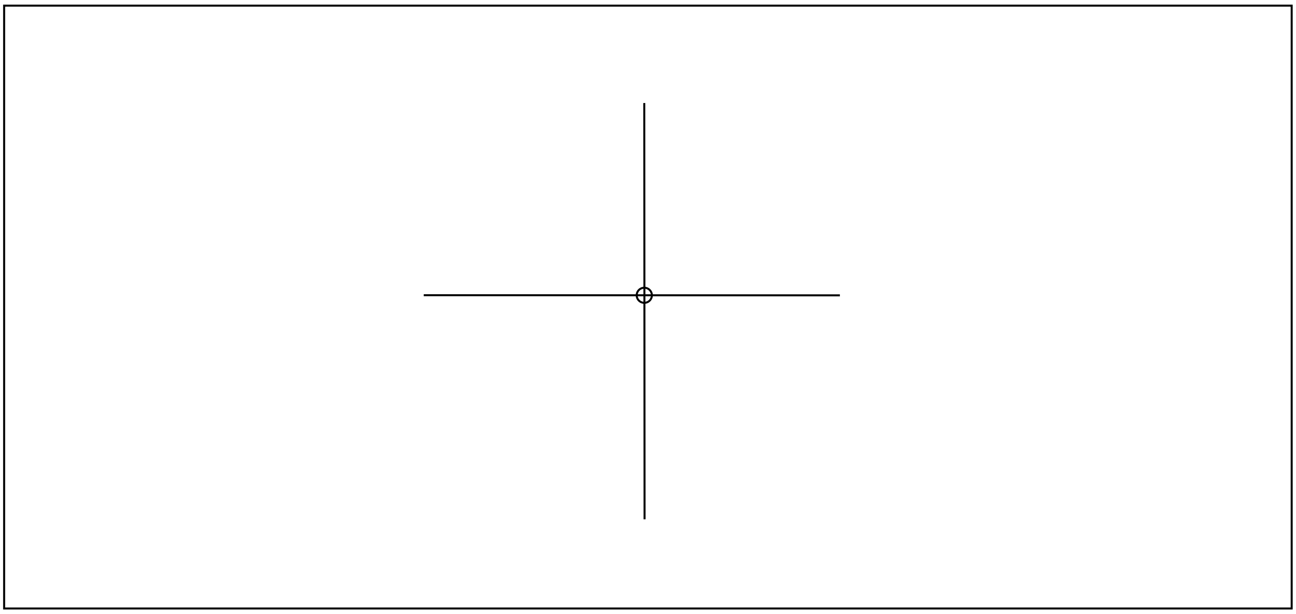


Figure 1.1 The Cross-Hair Game

Hit No	Distance X	Distance Y	Hit No	Distance X	Distance Y	Hit No	Distance X	Distance Y
1	8.5	16	*11*	1.5	5	*21*	1.5	5.5
2	7	9	*12*	1.5	20	*22*	3	3
3	4	16	*13*	3.5	3.5	*23*	3.5	0
4	3.5	2.5	*14*	2.5	12	*24*	2.5	6
5	5	24.5	*15*	3	24.5	*25*	0.5	2
6	5	16	*16*	4.5	6	*26*	1	2
7	7	10.5	*17*	4	12.5	*27*	3.5	10.5
8	5.5	9.5	*18*	5.5	5	*28*	1	9
9	2	3.5	*19*	1	9	*29*	4	14
10	3	2	*20*	6	4.5	*30*	0.5	3.5
			Average	X = 3.48	Y = 8.90			
			Spread	X = 0.5 - 8.5	Y = 0 - 24.5			

Table 1.1 Record of Cross Hair Game Hits

Observe the average and spread, of the 'X' and 'Y' results. In Table 1.1 no hits are within the two millimetre circle; some are on or near the edge while most are well away. Even though great effort was made to control the 'process', the results were across a wide band of outcomes. This same problem occurs in all business and operations processes. The outcomes of a process are spread across a range of results. That is variability. Variability becomes a problem for a business when the results from a process are not consistently within their required boundaries.

If the aim of the game is to have every pen-drop fall inside the 2mm circle, then we have a very poor process for achieving that outcome. To get better results requires changing the process. The results in Table 1.2 were from a process where the pen was dropped after aiming it at the circle from above, much like dropping a bomb from an aeroplane using targeting sights.

Hit No	Distance X	Distance Y	Hit No	Distance X	Distance Y	Hit No	Distance X	Distance Y
1	8	10	*11*	5.5	6	*21*	3.5	0
2	5	6	*12*	2	4.5	*22*	2	5
3	4	3.5	*13*	0	1	*23*	0.5	1
4	3	4	*14*	5	2	*24*	6.5	0
5	2.5	1	*15*	4	7	*25*	3.5	3
6	2	0.5	*16*	3	1	*26*	0	8.5
7	13.5	7.5	*17*	3.5	5	*27*	6	1.5
8	10.5	9.5	*18*	4	0	*28*	0	4
9	1.5	7	*19*	4	1	*29*	2	1.5
10	7.5	6.5	*20*	2	2.2	*30*	0	6.5
			Average	3.82	3.87			
			Spread	0 - 10.5	0 - 10			

Table 1.2 Record of Cross Hair Game Hits Using a Sighting Process

The results of the second attempt to play the cross-hair game using a modified process are better; the 'Y' values are virtually the same as the 'X'. The averages of the modified process indicate that the hits were closer to the intersection than those of the first process. There was less spread. But the second process is still not suitable for meeting the requirements of consistently getting the pen within the circle from a height of 300mm. It is very unlikely that any process using human hands to drop a pen within a 2mm circle can be controlled sufficiently accurately. If the requirement is to be met it will not be done by dropping the pen with human hands. To get the pen consistently within the circle requires the creation of a process that removes the variability caused by the human hand. A number of devices have been proposed. These include a long, tapered funnel to guide the pen onto the target, a vee-shaped slide to direct the pen into the circle and a robot with a steady manipulator to put the pen in place.

One answer jokingly suggested from time to time is to open the circle up to 50mm diameter and then everything will be on target. The suggestion totally defeats the purpose of having a process that delivers accurate results. But unfortunately it is the solution that many businesses select. They chose to 'widen the target' and accept any result, good, mediocre or disastrous, rather than improve their processes. A business that does not purse excellence in their activities will not last.

Examples of processes with inherent high variability are those that at some point:

- require decisions
- require choices
- are done without exacting training
- have no standards
- have inadequate procedures
- lack correct information
- are based on opinion
- involve emotion
- have multiple ways it can be done
- are not measured
- have high rates of equipment failure
- involve interpretation of data

When such situations arise in a process the chance of variability rises because the process contains varying degrees of randomness and uncertainty. Ill-defined, inexact processes and those with poor monitoring and control are at risk of being impacted badly by any change in performance of their critical success factors. This is particularly the case in sales and marketing, finance, human resources, administration, engineering, design, customer service, production, manufacturing, dispatch, after-sales service and maintenance.

Variability can be identified in processes by charting or graphing process parameters and process outputs over a period of time. Such charts are called 'run charts' and are used to locate the times that the process did not produce the required result. If you want immediate control over a process then track the process variables, those factors that influence the result, in real-time so they are observed as they change. If the change is bad you have time to react and correct it before too much damage is done. If you want pre-emptive control of a process then trend the variables of the process inputs before they enter the process. By being sure that the inputs into a process are correct and right you can be more certain that the process they feed into will be better behaved. If you only want to know how well a process performed then monitor its final output, the product from the process. Unfortunately monitoring the final output puts you into the position of asking 'what happened' every time something goes wrong. Just like the company in Example 1.1, who had no idea what had changed to cause a spate of raw material stock-outs. By tracing the replenishment process on a run chart it was possible to highlight process fluctuations and then identify the underlying causes of their problem.

Example 1.1: Inventory Replenishment Mayhem

The stock replenishment process involved the ocean shipment of raw material from a manufacturer to the company. For some months prior the investigation the company had been running out of stock across a range of products. The impact on the company's business was the inability to supply products on-time to their clients. Their warehouse replenishment process was not able to maintain adequate stocks of product. They were using their safety stock and not getting resupply quickly enough to reliably meet their client's orders. This was relayed back to them by annoyed clients through particularly strong correspondence and telephone calls. The company had no appreciation of what was causing the stock-outs and requested that the situation be investigated.

The investigation began by collecting data on products stocked-out over the previous two years. With that information a frequency plot of the products that had suffered stock-outs was developed on a spreadsheet. Figure 1.2 shows the frequency plot. From it can be identified time periods in the prior two years where the frequency of stock-outs had intensified. The company was currently suffering increased number of stock-out over an increasing number of product ranges. The frequency plot proved and confirmed the seriousness of the situation.

Item	Total	Jun	May	Apr	Mar	Feb	Jan	Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Dec	Nov	Oct	Sep
T166	21	1	1	2	2	3	1	1				1	1		1		1	1		1	1	1	1
T129	14			2	1	2	1			1	1			1	1							1	
T209	13	1		2			1											1		2	2	1	2
T201	10	1	1	1		1	1		1											1	1		1
T281	10	2	1		2																1	2	
T126	9	1	1	1										1			1			1	1	1	
T169	8	1	2	1				1				1								1	1		
T241	5	1															2			1			
T321	4																					1	
T161	5			2									2	1									
T361	3			1														1					
160N	11	1			1	1	2	2	2	1	1												
120N	9	1	1	1		2											1			3			

Figure 1.2 Frequency Plot of Product Stock-Out

The next step was to determine what was causing the lack of supply. For this it was necessary to look at the history of deliveries from the manufacturer. Historical records of delivery dates were sourced and trended. Figure 1.3 is a graph of a run chart for the delivery dates. It shows a great deal of variability in the deliveries for the most recent months. Basically the deliveries were not as regular as they historically were. In recent months they were up to two weeks late when they should have been arriving weekly.

Further information on the situation was identified in Figure 1.4, which is a graph of the numbers of orders in each delivery. This graph indicated that there was also variability in the amount of product being provided on each shipment. Instead of have regular shipments of ten to eleven containers each delivery. The ships were varying from four to twenty-seven containers per delivery.

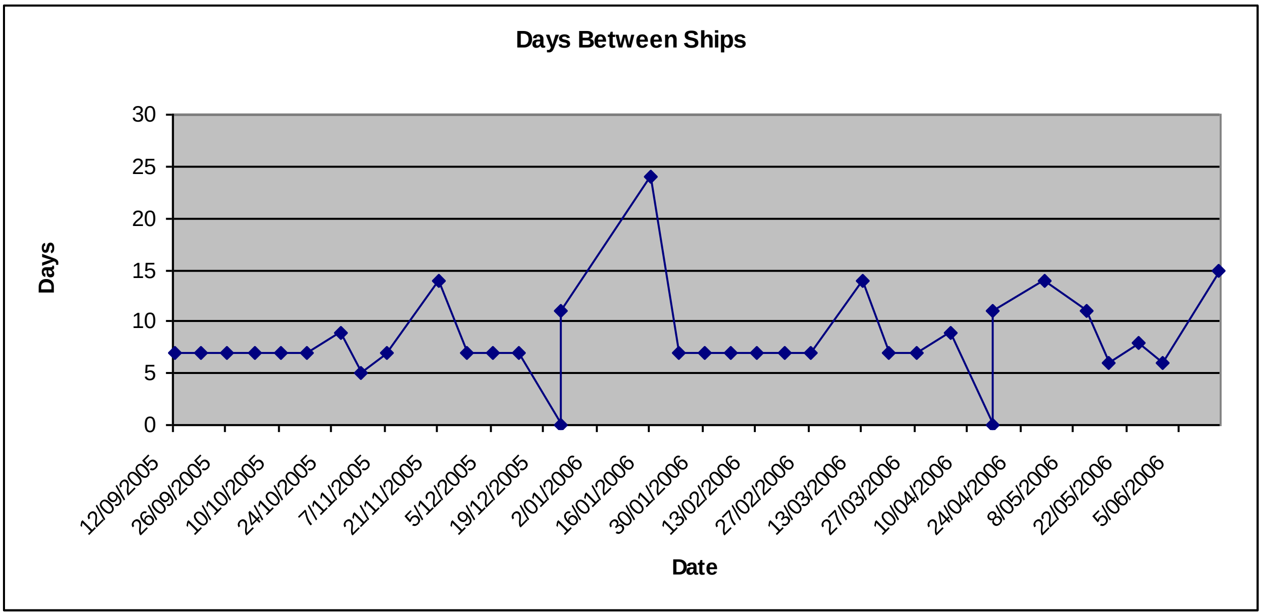


Figure 1.3 Ship Departure Dates

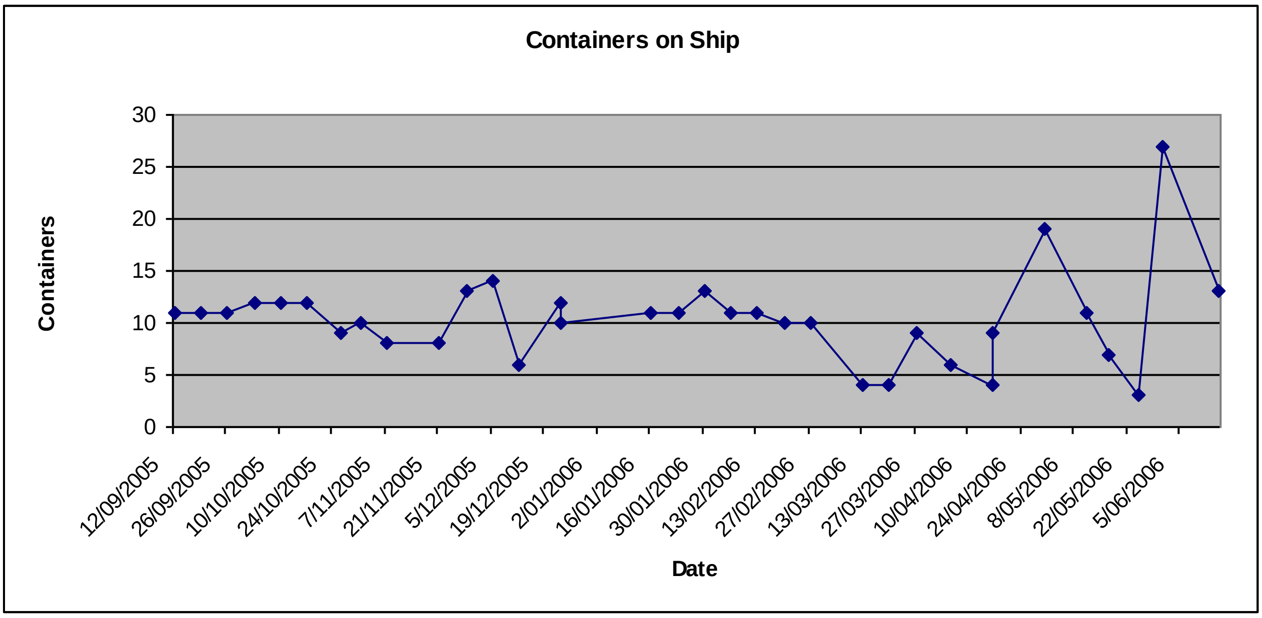


Figure 1.4 Numbers of Containers on Each Ship

When inquiries were made it was found that the regular shipping line had one of its two ships in for a two month maintenance outage. Where once there was regular weekly shipment, the only ship left on the run was now fortnightly. To get product to the customer during the maintenance outage the manufacturer had started booking transport with various international shipping companies. These ships had irregular departure schedules and only took numbers of sea containers they needed to fill the empty bays left after prior commitments were filled. Sometime they took few containers and other times they took many. The consequence of the irregular departure of the international carriers with either small or large amounts of product was the stock-outs suffered by the company.

The company suffered because of the irregular supply of goods from the manufacturer. The irregularity was due to the high variability of international ocean shipping, further complicated by the feast-or-famine quantities of product on each ship. Variability in the replenishment process had caused major disruption to the customer's business.

In response to the temporary shipping problems the customer increased the amount of stock in-transit, which effectively increased their inventory levels until the second ship was repaired and returned to the weekly run. To prevent stock-outs in future it would be useful to install pre-emptive monitoring of the manufacturer's shipping arrangements to identify when a sea shipment did not leave on-time so a rail delivery could be booked instead.

The disruption of regular delivery to the company in Example 1.1 was caused by a 'special cause' event – the ship repairs. A 'special cause' event is an extraordinary occurrence in a process that cannot be attributed to the process. Had there been no ship repairs the customer would have been supplied normally each week via the usual process. The ship failure was outside of the control of the replenishment process but it impacted badly on it.

Fluctuation that is due to the natural variability of a process is called 'common cause' variation. The cross hair game was an example of the effects of common cause variation. Where the pen landed depended on the behaviour of the process variables affecting the drop – steadiness of hand, accuracy over target, evenness of release, etc. The spread of hit locations is normal for the cross hair game process. To have the pen fall into the circle when dropped by hand has more to do with luck than with skill. To always hit within the circle needs a change of process that has no element of luck, not an increase in the skills of the person doing the job. Dropping a pen by human hand from a height of 300mm and expecting it always hit inside a 2mm circle is impossible, the common cause variability of that process is too great for the accuracy required.

There are many organisations trying to achieve impossible results using business and operating processes with ‘common cause’ variation that cannot reliably produce the performance they want. Such businesses employ processes containing inherent volatility that naturally produce outcomes outside the business requirements. Trying to manage an organisation with systems and processes that cannot achieve its business aims because they produce highly variable results is an exercise in futility that will cause great waste, distress for all involved and emotional burn-out for its managers.

Business process ‘common cause’ variability cannot be controlled unless changes are made in how the process operates. In contrast, ‘special cause’ variability can be controlled by stopping the influence of the extraordinary event. The effect of the ship repair in Example 1.1 could have been prevented by introducing other modes of transport, such as rail or road to replace the failed ship, if it was known that a delivery could not be made on-time. ‘Special cause’ issues can be addressed simply by stopping them from happening. But with ‘common cause’ issues nothing can be done to prevent them because they are inherent in the process.

It is the nature of every process to produce variation. The challenge for business and operations processes is two-fold. One is to create processes with only ‘natural’ variation and no ‘special cause’ variation. Second is to have processes with ‘natural’ variation well within the required performance. This allows the organisation to focus mainly on stopping ‘special cause’ problems sure in the knowledge that the process itself is inherently stable and produces good product.

When a business or operating process no longer performs within its normal limits first look for a ‘special cause’ of the change. Only after all ‘special causes’ are eliminated can you be sure that just natural ‘common cause’ variation remains. If the ‘common cause’ variations are still too volatile you have justification for improving or changing the process. By following that sequence you confirm if any special cause variations are masking the natural process variability and are producing effects to confuse the analysis. If a ‘special cause’ is mistaken for a ‘common cause’ the wrong decisions will be made to address the problem.

So far we have seen examples of variability in a game and variability in the supply chain of an organisation. Being able to get a picture of the variability brought a clearer appreciation of what was happening within the process. It allowed powerful, relevant questions to be asked that led to a more profound understanding of the situation’s causes and their resolution. There is great value to be gained when an organisation observes the variability of its business processes. Once a ‘picture’ is available of how a process behaves, focused effort can be brought to bear on controlling its variability. Example 1.2 is of a mining operation where the consensus was to invest a quarter of a billion dollars to expand production 50% when in fact it may have been unnecessary if production variability had first been addressed.

Example 2.2: The Hidden Factory

Here is an example of the value of first identifying causes of variability in a business before investing capital. In this case the production from a mine is trended on a simple bar graph. Figure 1.5 shows the graph of the hourly production rates of a 24/7/365 mining operation during eight consecutive weeks. It provides a lot of valuable information about the operation's capacity as well as a clear indication that the business is suffering wild fluctuations in its production throughput. An examination of the graph provides an insight into the facility's dilemmas.

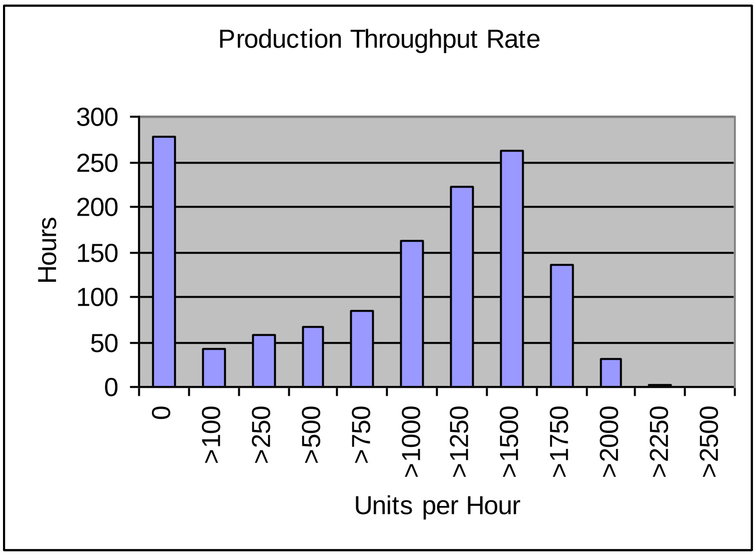


Figure 1.5 Production Rates

The plant design capacity is 1500 units per hour. The eight weeks of production shown on the graph represents 1344 production hours. For 275 of those hours there was no production, which means that for 20% of possible production time the plant was standing still. For 615 of the remaining hours it was running at under design rate. This means that for 57% of the time that it was operating it was delivering less than it was designed to produce. The actual average production rate for the entire eight weeks is 1000 units per hour, which is two-thirds of design duty. This facility is suffering severe production problems and investigations need to be made as to why it is not consistently producing at its design capacity.

There is additional information to be garnered from the graph. It is clear that for a significant number of hours the plant ran at above its design rate. The implication is that the plant can run at more than its design duty. There is a good chance that with minimal engineering changes the plant could run consistently at 2000 units per hour, which is 33% greater than design capacity and 100% higher than current average production. Though the converse could also be true – running the plant hard caused destructive failures. An analysis of the causes of the downtimes and slowdowns would highlight both problems and opportunities.

There are obvious questions to ask of a plant with such variability of performance. Such as, 'What is causing below design throughput so often?' And, 'If the plant can produce at higher rates by accidents of circumstance, then what could be produced if it was done intentionally?' It would be sensible to identify the causes of both the disastrous production losses so they can be solved and the fortuitous accidents of the past so then can be applied intentionally. The total 'lost' capacity represented by the stoppage time and slow throughput, plus the 'hidden' capacity available from higher production rates, means that this operation has plenty of opportunity to deliver a large production increase without significant capital investment.

This company's decision to spend $250,000,000 on a major capital upgrade to boost production 50% may not have been necessary. If the downtimes and low production rates were recovered, and the causes of the higher throughputs were made standard practice, the extra 50% capacity was probably achievable with the old plant. It was only necessary to conduct root cause investigations on why the production losses occurred and engineer them out. Combined with an analysis to understand why higher than design production rates occurred and re-engineer the process to deliver them consistently. The financial return on such an investment could be unbelievable. All these options became clear simply by measuring production variability.

To construct a graph like that in Figure 1.5 requires collecting the hourly production figures for a sufficiently long period of time so that the full range of variability affecting the process can be observed. The figures will show a range of performance around a mean value. The extent of the spread below the mean, from average to lowest, will indicate if there are production problems hampering throughput. The spread above the mean, from average to highest, will indicate if there is spare capacity available. If the spread is tight about the mean production rate then the operation is running well and it is performing as it should. But if, as in Figure 1.5, the spread is wide then the plant has 'hidden' opportunities to improve its production performance and efficiencies.

When production throughput graphs have a wide spread of production rates there is potential to increase plant capacity by removing the causes of operating losses with minor engineering upgrades and removing variability by adopting improved procedures and extensive training. Before investing more capital to expand plant capacity, investigate the variability of current production because there may already be a 'hidden factory' within the existing plant.

1.2. Controlling Variability

The purpose of controlling variability is to provide certainty of performance. Once the variability in a process is identified decisions can be made whether to leave the situation alone and accept fluctuating outcomes or to address the underlying problems causing the fluctuations. If improvements are wanted it is necessary to find the causes of the problems and identify means to solve them. By removing the performance fluctuations the process can be stabilised and its volatility reduced so the spread of results tighten around a consistent mean, as shown in Figure 1.6.

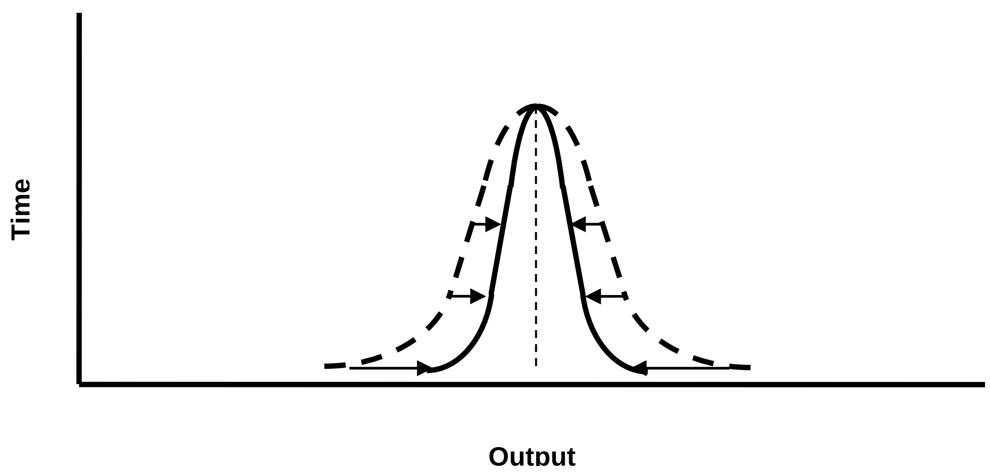


Figure 1.6 The Effect of Removing Volatility from Processes

Once a process produces consistent results with little fluctuation it becomes highly predictable and results can be guaranteed.

To control variability it is first necessary to observe it. This requires monitoring the process and the effect its variables have on its performance. A variable is any factor that influences the outcome of an action, process or decision. If the change in a variable and its effect is to be observed it needs to be presented in ways that are recognisable by the human senses. Graphic and visual displays are preferred but the other senses can also be used. Visual displays provide an understanding of a situation for quick monitoring. This is done with comparison plots, graphs, quality control charts and the like. The simpler the visual tracking device the better provided it accurately reflects the situation and has the necessary precision to keep control.

Figure 1.7 is an example of a range control chart layout showing the performance standard required and the acceptable tolerance limits. The chart is used to monitor process and variable performance by recording measurements from the actual operation and plotting them on the chart. If the results are within tolerance the process is in control. When they show a trend toward loss of control, or are outside the tolerance limits, you have accurate information to make the decision to alter, change or stop the process or operation. There are numerous types of control charts and other statistical techniques that can be applied to monitor process and variable performance.

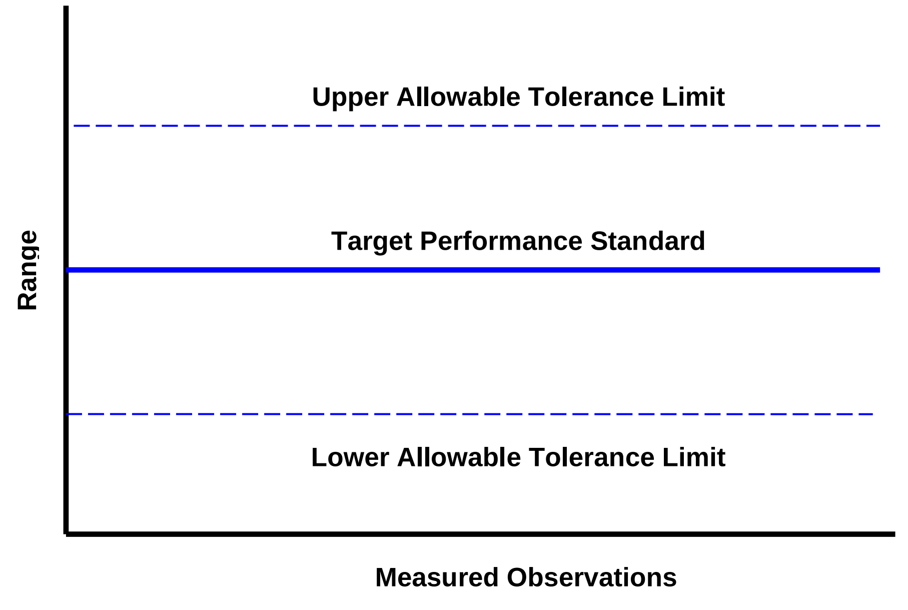


Figure 1.7 A Basic Control Chart

Enlist your operators and maintainers in the continual observation of the signs of variation. By giving them low-cost diagnostic tools, such as the ones in Figure 1.8, and letting them experience process variations and equipment condition variations for themselves they will learn to identify changes from normal operation and recognise impending problems. Providing operators and maintainers with simple, hands-on diagnostic tools gives them the opportunity and responsibility to find problems and to fix them before failure stops the operation. It hands ownership of plant and equipment operation and well-being to them – the best placed people to get the best performance from their equipment.

Figure 1.8 Stethoscope Laser Thermometer Touch Thermometer Vibration Pen

1.3. Variability Causes Defects and Failures

Because variability exists in all processes a range of outcomes are possible. The cross-hair game, and the examples in this chapter, highlights some of the bad effects and results process variability causes organisations. When variability becomes excessive defects occur and failures can result.

A defect is a 'non-conformance to requirements or function'. It is a deficiency. A non-conformance to specified limits has been produced by a process and put into service. Defects that escape correction lay hidden and may not become apparent until they cause a failure. A failure is 'an event or circumstance which prevents the accomplishment of an intended purpose'. A failure happens when a system or component is unable to perform its required role in the environment it was designed for. A failure means a thing did not do its job.

Variability crosses borders. It leaves the manufacturer and goes to the purchaser. Every product purchased, every service requested has within it the effects of the variability of the process used in its creation and delivery. An item or service is supplied within a range of acceptability specified by the manufacturer or provider. The range is chosen to match the variations in their processes. If the manufacturer has systems that produce a very narrow spread of results in their products then the equipment or service will have consistent performance. If instead they have 'widened the target' and accept large process variations, then their customer will have problems.

Because every process in a business produces fluctuating results, the more processes used by a business to make its products, the greater the opportunity for the variability in each process to produce defects and failures in the product. Those organisations that try and do everything themselves when making products have many processes to manage and control. Each process will introduce its own range of variation. When the final product is made it will contain the full range of variability from each process used. External suppliers can provide parts and services in-place of using in-house produced commodities. But their processes also produce variable results. When external suppliers are used it is necessary to have protection against the worst excesses of their processes and ensure compliance to precise and agreed specifications.

Variability acts across processes. Variability in one process can reduce the effects of variability in an interacting process. The opposite can also happen, where variability combines to produce problems of greater magnitude. Much like water rebounding off a cliff, variability between interconnected processes can act to calm the waters or to create surging waves. This was the case with Example 1.1 where the international shipping line policies of not having fixed schedules and not providing regular container slots compounded the replenishment problems of its users. Variability that compounds problems requires identification and the offending process redesigned to remove the negative impact on interacting processes.

An example of a process that compounds problems is when companies purchase the same item from several suppliers. They suffer more problems with the item than a company using only one supplier. The reason is that each supplier has their own processes with their own variability. When items are brought from a supplier you also buy their process problems. By staying with one supplier you either adapt your systems to their process variability or you get them to modify their process to provide the product you want. To try and do the same with a range of suppliers causes a great deal of work and requires much effort. Hence it does not happen and instead every supplier's product variability problems end-up in your business.

The processes used by a business to make their goods produce variable product. Products and services brought into a business from other businesses are the outcomes of processes producing variable results. These realities imply two possible scenarios for future failure. One is that the products which are towards the extremes of variability from poorly controlled processes may contain defects and weaknesses of one nature or another. When these products enter operation they are put under situational and environmental stress. If the capacity of the product is not up to the difficulties of the situation its weaknesses will cause it to fail prematurely and unexpectedly. The second failure scenario is that product or service variability is well controlled and has little spread but the product or service is wrongly specified for the duty. In such circumstances there is nothing wrong with the product or service but the situation or environment it must accommodate is beyond what it can handle and failure again results prematurely and unexpectedly.

Figure 1.9 is a modified version of the DuPont defect and failure model. It highlights some of the many processes where failure causing defects and errors come into a business.

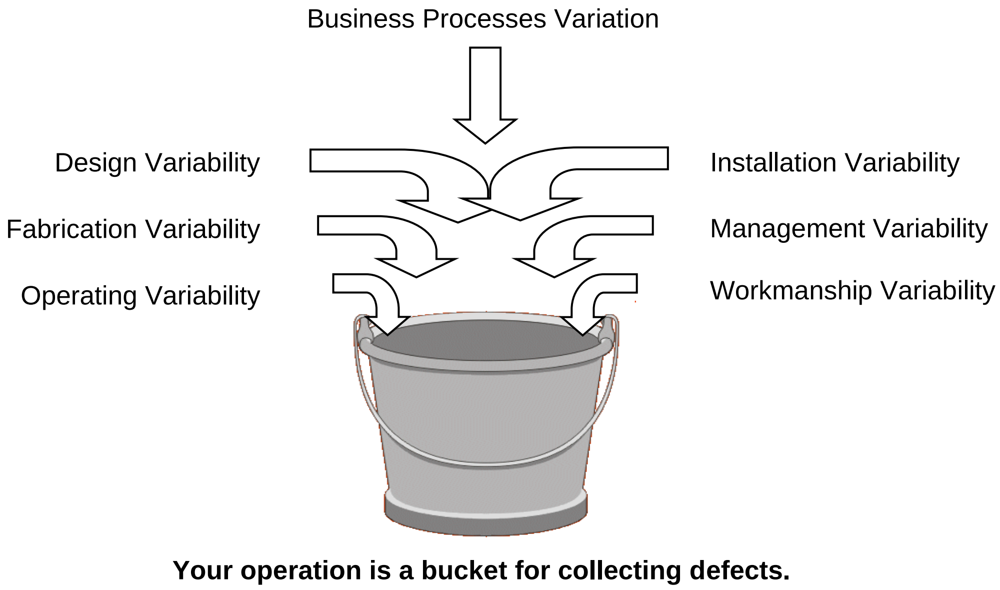


Figure 1.9 Defect Creation

Most businesses typically react as shown in Figure 1.10. They introduce maintenance and repair systems to manage the failures. They accept defects as normal. As a consequence they suffer production downtime in trying to limit the effects of the problems and in fixing the ones that break.

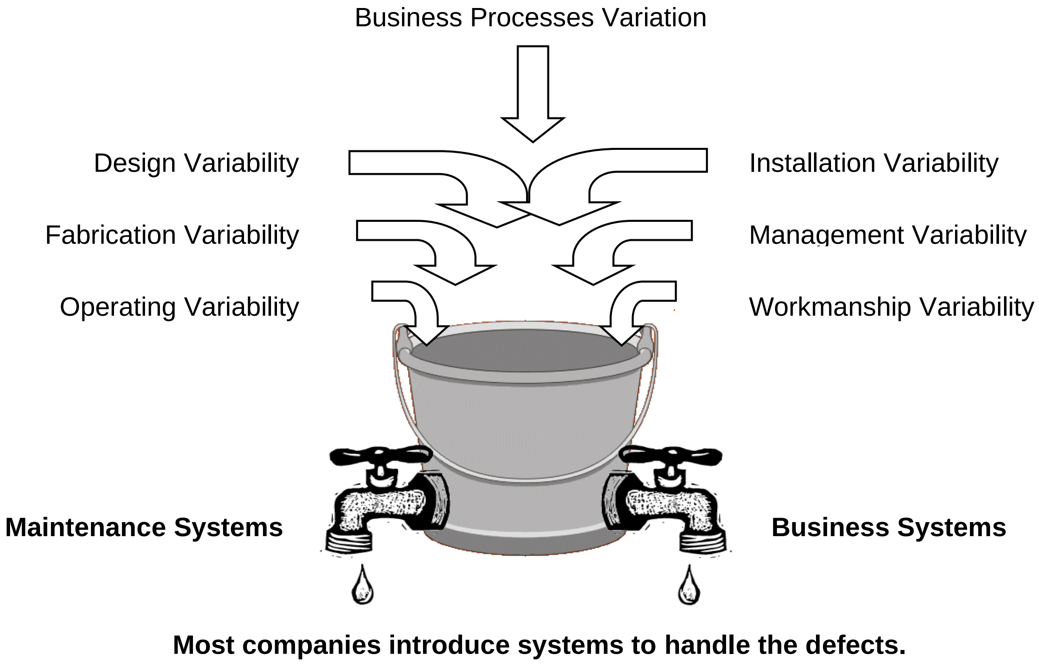
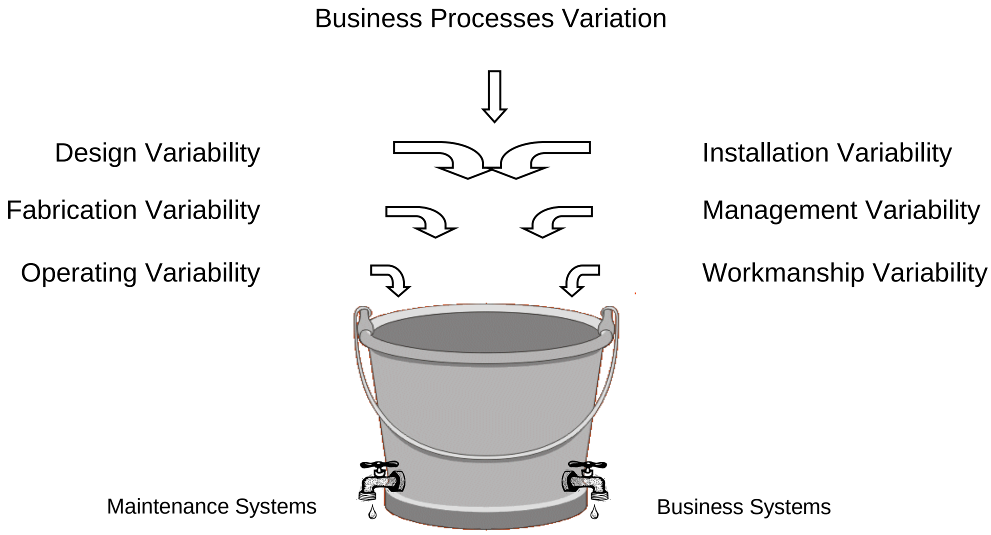


Figure 1.10 Defect Management

Figure 1.11 shows the best strategy. It is to stop defects entering your business. As a consequence maintenance costs reduce, production downtime falls and there is an increase in equipment reliability, plant availability and productivity.



The best companies stop defects entering their business.

Figure 1.11 Defect Elimination

Accepting process variability as inevitable is sensible, accepting the accompanying failure consequences as inevitable is disastrous. Proactive defect elimination and failure prevention is a most effective variability control methodology for reducing plant and equipment downtime. The best way to fix a problem is not to have it.

2. The Instantaneous Cost of Failure

Here are four newspaper headlines over a six week period in Australia during 2005.

"$30 Million Refinery Glitch Stalls Fuel Users" The failure of a flange on a key piece of processing equipment meant no gasoline was made in the state for 2 weeks.

"Liquefied Natural Gas Project Back On Track after Production Train Repairs" The event cost $300 million in lost profit.

"Refuelling Problems Delay $250 Million Airport Terminal Operation" Jet fuel in the pipes at this airport had been contaminated with a protective anticorrosive coating left on the inside of the fuel pipes. If it had not been detected contaminated fuel would have gone into the fuel tanks of jet planes carrying thousands of people.

"330 Hospital Patients Suffer Cold Winter Showers for Two Days" A steam boiler failed putting the hospital at increased risk of spreading infection to hundreds of its patients and visitors.

These failures made it to the news sheets. In a short six week period, in a lightly industrialised country, just four failures cost business hundreds of millions of dollars and put life at risk. How many failures happen that do not make the news? These real events indicate the huge financial and business consequences that arise when a failure incident happens. The cumulative cost of failure in a business, based on the single incidents detected by the newspapers noted above, must be astronomical. The cost of an incident may be no worse than inconveniencing 330 hospital patients or it can be the cost of aeroplanes full of passengers falling out of the sky.

2.1. The Effect of Failure Incidents on a Business

Figure 2.1 is a simple accounting model for an operating business that every new accountancy student is shown. When a business operates it expends fixed and variable costs to make a product which it sells for a profit. The fixed costs must be carried regardless of production. These include the cost of building rent, the manager's salary, the permanent staff and employees' wages, insurances, equipment leases, etc. There are variable costs as well, such as fuel, power, hire labour, raw materials to make product, etc. From doing business a profit is made that keeps it trading.

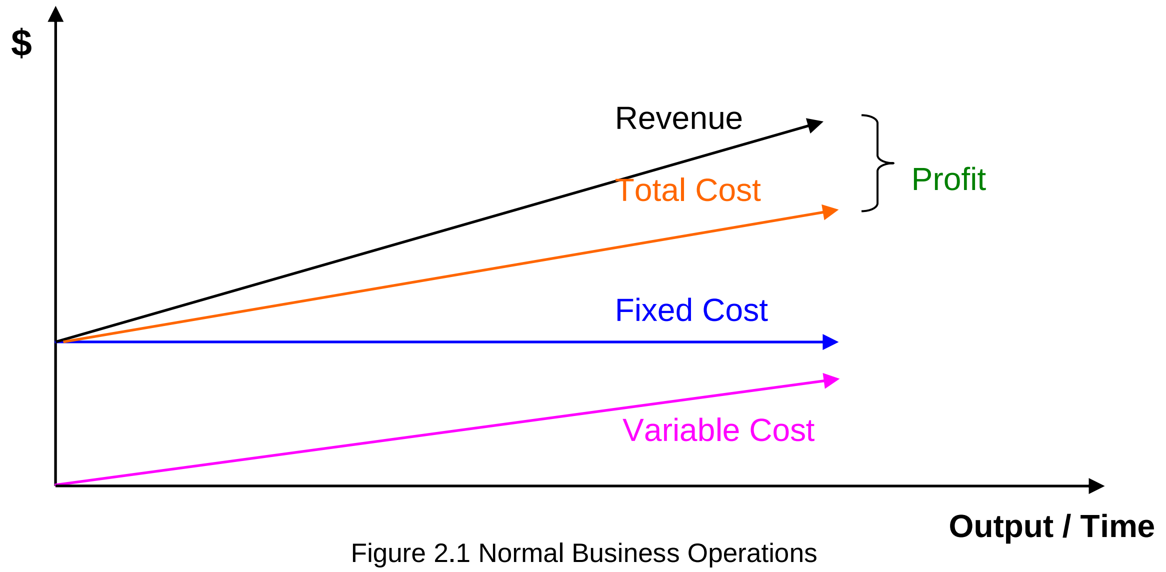


Figure 2.1 Normal Business Operations

From the business model two simple accounting equations are derived and shown to the new accountancy students. The first equation below explains how to make money in business.

Profit ($) = Revenue ($) - Total Costs ($) *Eq. 2.1*

If the costs in a business are less than the revenue then the business is profitable. The next equation explains where expenses and costs arise in business.

Total Costs ($) = Fixed Costs ($) + Variable Costs ($) *Eq. 2.2*

In reality the total cost equation above is incomplete since it hides the cost of waste in a business as a fixed cost or a variable cost. The complete total cost equation, which new accountancy students are not shown, is below.

Total Costs ($) = Fixed Costs ($) + Variable Costs ($) + Cost of Loss ($) *Eq. 2.3*

Equation 2.3 is unusual because it recognises the presence of unnecessary losses and waste in a business. Normal accounting methods do not identify unnecessary losses and those costs are never shown in monthly financial reports. Standard accounting methods identify a variance from budget but they do not recognise wasted and lost moneys. All costs are seen as either fixed or variable, they are viewed as the cost of doing business and no indication is made of the proportion of the costs which was wasted resources and money. From the third equation it is possible to identify another equation that explains how to lose a great deal of money in a business even though it is trading profitably.

$$\text{Cost of Loss} = \text{Frequency of Loss Occurrence} \times \text{Cost of Occurrence} \qquad \textit{Eq. 2.4}$$

$$\$ = N \times \$$$

Equation 2.3 indicates the cost of loss and waste to a business is a real cost. Equation 2.4 tells us that money is lost whenever loss and waste in all their forms occurs in a business. The more the number of loss events (N), or the more expensive a failure is, the greater the financial loss. In other words, the more problems a business has, or the bigger they are, the less profit it will keep.

Chapter 1 explained that the presence of defects increases the chance of failures. Every failure causes unnecessary problems and loss. Every failure incident is preventable by controlling the responsible processes. Whether it is worth preventing a failure becomes a financial decision based on the risk to the business. Examples of failure and loss in a business are those things that need to be done twice or three times, those jobs that create waste and scrap, those tasks that are unplanned and unprepared and take twice and three times the time they should take, any incident where someone is hurt, each time that the wrong materials are supplied by vendors, those times wrong items are supplied to customers, and every time equipment breaks down. These are but a few examples of the effort, time and money lost in business because of failures. Normal financial accounting practices hide these losses as a cost of doing business and they are not recognised for what they are, unnecessary waste and loss. Hence little is done to stop them because they are hidden from view. The costs of failure cannot be escaped and can be counted in many millions of dollars of lost profit per year. The total defect and failure true costs are not normally recognised by accountants and managers, yet they can send businesses bankrupt.

Failure, as previously defined, is ‘an event or circumstance which prevents the accomplishment of an intended purpose’. This definition encompasses all the work performed throughout the entire organisation. An unplanned machine stoppage in the production department and a customer getting their delivery a day late are both failures. Each has consequences on the organisation. The equipment failure means lost production, unwanted repair and consequential knock-on costs. The late delivery can cause no inconvenience to the customer at all, through to their death if it was a necessary life-saving item. How badly the customer views the incident will impact on future sales to them and the acquaintances they tell their story too.

A failure incident causes consequential loss of profits and amassing of costs. The cost of failure includes lost profit, the cost of the repair, the fixed and variable operating costs wasted during the downtime and a myriad of consequential costs that reverberate and surge through the business. These are all paid for by the organisation and are seen as poor financial performance. In order to see the effects of failure on a business Figure 2.2 introduces a production failure into the model business of Figure 2.1.

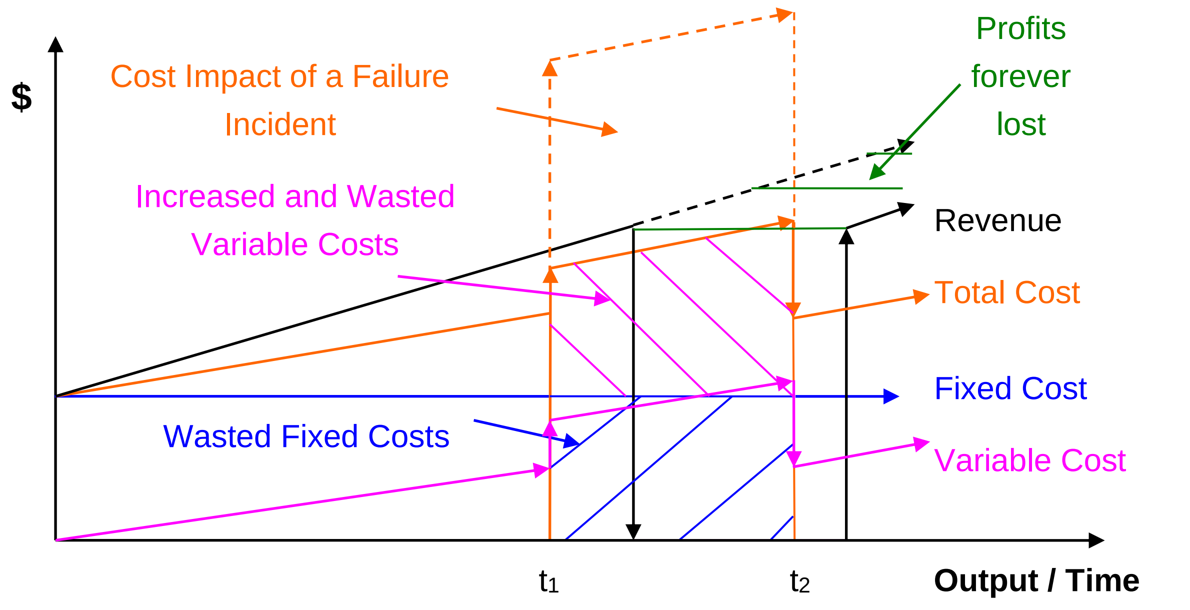


Figure 2.2 Effects on Costs and Profit of a Failure Incident

The failure incident affects production starting at time t_1 and stops the operation. A number of things immediately happen to the business. Future profits are lost because no product can be made (though inventory can still be sold until it is gone). The fixed costs continue accumulating but are now wasted because no product is being produced. Some of the variable costs fall because they are not used, whereas some, like maintenance and management costs, suddenly rise in response to the incident. Other variable costs are retained in the expectation that the equipment will be back in operation quickly. These are also wasted because they are no longer involved in making saleable product. Usually workers are put onto other duties they are not meant to be doing. Losses and wastes continue until the plant is back in operation at time t_2. The cost for repair from a severe outage can be many times the profit that would have been made in the same time period (the dotted outline in Figure 2.2).

The shaded areas in Figure 2.2 show that when a failure happens the cost to the business is lost future profits, plus wasted fixed costs, plus wasted variable costs, plus the added variable costs needed to get the operation back in production. Not shown are the many consequential and opportunity costs that extend into the future and are forfeited because of past failures.

When equipment fails operators stop normal duties that make money and start doing duties that cost money. The production supervisors and operators, the maintenance supervisors, planners, purchasers and repairmen spend time and money addressing the stoppage. Meetings are held, overtime is worked, subcontractors are hired, engineers investigate, parts and spares are purchased to get back in operation. Instead of the variable costs being a proportion of production, as intended, they instead rise and take on a life of their own in response to the failure. The losses grow proportionally bigger the longer the repair takes or the greater the consequences of the failure.

If it escalates managers from several departments get involved – production, maintenance, sales, despatch, finance – wanting to know what is being done to fix the stoppage. Formal meetings are held in meeting rooms and impromptu meetings occur in corridors. Parts are purchased and specialists may be brought in. Customers do not get deliveries and liability clauses may be invoked. Word can spread that the company does not meet its schedules and future business is lost. A rushed work-around is developed that puts people at higher risk of injury. Items are brought, men are moved, materials and equipment are transported in an effort to get production going. Time and money better used on business-building activities is drawn into the 'black hole of failure'.

On and upward the costs build, and people throughout the company waste time because of the failure. The reactive costs and the resulting wastes start immediately upon failure and continue until the last cent is paid on the final invoice. Some consequential costs may continue for years after. The company pays for all from its profits, which then reflect as poor financial performance.

Additional operating time can be worked after a failure to make-up for lost production in order to fill orders and replenish stocks. But that time is new time that could have been used to make new products to sell, not to catch-up on lost production. Once time is lost on a failure the production and profit that should have been made in that time is also lost. It gets much worse if there are many failures. Figure 2.3 shows the effect of repeated failures on the operation of our model business. Clearly repeated failures cause a business to bleed profit from 'a death of many cuts'.

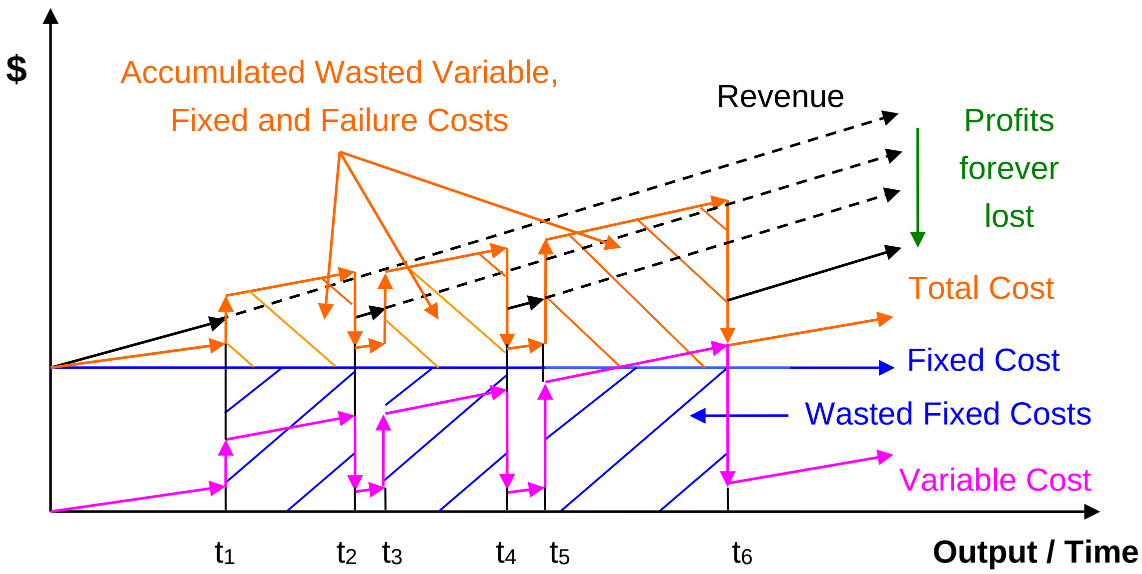


Figure 2.3 Effects on Profitability of Repeated Failure Incidents

The true cost of failure to a business is far bigger that simply the time, resources and money that goes into the repair. If too many failures or downtime incidents occur it will become unprofitable. Failures and stoppages are the number one enemy in running a profitable operation. They seem so small, and are so easily dealt with, that no one notices their cumulative impact on the operation's performance. The cost of failure concept explains how many of the costs are created in an operation and where much of the profit goes in a business. The money to fix failures and to pay for the wasted costs comes from business profits.

2.2. 60 Hidden Costs of Failure

The total cost to the organisation of an incident will be shared amongst the departments and people involved. The proportion of the cost each department carries depends on the extent of its involvement. There will be costs for rectification and restitution, for manpower, for subcontracted services, for parts, for urgent overtime, for use of utilities, for the use of buildings and for many other requirements that were not needed before the failure happened. As well as the costs incurred by the departments most effected, additional costs will also be incurred by many other departments in the organisation. Administration incurs costs if senior managers are involved in reviewing the failure, the Information Technology group may be involved in extracting data from computer systems, the finance people will process purchase orders and invoices and make payments, Engineering will incur costs if their resources are used, Supply and Despatch will be required to handle more purchases and deliveries, and so forth the failure surges through the department of an organisation. The costs to address a failure are all unwanted costs and draw money and resources away from elsewhere. Failures cause direct and obvious losses but there are also wasted costs.

The costs of waste include the energy lost in cooling equipment, the energy spent in reheating it, the scraped products, the cost to prepare equipment so it can be safely worked-on, and the cost to purchase replacement raw materials, along with many other wasteful requirements that arise with every failure.

Another loss category is opportunity costs such as the wages of people waiting to work on idle machines, costs for machinery standing idle, lost profits on sales that could have been made, penalties paid because product is not available when required, people at home unable to work through injury, as well as numerous other opportunity costs. The direct costs of failure, the costs of waste, the opportunity costs and all other losses caused by a failure are additional expenses to the normal costs of running an operation and must be carried by the business. They are lost profits that could have been made and put in the bank.

The total and true costs incurred by a business from a failure event reverberate and surge throughout the organisation. The 60 consequential costs of failure listed below reflect a good number of them. But there are others specific to each organisation and they too need to be identified and recorded. So many of these costs are not noticeable and are never recognised when either the office light fails or production comes to a standstill from an equipment breakdown. Hidden though these costs are from casual observation, they exist and they strip fortunes out of company coffers … and no one is the wiser.

- Labour : both direct and indirect
    - operators
    - repairers
    - supervisory
    - management
    - engineering
    - overtime/penalty rates
- Product waste
    - scrap
    - replacement production
    - clean-up
    - reprocessing
    - handover/hand-back
    - lost production
    - lost spot sales
    - off-site storage
    - environmental rectification
- Services
    - emergency hire
    - sub-contractors
    - travelling
    - consultants
    - utility repairs

- temporary accommodation
- Materials
  - replacement parts
  - fabricated parts
    - materials
    - welding consumables
    - workshop hire
  - shipping
  - storage
    - space
    - handling
  - disposal
  - design changes
  - inventory replenishment
  - quality control
- Equipment
  - OEM
  - energy waste
  - shutdown
  - handover
  - start-up
  - inefficiencies
  - emergency hire
  - damaged items
- Capital
  - replacement equipment
  - new insurance spares
  - buildings and storage
  - asset write-off
- Consequential
  - penalty payments
  - lost future sales
  - litigation and legal fees
  - loss of future contracts
  - environmental clean-up
  - death and injury
  - safety rectification
  - product recalls
- Administration
  - documents and reports
  - purchase orders
  - meetings
  - meeting rooms
  - stationary
  - planning, schedule changes
  - investigations and audits
  - invoicing and matching
- Lost Value from Curtailed Lives
  - lost equipment/materials life
  - labour/resources wasted
  - outsourced services value lost

These lost and wasted moneys can be considered as the 'Instantaneous Costs of Failure' (ICOF). They are instantaneous because as soon as a failure happens they will be wasted and they will be spent. Failure causes instantaneous costs because the moment a failure incident occurs, the cost to fix the item or the situation and return it back to usable condition is committed. The money to fix the problem will have to be spent and the obligation to spend it happens the instant of the failure happens. It may take some time to actually complete the repairs and rectification, but the moneys will be spent, and the requirement to spend them arose at the instance of the failure.

There is no alternative but to expend them to get the business back into production. The moneys spent to fix the problem, the lost income from no production, the payment of unproductive labour, the loss from waste, the handling of the company-wide disruptions and the loss of future business is money lost forever. However, they would not have had to be spent if the failure had not happened.

In fact the requirement to spend moneys on repairs and rectification of a failure incident arises even earlier in time. The loss and the obligation to spend money on a failure are incurred at the point in time the failure is initiated. Figure 2.4 shows the sequences of degradation once an equipment failure is initiated. The failure may not happen for some days, weeks, months and even years, but once initiated it will happen. At the instance of every failure initiation the organisation will, at some point in the future, get a bill for its repair and correction. That cost can only be avoided if the failure sequence is never started.

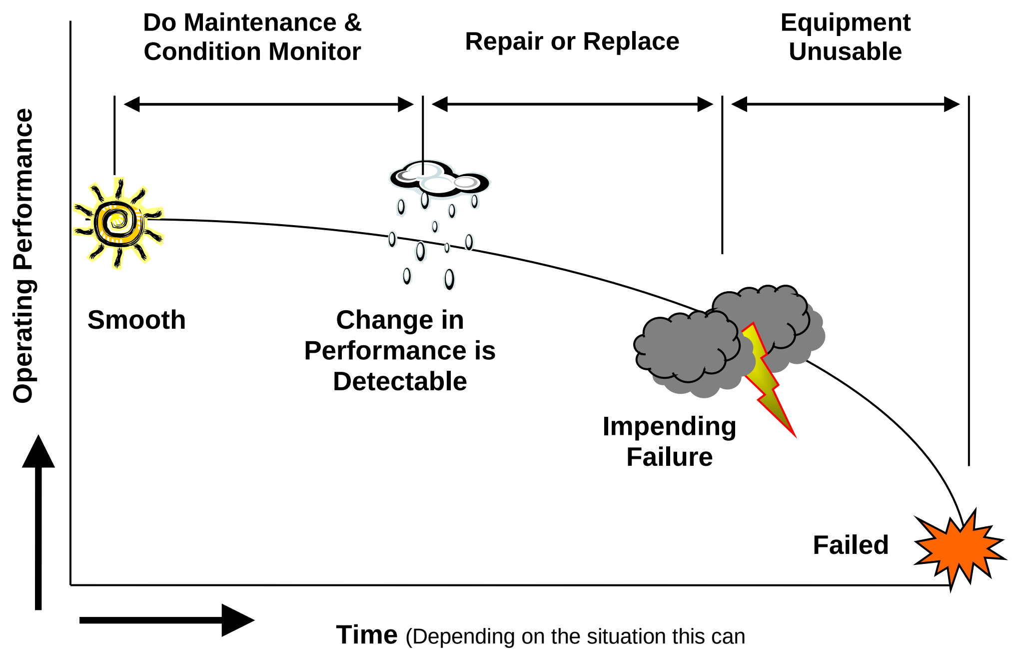


Figure 2.4 The Failure Degradation Sequence

The sum totals of the organisation-wide instantaneous costs of failure are not usually considered when the cost of a failure incident is determined. Most companies do not fully appreciate the huge consequential costs they incur with every failure incident. Few companies would cost the time spent by the accounts clerk in matching invoices to the purchase orders raised because of a failure. But the clerk would not be doing the work if there had been no failure. The cost was incurred only because the failure happened. The same logic applies for all the costs due to a failure – if there had been no failure there would have been no costs and no waste. Prevent failures and the money otherwise spent will be kept in the business as profit. Many of the ICOF costs are never recognised when the cost of failure is tallied and the true total magnitude of moneys involved are left out of failure cost calculations.

It is not important to know how many times a failure incident happens to justify calculating the instantaneous cost of failure. It is only important to ask what would be the cost if it did happen. An extraordinary example of the magnitudes of costs associated with failure occurred in 1986. A 150-mm diameter PVC pipe carrying softened, demineralised water for a major power station failed at a glued joint. With the pipe broken the water supply to three boilers supplying steam to six steam turbines stopped. It was only by supplementing the water supply with untreated mains water that the power plant remained in operation until the failure was repaired. Had the failure progressed to its disastrous conclusion a city of 1.5 million people, and all its industry, would have lost power as each turbine progressively stopped from loss of steam. The repair of the pipe was done for several thousand dollars, but the consequence of the failure was in the hundreds of millions, even billions of dollars. Had the instantaneous cost of failure been calculated first, far greater precautions would have been put into place to control the hidden risks inherent in the job. Before a change is made or a new design undertaken quickly calculate the ICOF and identify the true consequences of failure to the organisation.

The full cost of all ‘instantaneous losses’ from a failure incident can be calculated in a spreadsheet. Trace all the departments and people affected by an incident, identify all the expenditures and costs incurred throughout the company, determine the fixed and variable costs wasted, discover the consequential costs, find-out the profit from sales lost and include any recognised lost opportunities due to the failure and tally them all up. It will astound people when you show them how much money was lost and profit destroyed by one small equipment failure.

2.3. Costing Failure Consequences

A few large catastrophes close together in time or many smaller problems occurring regularly will destroy an organisation’s profitability. Too many defects, errors and failures will send a company bankrupt. Vast sums of money are lost when things go wrong. Typically when failures happen in the workplace they are quickly addressed. They are repaired and made good. Work then continues as usual. If anyone enquires on the cost of the incident the number usually quoted is the cost of parts and labour to fix it. The cost impact throughout the organisation and the loss in productivity on all the other activity generated because of the failure is forgotten. The importance of knowing the true cost of a failure is to know its full effect on the organisation's profitability and then act to prevent it happening again.

Collating all the costs associated with a failure requires the development of a list of all possible cost categories, cost sub-categories and cost sub-sub-categories so that every charge, fee, penalty, payment and loss is identified. The potential number of cost allocations is numerous. Each cost category and sub-category may receive several charges against them over the period of time being analysed. All of these charges need to be captured in the analysis.

A worked example in Table 2.1 of a pump failure will identify what it truly costs. For simplicity we will use a common centrifugal pump failure. They are often used in industry and around the home and most people know of them. In this pump the inboard shaft bearing has collapsed. This bearing is on a 3 inch (76 mm) shaft. It is a tapered roller bearing that can be brought straight-off the shelf. A common enough failure and one that most people in industry would not be greatly bothered by. It would simply be fixed and no more would be thought about it.

For the example a number of costs and pay rates will be assumed. The wages employees, including on-costs to the company, are paid $40 per hour and the more senior people are on $60 per hour. The product costs $0.50 a litre to make and sells for $0.75 per litre. Throughput is 10,000 liters per hour. Electricity costs $0.10 per kW.Hr. All product made can be sold. The failure incident costs are individually tallied and recorded.

Action No.	**Description**	**Time** minutes	**Labour Cost**	**Materials Cost**
1	First the pump stops and there is no product flow.			
2	The process stops.			
3	The control room sends an operator to look.	10	7	
4	Operator looks over the pump and reports back.	10	7	
5	Control room contacts Maintenance.	5	3	
6	Maintenance sends out a craftsman.	15	10	
7	Craftsman diagnoses problem and tells control room.	10	7	
8	Control room decides what to do.	10	7	
9	Control room raises a work order for repair.	5	3	
10	Maintenance leader or Planner looks the job over and authorizes the work order.	30	20	
11	Maintenance leader or Planner writes out parts needed on a stores request.	15	10	
12	Storeman gathers spares parts together and puts them in pick-up area. (Bearings, gaskets, etc)	20	13	350
13	Maintenance leader delegates two men for the repair.	5	3	
14	Maintenance leader or Planner organizes a crane and crane driver to remove the pump.	5	3	

15	Repair men pick up the parts from store and return to the workshop.	10	20	
16	Repair men go to job site.	15	20	
17	Pump is electrically isolated and danger tagged out.	15	40	
18	Pump is physically isolated from the process and tagged.	30	40	
19	Operators drain-out the process fluid safely and wash down the pump.	30	120	
20	Repair men remove drive coupling, backing plate, unbolt bearing housing, prepare pump for removal of bearing housing.	90	20	
21	Crane lifts bearing housing onto a truck.	15	7	
22	Truck drives to the workshop.	5	7	
13	Bearing housing moved to work bench.	5	27	
24	Shaft seal is removed in good condition.	20	120	
25	Bearing housing stripped.	90	160	
26	New bearings installed and shaft fitted back into housing.	120	27	
28	Mechanical seal put back on shaft.	20	13	
29	Backing plate and bearing housing put back on truck.	10	7	
30	Truck goes to back to job site.	5	27	
31	Crane and crane driver lift housing back into place.	20	80	
32	Repairmen reassemble pump and position the mechanical seal.	60	80	
33	Laser align pump.	60	80	
34	Isolation tags removed.	10	20	
35	Electrical isolation removed.	15	20	
36	Process liquid reintroduced into pump.	30	20	
37	Pump operation tested by operators.	15	10	
38	Pump put back on-line by Control Room.	5	3	
	TOTAL	**755**	**$970**	**$350**

Table 2.1 Apparent Costs of a Pump Bearing Failure

To do the whole job took 12.6 hours at an apparent repair cost of $1,320. The downtime was clearly a disaster but the repair cost was not too bad. Another problem solved. But wait, all the costs are not yet collected. There are still more costs to be accounted for as shown in Table 2.2.

Action No.	**Description**	**Time** minutes	**Labour Cost**	**Other Cost/Loss**
39	Control Room meets with Maintenance Leader.	10	20	
40	Control Room meets with repairmen over isolation requirements.	10	20	
41	Production Manager meets Maintenance Leader	5	10	
42	Production Manager meets Maintenance Manager.	5	10	
43	Production morning meeting discussion takes 5 minutes with 10 people management and supervisory present.	5	100	
44	Production Planner meets with Maintenance Planner	5	10	
45	General Manager meets with Production Manager	5	10	
46	Courier used to ferry inboard bearing as only one bearing was in stock.		30	
47	Storeman raises special order for bearing.	5	3	Included
48	Storeman raises special order for gaskets.	5	3	Included
49	Storeman raised special order for stainless shims used on pump alignment but has to buy minimum quantity.	5	3	250

50	Storeman raises order to replenish spare bearing and raises reorder minimum quantity to two bearings.	5	3	125
51	Storeman raises order to replenish isolation tags.	5	3	5
52	Crane driver worked over time.	300	200	
53	Both repairmen worked overtime.	600	400	
54	Extra charge to replace damaged/soiled clothing.			100
55	Lost 200 liters of product drained out of pump and piping.			100
56	Wash down water used 1000 liters.			10
57	Handling and treatment of waste product and water.	15	10	20
58	Pump start-up 75 kW motor electrical load usage.			5
59	13.7 hours of lost production at $2,500/hour profit.			32,000
60	Account clerk raises purchase orders, matches invoices; queries order details, files documents, does financial reports. Paper, inks, clips,	60	40	20
61	Storeman answer order queries.	20	13	
62	Maintenance workshop 1000 watt lighting on for 10 hours.			150
63	Two operators standing about for 13 hours	750	1000	
64	Write incident notes for weekly/monthly reports	30	30	
65	Incident discussed at senior levels three more times.	15	30	
66	Stocks of product run down during outage and production plan/schedule altered and new plan advised. Paper, inks, printing	30	30	10
67	Reschedule deliveries of other products to customers and inform transport/production people.	30	20	10
68	Ring customers to advise them of delivery changes.	30	20	50
69	Electricity for lighting and air conditioning used in offices and rooms during meetings/calls.			50
	TOTAL OF EXTRA COSTS		**$2,018**	**$32,905**

Table 2.2 Total Costs of a Pump Bearing Failure

The true cost of the pump failure was not $1,320, it was $36,243. The apparent cost of the failure is miniscule in comparison to the total cost of its affect across the company. That is where profits go when failure happens; they are spent throughout the company handling the problems the failure has created and on lost opportunities. Identifying total failure costs produces an instantaneous cost of failure many times greater than what appears obvious. Vast amounts of money and time are wasted throughout an organisation when a failure happens. The money from sales that could have been made never is lost. The bigger the failures, or the more often they happen; the more resources and money that are lost. The profits that could have been made are gone, wasted, and they can never be recouped.

The huge financial and time loss consequences of failure justify applying failure prevention methods. It is critical to a company's profitability that failures are stopped. They will only be stopped when companies understand the magnitude of the losses and introduce systems, training and behaviours required to prevent them.

2.4. Introduction to Defect and Failure True (DAFT) Cost

In order to focus on controlling loss it is necessary to have a means to find the total costs of a failure to identify their full impact on an operation. The moneys from a failure are lost in Administration, in Finance, in Operations, in Maintenance, in Service, in Supply, in Delivery and even in Sales.

As part of conducting a thorough analysis into a failure, the total and complete financial cost of the failure incident history and consequences needs to be compiled. The process of collecting, analysing and reporting all costs due to the failure is known as the 'Defect and Failure True Cost' (DAFT Cost) method. DAFT Costing incorporates the instantaneous cost of failure to show the vast amounts of money wasted throughout an organisation from failure into a formalized accounting process. The acronym 'DAFT Cost' reflects the senselessness of these unnecessary costs being allowed to happen in a business, organisation or operation.

Collating all the costs associated with a failure requires the development of a list of all possible cost categories, cost sub-categories and cost sub-sub-categories so that every charge, fee, penalty, payment and loss is identified. The potential number of cost allocations is numerous. Each cost category and sub-category may receive several charges against them over the period of time being analysed. All of these charges need to be captured in the analysis. To assist in compiling the DAFT Cost list it is useful to use the company's Chart of Accounts, as it contains all the accounting cost codes that would typically be used to allocate costs and charge payments in the organisation. If new cost centres are developed because of the failure these also must be included in the cost list.

2.5. Calculating DAFT Cost using Activity Based Costing

Activity Based Costing (ABC) is an accounting technique that identifies the total and complete costs of the activities undertaken to perform a function and produce a product. ABC applied to DAFT Costs allows an organisation to determine the actual cost of all resources and services used throughout the organisational impacted by a failure. It is a powerful tool for measuring business failure costs since it itemises every expense and identifies its make-up.

An overview of the ABC process as used for DAFT Costing is presented below. The requirement is to trace the cost of every action and task caused by the failure event through the organisation to its final conclusion. Figure 2.5 a symbolic representation of the cost surge that reverberate through an organisation with each failure, stripping profit from the business as resources are marshalled and diverted from profit-making activities to combat and overcome the failure and its effects. DAFT Costing traces the surge thorough the organisation capturing every cost of its effect so a true and total picture of failure is seen.

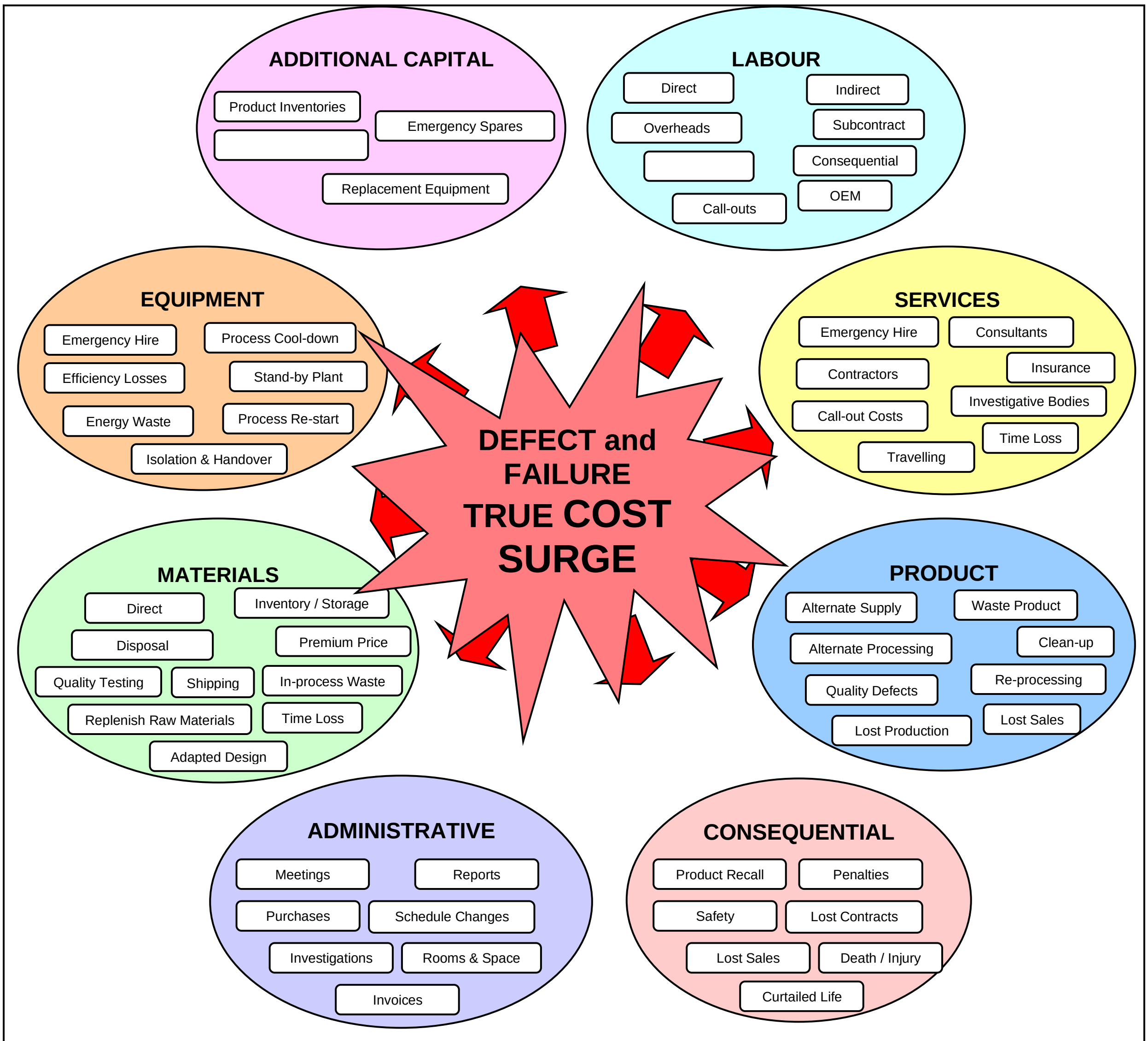


Figure 2.5 A Multitude of Costs Arise and Profits are Lost Due to Defects and Failures

2.6. Using DAFT Costs to Rate Equipment Criticality

Equipment Criticality is used to identify operating equipment in priority order of importance to the continued operation of a facility. Those equipment items that stop the operation, or cause major costs if they fail are identified as critical. Higher quality engineering design, better materials selection and more demanding levels of maintenance and operator precision and care are given to those items to maximise their level of availability and benefits for production.

Equipment Criticality is a risk rating indicator. This means it uses the risk formula to identify the cost to a business if a failure was to happen on a piece of equipment. The formula used is:

Equipment Criticality = Risk = Failure Frequency (/yr) x Cost Consequence ($) *Eq. 2.5*

The 'cost consequence' is normally estimated from the costs of lost production plus the costs of repair, which you are now aware of, are usually well short of the true cost. The 'failure frequency' is estimated from the company's maintenance history or from industry norms for a similar operation. Equipment criticality leads to the development of a priority scale by which all of a facility's plant and equipment is graded. The same method is then applied to the assemblies and components in individual items of plant and equipment to identify which are highest in priority to its continued operation. The facility's resources, maintenance and training are matched to the priority and importance of the item to the operation.

Typically the equipment criticality priority for a facility is arrived at by a competent group of people formed to analyse the plant and equipment and categorise each item using a formalised, documented process. Usually the review group consists of the operators, the maintainers and designers of equipment. Drawings of the facility's processes showing every item of plant and equipment are used in the review. Equipment by equipment the group analyses the consequences of failure to the operation and develops a table showing each equipments criticality rating.

Once the priority of the equipment is set, a matching minimum level of maintenance and operator care is specified for it. The most important items to the operation get sufficient and appropriate resources, maintenance and monitoring to keep them as available for service as is required. Those items that can cause inconvenience are also given the amount and type of maintenance suitable to their situation.

DAFT Costing tells us that the real costs of failure to a company are far more than the cost of lost production time and maintenance typically used in calculating equipment criticality. Unless the true and total costs are included in determining equipment criticality the full risk of equipment failure to the business has not been recognised. The DAFT Costing method is a better way to determine the total financial consequence of a failure for equipment criticality analysis review. By using DAFT Costing a far more accurate value of consequential loss to the business, and hence the true business risk, is determined than by the usual cost estimating methods.

The Defect and Failure True Cost method highlights that many risks to the business previously considered minor are actually high and they require a management plan be put into place to address those risks. The frequency of occurrence maybe low but the cost consequences can be massive and so the real risk for the organisation is actually high.

2.7. Analysing Project Design and Consequences Using DAFT Costing

DAFT Costing provides a means to price future failure incidents and so rate future operating risk while projects are still on the drawing board. The cost outcomes of project decisions can be clearly and accurately identified and priced using the design drawings. Those that are unfavourable can be analysed and modified to reduce the likelihood of their occurrence and limit the consequences of a failure.

Figure 2.6 shows the phases of a typical project and the points during its life that its life cycle costs are committed. The life cycle cost includes its capital cost and subsequent lifetime operating costs. Clearly the vast majority of operating costs are set by the design. A facility's operating costs result largely from decisions and selections made during project conception and design. Poor design choices plague an operation all its life.

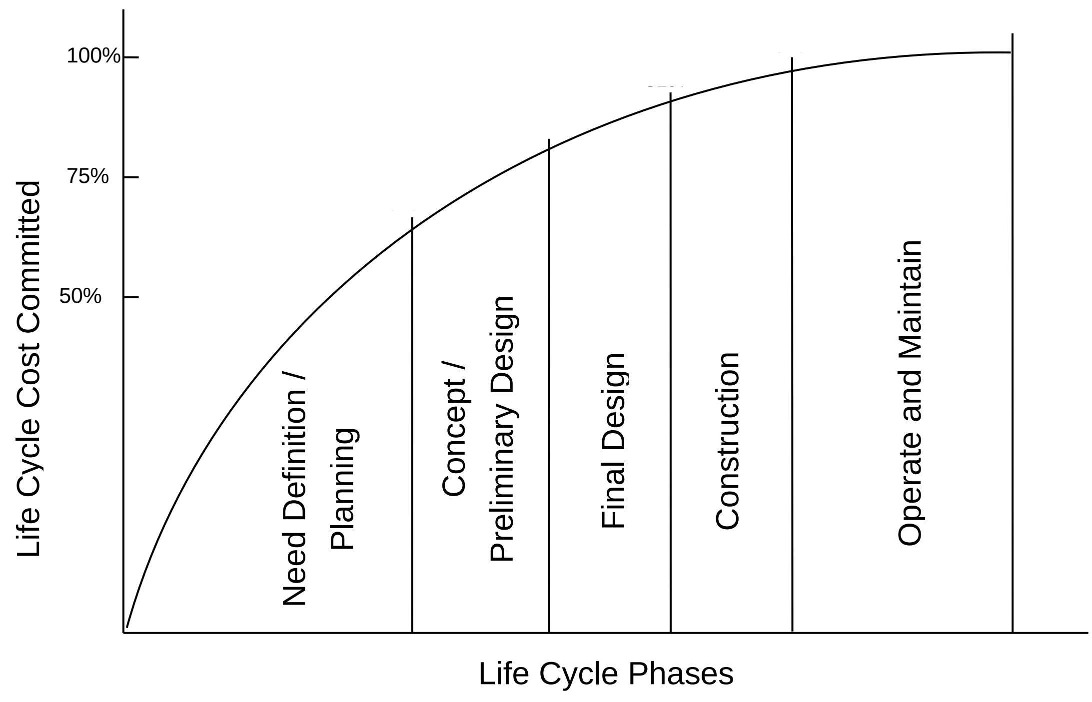


Figure 2.6 Life Cycle Cost Commitments

Further confirmation of the profound effect on operating costs that result from design decisions is found in this extract from a paper by H. Paul Barringer, P.E titled *Life Cycle Cost & Reliability for Process Equipment*[1]. "Frequently the cost of sustaining equipment is 2 to 20 times the acquisition cost. Consider the cost for a simple, continuously operating, pump—the power cost for driving the pump is many times larger than the acquisition cost of the pump. This means pumps must be procured with an emphasis on energy efficient drivers and energy efficient rotating parts while incurring modest increases in procurement costs to save large amounts of money over the life of the equipment. Here is an often cited rule of thumb: 65% of the total Life Cycle Cost is set when the equipment is specified!! As a result, do not consider specification processes lightly—unless you can afford it."

By applying DAFT Costing to 'imagined' equipment failures it is possible to identify which equipment has the least consequences of use. By assuming a failure occurs and building a DAFT Cost model on a spreadsheet it is possible to cost the failure. This allows the designer to identify designs and component selections that minimise future failure costs. Before large amounts of money are spent on designs and equipment selection it is clear which choices lead to better project financial performance.

DAFT Costing can also be used to estimate the lifetime operating cost of a proposed design. The operating and maintenance consequences of capital equipment selection can be modelled while still on the drawing board and so identify which equipment operating and maintenance practices produce the least life cycle cost and most life cycle profit. Financial robustness over a project's life and the risk on the return on capital invested can be readily confirmed by applying DAFT Costing. The costs used in such analysis are normally taken from costs incurred by the industry in the country concerned. More preferable is to use those costs from the organisation that will use the equipment, as their real costs will reflect current operation and maintenance methodologies and practices.

Using DAFT Costs compiled from actual current operating practices for capital expenditure justification makes the estimate of operating and maintenance costs for a project decision realistic. By applying real costs of operation to the capital design and equipment selection the consequent effect of its use on operating profitability can be determined. The financial consequences of projects can now be simulated to good accuracy and project designs can be 'tuned' for selected results through using DAFT Costing. A project can be designed and tested for least capital expenditure, or least risk, or least operating cost, or least maintenance, or some other chosen parameter. DAFT Costing provides a powerful tool to make good investment decisions. It uses real costs in scenarios that more truly reflect the future and allows sound practical choices and financial judgments to be made in project capital equipment selection, project design, operation and maintenance. Applying DAFT Costing reduces the chance of poor decisions being made from not understanding their total consequential costs.

2.8. Design and Operations Cost Total Optimisation Review (DOCTOR)

Using DAFT Costing to optimise the design and selection of project equipment and designs based on future consequential operating costs and failures is called 'Design, Operations and Cost Total Optimisation Review'. The acronym is DOCTOR.

The process first entails taking each separate item of equipment in a project design and assuming it will fail in the most catastrophic way possible. The costs resulting from such a failure are then compiled. Secondly, the item is assumed to fail in its more likely ways and the consequential costs calculated. The cost of repairing the failure is the DAFT Cost based on the real costs of current practices in the organisation using the equipment. The final costs are used to review the design choice and to compare it against other choices and their costs.

Every item of plant and equipment, down to an individual pipe flange or gearbox shaft, can be put through the DOCTOR process. The costs of all catastrophic failures and the more likely failures are used to rate the robustness of the design decision. If the failure costs are unacceptable then either a design change is made to reduce the financial consequence or additional mitigating requirements are included into the design or the operating and maintenance practices to reduce the risk and operating cost.

DOCTOR applies risk analysis to determine the likelihood of an incident and uses DAFT Costing to estimate the real costs of failure when the business is in operation. It takes the costs incurred in an operations failure and brings them back to the design stage so the designer can make more profitable business decisions and build them into the future operation of the business. Figure 2.7 shows how DOCTOR is used during the project design phase.

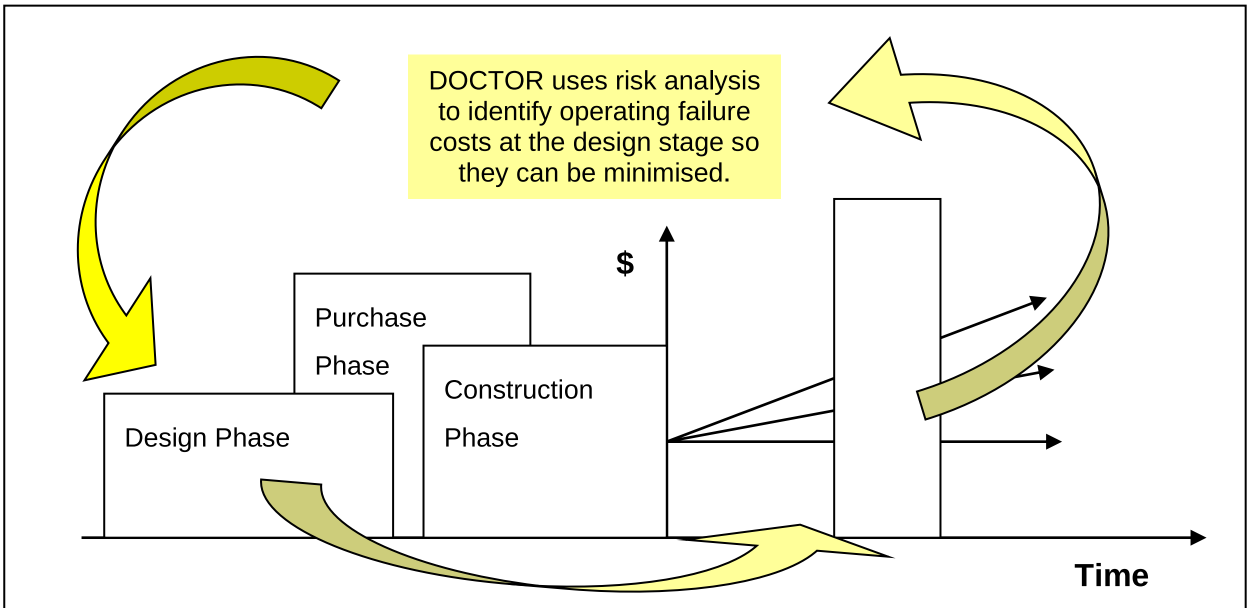


Figure 2.7 Identifying Operating Failure Costs with DOCTOR

After the new decisions are made to the design or operating practices the new model is again put through the DOCTOR and compared with the previous result. In this iterative way the design can be optimised for the desired cost.

2.9. Setting Business Priorities Based on DAFT Costs

There are numerous priorities facing organisations and businesses every day. It is well understood that it is necessary to tackle priorities in order of importance to the continued generation of profit. Selecting what to work on is a matter of listing jobs in priority order and starting with the highest priority job first. The difficulty arises in being sure that the order is right; from highest to lowest.

Because DAFT Cost is a means to identify the direct, indirect and knock-on costs from a decision it can be used to make good decisions in any situation where understanding the right financial consequences are critical to success. If the criterion for selecting job priority is based on the financial cost to the organisation it would be useful to set priorities using DAFT Costing. The DAFT Cost represents the real total costs of a decision or potential incident. Once you have a list of jobs that can be prioritised in order of their financial impact on the organisation it becomes clear in which order they need to be done.

Choosing a solution to an issue is simpler once the DAFT Costs are known. The consequential cost and the difficulty of solving the issue can be used to choose the solution. A prioritisation matrix of the solutions can be developed. An example of a prioritisation matrix for production equipment problems is shown in Figure 2.8. It identifies the methods and choices which an organisation has available to address the production risks identified by a DAFT Cost analysis.

Cost of Solution		Cost of Consequences: Low	Cost of Consequences: High
	High	*Accuracy Control the Risk*	*Budget to Design-out Risk; Start Accuracy Controls*
	Low	*Accuracy Control or Design-out Risk, (as appropriate)*	*Design-Out Risk Immediately*

Figure 2.8 A Sample Prioritisation Matrix for Equipment Failures

The ‘accuracy control’ term used in the matrix is not the same as saying ‘apply improved quality control’. The accuracy control mentioned in the matrix is the methodology discussed in Chapter 4. Quality control has become a marketing concept and resulted in the degradation of the true and great worth of quality management systems to business success. Valuable and worthwhile though a quality control program may be, what is often only required to reduce risk of failure is to improve the accuracy in doing the work. Applying a quality control system throughout the organisation is often unnecessary if the work is done more accurately to start with.

3. Chance Reduction Risk Management

Risk exists in everything we do. Risk is the chance or possibility of loss. Mathematically it is the combination of two elements - the frequency, or probability of the occurrence of a specified event with the consequence should the event happen. But 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 total loss. The challenge is to develop methods to increasing the likelihood of good outcomes while addressing and mitigating the bad.

Risk-based management solutions are seen as a means to minimise the cost of operation. If the frequency of bad events or their consequential costs lower, then operation cost is reduced. The difficulty is in selecting the appropriate strategies that realise the maximum risk reduction for the greatest period of time at the least implementation cost. Few industrial organisations achieve this aim, as can be evidenced by high production and maintenance costs year after year. Because risk has such profound impact in everything to do with business and commerce it is critical to understand it. The right perspective on risk can help identify those risk management strategies that continually provide the greatest financial, production and safety benefits to an organisation.

3.1. The Risk Equation

The mathematical definition of risk is reflected in the simple equation introduced for rating equipment criticality in Chapter 2 and repeated again below.

Risk $_{(\$/Yr)}$ = Frequency of Occurrence $_{(/Yr)}$ x Consequence of Occurrence $_{(\$)}$ *Eq. 3.1*

Using mathematically symbols Equation 3.1 is written as:

$$R = \lambda.C \qquad \textit{Eq. 3.2}$$

The word frequency is replaced by the Greek symbol ‘λ’ known as ‘lambda’, risk is replaced by ‘R’ and consequence is replaced by ‘C’. The equation gives us the financial cost of a risk.

Cost of Risk = Frequency Of Occurrence x Consequence of Occurrence *Eq. 3.3*

\$ = λ x C

The equation says that risk is equal to the frequency of an event occurring multiplied by its consequence should it occur. The 'frequency' in the equation is the number of times an event will happen during a period of time. Usually a year is used. An event that happens every five years has a frequency of once in five years. This is annually equivalent to 0.2 times a year. A once-in-five-years event and a 0.2 times-a-year event are of equal frequency. The consequence of an occurrence is the total financial impact of the event. It is usually measured in financial value. By measuring the 'frequency' of an event per year, and making 'consequence of the occurrence' a monetary value, the equation measures the annual cost of the risk. With this equation risk is given a financial value. It provides a means to quantify the yearly cost to the organisation of every bad (or good) risk it suffers. It also provides a means to scale one risk against another and hence set priorities for addressing the risk.

Frequency is typically measured in events per year so its annual effect on budgets can be identified. Consequence is measured in financial terms because we are interested in quantifying the monetary cost of the incident. A simple example is for an event that happens twice a year and costs $10,000 each time it occurs. Putting the numbers into the equation gives:

$$\text{Cost of Risk} = 2 \text{ events per year} \times \$10{,}000 \text{ per event}$$

The cost of the risk is $20,000 per year. If the event can be mitigated so that it happens every two years while costs remain at $10,000, the risk becomes:

$$\text{Cost of Risk} = 0.5 \text{ events per year} \times \$10{,}000 \text{ per event}$$

In this case the cost of the risk is $5,000 per year.

These two simple examples show the great benefits available to a business by using risk management philosophies and practices. If the chance of an event is reduced so it happens less frequently money will be saved because it no longer needs to be spent on the problem.

Equation 3.3, the Cost of Risk equation, is identical to the Cost of Loss Equation 2.4 identified in the 'Effect of Failure Incidents on a Business' section in Chapter 2 and shown again below.

$$\text{Cost of Loss} = \text{Frequency Of Occurrence} \times \text{Cost of Occurrence} \qquad \textit{Eq. 2.4}$$
$$\$ = N \times \$$$

Controlling risk and controlling failure have identical implications to a business. Risk and failure produce like financial effects. They are interconnected. Reduce the numbers of failures and risk is reduced. Reduce the amount of risk and there will be fewer failures. For the purpose of interrogating its secrets the risk equation is better written as:

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

'Chance' is also measured as 'the number of events in a time period'; a 50% chance the colour will be black in a roulette spin, an 80% chance of rain today. The word 'chance' is a more suitable choice of word for explaining risk than is 'frequency'. Chance has the connotation of uncertainty, of unpredictability. It implies that we do not know when an event will occur. It reflects the real world much more truthfully than does the word 'frequency'. Chance tells us that a once-in-five-year event can happen at any second during that five-year period. 'Chance' provides a clearer connotation of risk.

Chance events require opportune occurrences to coincide. It has long been understood in the occupational health and safety industry that a bad incident only occurs when several unconnected factors align in such a way that the incident becomes possible. For a fire to start there must be fuel, air and an ignition source. All three must be present. The fire cannot start until all three requirements come together at once. For an accident to occur several necessary factors must exist together. It can be said that accidents do not happen by accident; rather they are created in error and ignorance of how factors align to provide opportunity for disaster.

The risk equation tells us that risk has two components - chance and consequences - or using two other words commonly applied to describe risk - probability and severity. Reduce the chance, or probability, of an event occurring and you reduce the risk. Stop one of the necessary requirements for an incident to happen and the incident cannot occur. The use of 'chance reduction techniques' is one principle for controlling risk.

Risk can also be reduced by lessen the consequences of an incident. The 'consequence reduction techniques' allows an incident to happen in such a way that there is little or no impact from it. Risk can be reduced by lowering the chance of an incident's occurrence and by lessening the consequences resulting from the incident.

But in the risk equation the two factors, chance and consequence, are multiplied together. It would seem that the impact of either factor has equal effect on the risk. Halving the chance is equally as good as halving the consequences. Unfortunately this is a trap that most organisations fall into. They think that it does not matter how they reduce their risk because either path produces the same result. It is not true. In reality the two 'paths' to reducing risk have totally different impacts on the prosperity of an organisation. This is best understood by reviewing the simple business model introduced in Chapter 2. The application of basic accountancy is sufficient to explain why the best path to take in risk management is to reduce the 'chance' of failure and not its 'consequence'.

3.2. Impact of Risk Management Strategy

Recall that Figure 2.1 was a simple accounting model of a business and Figure 2.2 showed the effect of a failure incident on the business costs and profits. Figure 2.3 showed the 'death of many cuts' effect on profit from repeated failures. By individually applying the risk management options - chance reduction and consequence reduction – to the business model we can identify their financial effect on the operation.

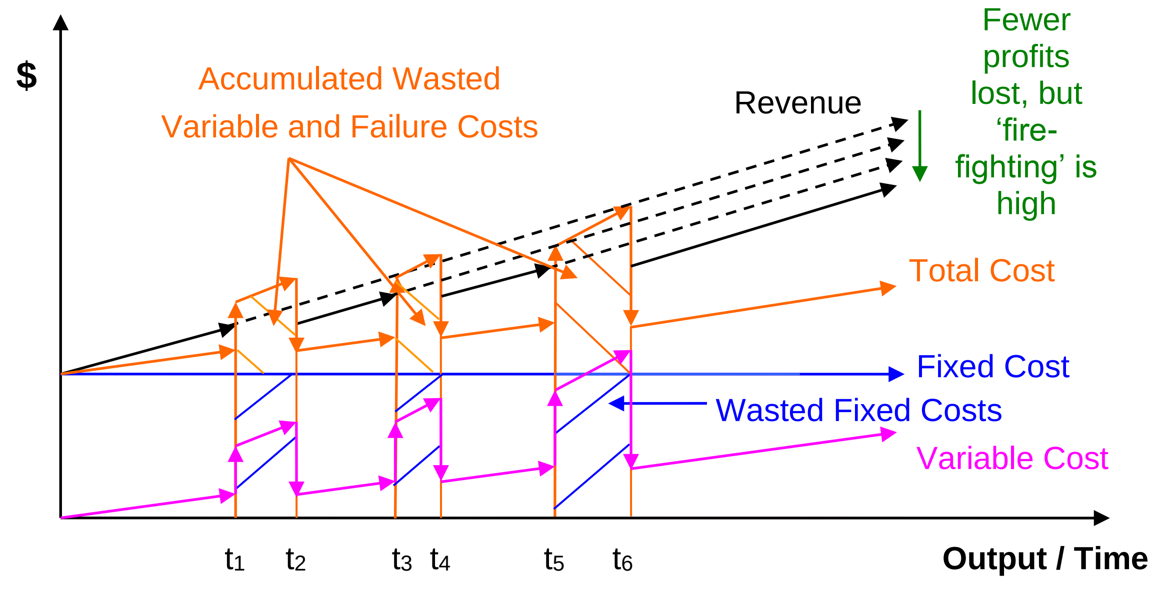


Figure 3.1 Effects on Profitability of Reducing Consequence Only

Figure 3.1 is the business model suffering repeated failures when consequences reduction strategies are used to reduce risk. In this case the production time loss is reduced while all else remains the same. Production time lost is lessened by practices such as holding spare parts on-site or improving the equipment maintainability so repairs are done faster. A visual comparison between Figures 2.3 and 3.2 shows that reducing the time loss clearly produces profit improvement. Losses are held down if the operating plant gets back into production quickly. Consequence reduction strategies do reduce the cost of risk. What is interesting with the model in Figure 3.1 is that though costs are reduced there will be much frantic activity and 'fire-fighting' happening in this operation. Minimising risk by reducing its consequences accepts failure incidents as a normal way of doing our business. In organisations that use consequence failure management many things go wrong. Its people wait for the failures and then to react to them. In this way a reactive culture is instilled in the organisation. Reducing only the consequences of risk makes work for everyone. This work is all wasted time, money and effort because people and resources are diverted away from making product to fixing problems; instead of spending that time, money and effort improving the business.

The alternate risk management strategy is to apply change reduction techniques. Let us now look at what happens to the operation and profit if our risk management efforts are targeted at reducing the chance of failure incidents occurring. In Figure 3.2 there is only one incident during the same period as there were three in Figure 3.1 while all else remains the same.

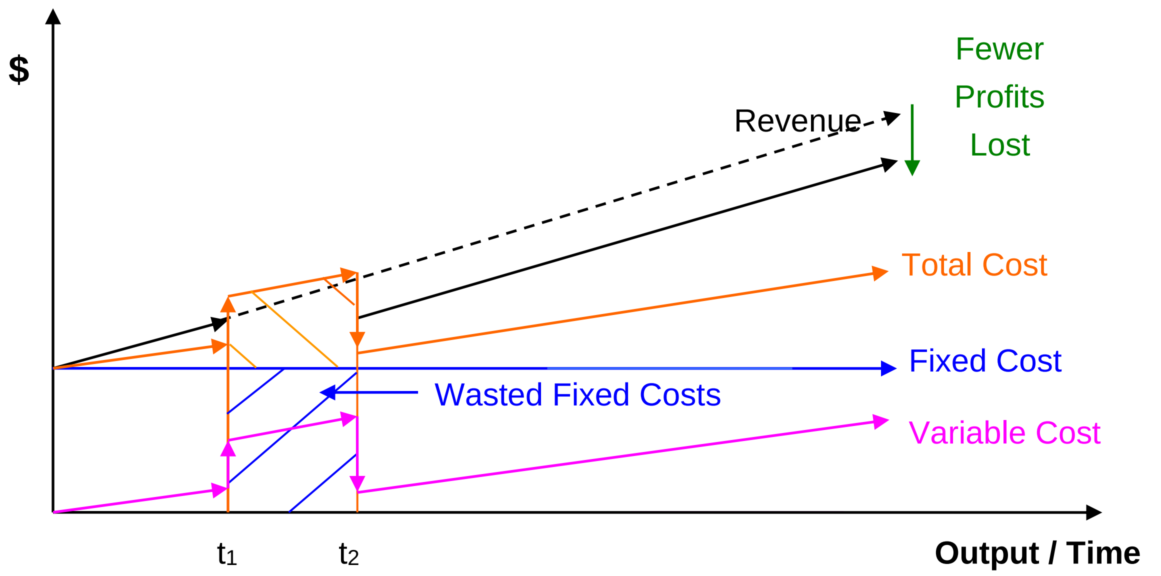


Figure 3.2 Effects on Profit of Reducing Chance Only

Here we can see that profit is also improved, as you would expect if there are fewer failure incidents in a given period of time. Whether there is more profit to be regained by using chance-reduction strategies or consequence-reduction strategies is not evident in the graphical models.

What can be said is that risk is reduced and profit is improved if risk management strategies target either chance reduction or consequence reduction. Obviously if both strategies are used at the same time the maximum profit is retained. This outcome is evident in Figure 3.3.

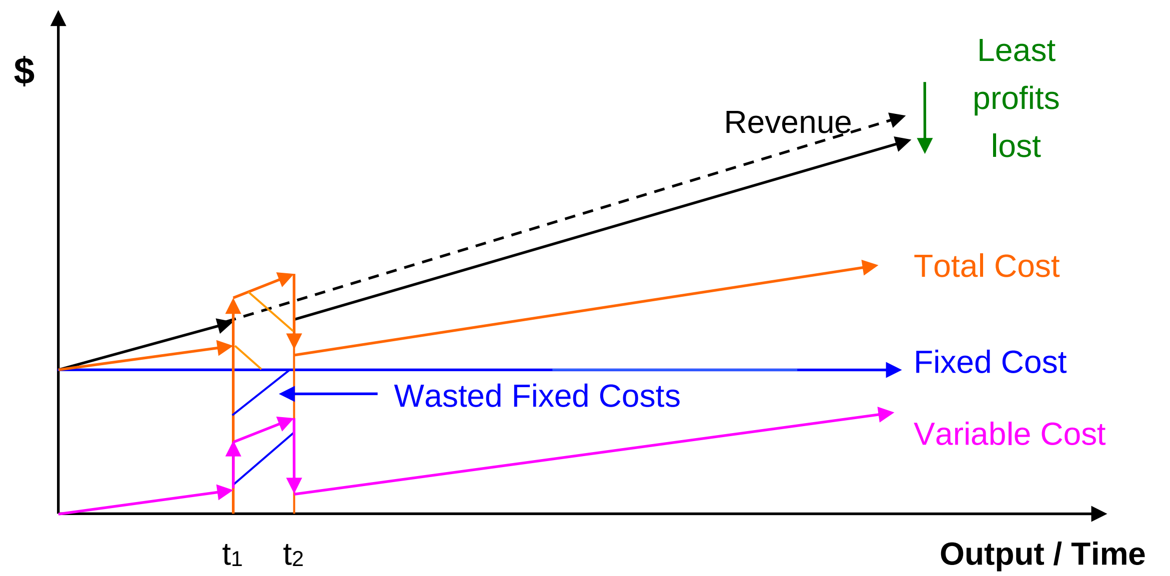


Figure 3.3 Effects on Profitability of Reducing Both Chance and Consequence

To understand which of the two types of risk management strategies is better to use it is necessary to consider the total cost of failure. Recall in Chapter 2 that each failure reverberated through many departments in an organisation and the real costs of failure were far more than the repair and production costs. Therefore those strategies that deliver fewer failures will retain greater profit in the business. Chance reduction strategies require fewer resources, reduce risk further and create more profit compared to consequence reduction strategies. Consequence reduction strategies will reduce risk but are costly and resource consuming.

Another comparison between alternate risk management strategies is shown in Figure 3.4 which lists a sample of the current industrial risk management methods often used to address risk. The various methods are classified into chance reduction and consequence reduction strategies. Other methods also exist but are not shown due to space limitations.

Risk = Chance x Consequence

Chance Reduction Strategies

- Engineering & Maintenance Standards
- Standard Operating Procedures
- Failure Mode Effects & Criticality Analysis (FMECA)
- Hazard and Operability Study (HAZOP)
- Hazard Identification (HAZID)
- Root Cause Failure Analysis (RCFA)
- Precision Maintenance
- Shaft Alignment
- Training & Up-skilling
- Quality Management Systems
- Planning and Scheduling
- Continuous Improvement
- Supply Chain Management
- Accuracy Controlled Enterprise (ACE)
- Design, Operations and Cost Total Optimisation Review (DOCTOR)
- Defect and Failure True Cost (DAFTC)
- De-rate/Oversize Equipment
- Reliability Engineering

Consequence Reduction Strategies

- Preventative Maintenance
- Corrective Maintenance
- Total Productive Maintenance (TPM)
- Non-Destructive Testing
- Vibration Analysis
- Oil Analysis
- Thermography
- Motor Current Analysis
- Prognostic Analysis
- Emergency Management
- Computerised Maintenance Management System (CMMS)
- Key Performance Indicators (KPI)
- Risk Based Inspection (RBI)
- Operator Watch-keeping
- Value Contribution Mapping (Process step activity based costing)
- Logistics, stores and warehouses
- Maintenance Engineering

Figure 3.4 Various Risk Management Methods

Several observations can be made when viewing the two risk management 'paths'. Consequence reduction strategies all require an incident to occur. The failure happens and then the strategies are used to manage it so least time, money and effort are lost. The consequence reduction strategies live with failure and its losses as normal and accept that it is only a matter of time before the operation will be severely affected. Notice that many consequence reduction strategies require high levels of technology and specialists skills to support them. Using high-technology based strategies commits organisations to use of dedicated technical specialists and on-going support costs.

In comparison the chance reduction strategies focus on identification of future problems and the application of system changes to prevent the occurrence, or re-introduction, of failure causing agents. The chance reduction strategies view failure as avoidable and preventable. These methodologies rely heavily on improving the business systems rather than improving failure detection methods. The time, money and effort are expended early and problems identified and fixed so the chance of future failure is minimised. The organisations that apply chance reduction strategies truly have set-up their business to ensure decreasing numbers of failures.

3.3. Power Law Implications

Equations of the risk and loss type are special. They are known as power laws and take the general form $x = zy^n$. For the risk equation the exponent 'n' equals 1. Figure 3.5 shows plots of the risk equation on a normal linear-linear graph[1]. The risk plots out as curves. A risk curve is developed by keeping the value of risk constant and then varying the frequency and the consequence through a range of numbers. If the calculation is done often enough and the answers plotted on a graph the curves develop. Anywhere on a curve is the same risk.

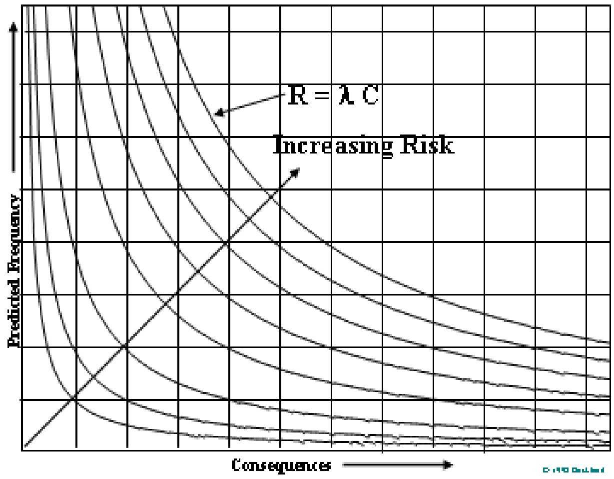


Figure 3.5 Risk Curves on a Linear Graph

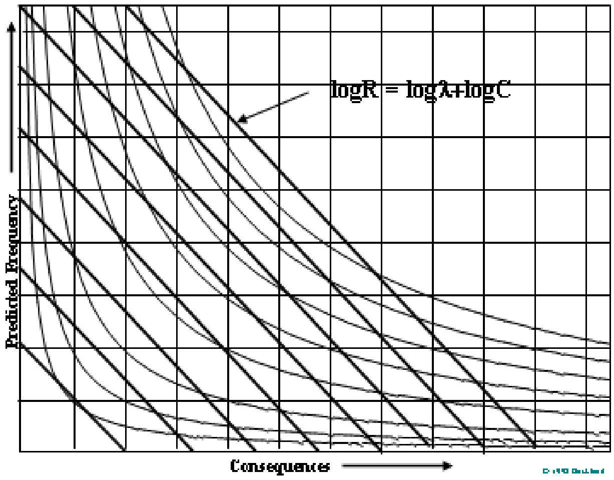


Figure 3.6 Risk Lines on a Log-Log Graph

Figure 3.6 shows the log of the same equation plotted on a log-log graph. The fact that the logarithm of the risk equation plots as straight lines has special significance. This is an example of where power laws have been found to uncannily reflect the real world. The risk equation closely represents what actually happens with human endeavours. The insurance industry uses such curves to set insurance premiums.

Power laws have particular properties. For example they are 'scale-free'[2]. In the case of risk this means the risk equation applies to every size of risk. Failure costs are not linear and while one incident may lose a few dollars, another can total immense sums. They are 'typically a signature of some process governed by strong interaction between the 'decision-making' agents in the system'[3]. This implies that risk does not arise entirely randomly; rather it is affected by the 'decision-makers' present in a system. Situations that follow power laws have a higher number of large events occurring than those of a normal distribution[4]. For risk this means that catastrophic events will occur more often than by pure chance. In power-law-mirrored events a few factors have huge impacts while all the numerous rest have little effect[5]. For risk this means there are a few key factors that influence the likelihood of catastrophe. Control these and you increase the chance of success. They are known as the critical success factors.

Power laws that reflect the human world also tell us much about the situations from which they arise. Perhaps the most important understanding from the risk equation being a power law is the presence of ‘decision-making agents’ within the system to which it applies. Philip Ball in his book, ‘Critical Mass’, points out that “Physicists’ long experience with power laws … leads them to believe that such laws are the universal signature of interdependence. A power law generally emerges from collective behaviour between entities through which local interactions can develop into long-range influences of one entity on another.[6]”

Our simple risk and loss equations now take on far greater and menacing implications.

Risk is affected by the presence of ‘agents’ working uncoordinatedly within a system. The effects of these ‘independent agents’ move through the system in unknown ways but the results of their uncoordinated, and most likely perfectly justifiable, efforts is to increase the risk. Perhaps it now becomes clear why chance reduction strategies are more successful than consequence reduction strategies in reducing long-term organisational risk. The chance reduction strategies work on the systems in a business. They align and coordinate masses of people and information, thereby removing the randomness of ‘independent agent’ influence which unwittingly act to increase the causes of risk and failure in a system.

Gradually and continually the chance reduction strategies act to align and organize the efforts of the mysterious ‘independent agents’ so the randomness of their actions and effects are reduced and finally removed. Chance reduction strategies are the total opposite to consequence reduction strategies, which live with risk and failure as normal. Instead chance reduction strategies forever reduce risk. Because they strike at the random behaviour of the ‘independent agents’ within a system they align people, decisions, actions, behaviours and the over-arching system toward achieving the same organisational outcomes using a specific agreed approach. Randomness and unplanned interactions are removed from the system by chance-reduction strategies. It is in your organisation’s best interest, and it will generate the most profit consistently for the least amount of work, to focus strongly on the use of chance reduction strategies.

Consequence reduction strategies cannot be forgotten, they are important and necessary. Once a failure sequence has been initiated you must find it, address it and minimise its effects so you lose the least amount of money. But consequence-reduction will not make your organisation successful and profitable because it causes resources to be expended. Whereas chance reduction strategies prevent the incident through defect elimination and failure prevention and so the resources that are not required remain as profit in the business.

3.3.1. Similarity between Safety Incidents and Failures

Some consequences of risk will be negligible and perhaps only an inconvenience at worst. Others will be severe, and some catastrophic. Figure 3.7 is the 1931 H.W. Heinrich ‘theoretic accident pyramid’ that highlights for every serious injury there are many minor incidents preceding it. The pyramid is used to explain that if there are sufficient numbers of incidents then probability implies that at some stage one will progress to being a serious injury.

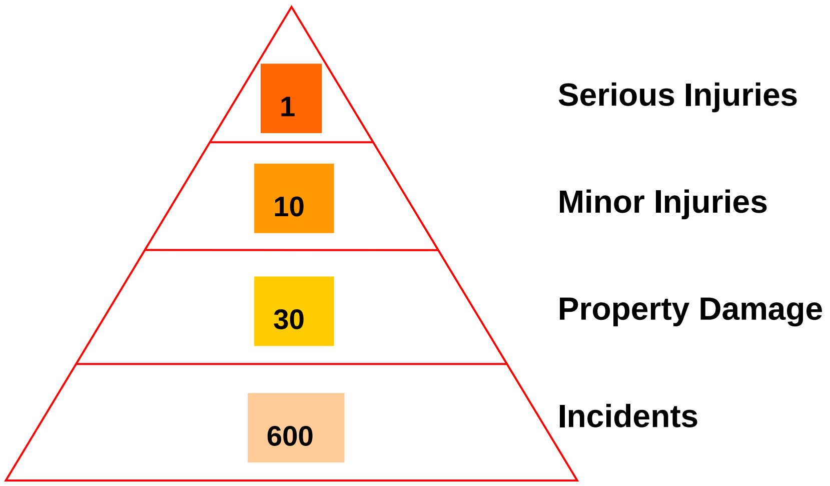


Figure 3.7 The Heinrich Accident Pyramid

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

There is equivalent data for the number of error incidents before there is a serious failure, and the concept of a failure pyramid with many small errors below the ever increasingly greater consequence levels above also applies[7]. Figure 3.8 is a simple representation.

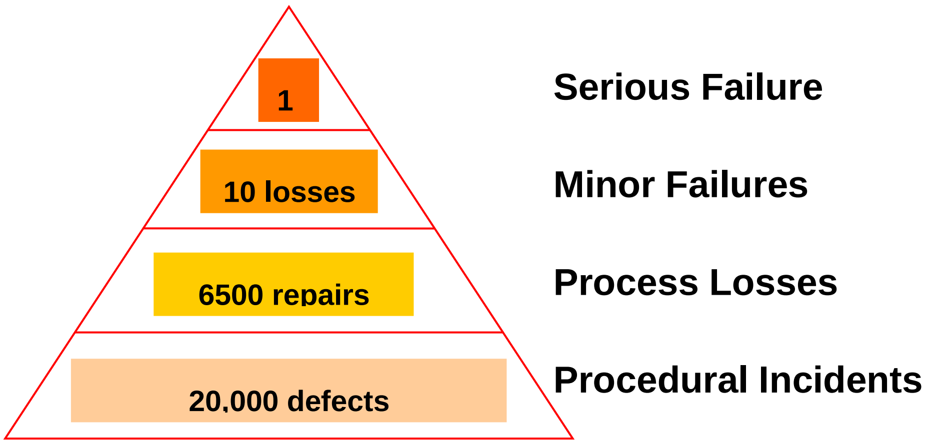


Figure 3.8 The Failure Pyramid

As with the accident pyramid the failure pyramid is expected to reflect a power law, which means that catastrophic failures will not be prevented by stopping minor failures. Catastrophic loss is not controllable unless the 'decision making elements' in a system are controlled. What the failure pyramid tells us is that, like minor injuries, minor failures can be reduced by preventing the numerous and ever-occurring small errors that precede them. But catastrophic failures can only be addressed by imagining the worst outcomes and actively putting into place necessary measures to prevent them from happening.

Example 3.1 When Gaps in Protection Systems Align –The Titanic Disaster

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

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

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

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

Failure incidents are prevented by providing numerous layers of various means of protection and by ensuring that each requirement for that layer of protection is followed to the letter. A good rule of thumb is to have a minimum of three independent, unconnected layers of protection in place everywhere. For example in a production environment start with well-documented, accuracy-controlled procedures, then add thorough training and retraining and finally a comprehensive testing and audit process of workplace practices. A second example is a capital project to increase plant capacity. Start the design with detailed and clear operational, equipment reliability and financial performance requirements written by the ‘customer’, during the design phase test and prove the proposals will deliver all requirements by prototyping, modelling or third-party review, the third layer is to conduct thorough and comprehensive reliability, availability, maintainability, safety and profitability studies and reviews with the ‘customers’ involvement before purchasing plant and equipment. Those organisations that do not have multiple ways to prevent a failure or problem occurring, or do not demand and enforce the proper and full adherence to installed risk management practices, will always suffer numerous losses, high costs and waste.

3.4. A Better Way to Use the Risk Equation

The risk equation requires its users to know the chance and the consequence before a risk can be determined. The cost consequence is calculated by logically following the financial impact of the incident and tallying the costs using DAFT Costing. In an example of a vehicle accident the costs of the accident can be determined by pricing a range of possible accident outcomes. The accident could be a dent or it could be as severe as the total destruction of the vehicle. There may also be injuries to be priced. Estimating the financial consequences of an incident for use in the risk equation can be done quite comprehensively for the complete range of severities with DAFT Costing.

What is not easy to determine is the ‘chance’ factor. Because an incident requires several permitting causes to occur at once, and each has its own degree of change, then the probability of all factors coming together is an estimate, a guess. There are few businesses that want to operate on guess-work as their strategy for being profitable. Typically a business then looks at the history of an incident and uses recorded evidence to determine a frequency. Alternately industry data is used if it is available and it is reflective of the situation under consideration. Where there is insufficient or no historic data available for an incident, then laboratory and controlled trails and tests can be conducted to estimate the conditions for a failure incident to occur. With the test data an engineering and scientific analysis and review is conducted to estimate a 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. For those loss incidents that hardly-ever happen or happen infrequently the estimated risk cost could be terribly wrong. The situation is further complicated by the fact that as soon as the chance of the incident happening is altered by unknown events, remember the ‘decision-making agents’ in power law systems, then the frequency figure is unwittingly wrong. It requires only one change to the factors needed for an incident to occur and the event frequency is completely altered.

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 its full value.

Recall that the risk equation is written as:

Risk = Chance x Consequence

By simple mathematical manipulation it can also be written as:

Chance = Risk ÷ Consequence *Eq. 3.4*

With the equation written in this form we are in total 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. If we have a risk where the 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 re-formatted the risk equation as shown below to identify the frequency we are prepared to accept.

Chance = Risk ÷ Consequence
Chance = $10,000 per year ÷ $100,000 per event
= 0.1 events per year *(Once in ten years)*

The answer tells us that if we only want the event to happen once a decade we must put into place the necessary practices and methods to ensure the event only happens once in ten years. This frequency is no longer guesswork. This frequency is what you want to have happen. This approach permits risk suitable strategies and plans to be developed and actioned that deliver the 'chance' you want. Resources and money can be devoted to accomplishing it with far greater certainty it will be achieved. It is a better way to use the risk equation than hoping an estimate for frequency is close to being right and wondering if current business systems and practices will provide that level of protection. A second benefit of the alternate way to use the risk equation is in knowing how much to pay for risk control. For an event that costs $100,000 must happen no more than once in ten years you can afford to pay up to $10,000 a year to prevent it. If it costs more than $10,000 annually to prevent the once-in-a-decade risk it is necessary to identify and address the causes of the higher annual cost. If the annual cost of mitigating the risk cannot be reduced, while still retaining the once-in-a-decade chance requirement, then the consequential costs are higher than originally estimated and the risk is greater than envisioned. As a risk rises more money can be justified in reducing the likelihood, or frequency, of its occurrence.

The real benefit of risk management to a business arises when it can get the once-in-ten-years chance for less than $10,000 a year. The money you do not spend remains in the bank and the risk is still managed down to what it must be. The opportunity for business in managing risk for less cost is to identify those methods, systems and practices that reduce the chance of risk arising and implementing them with great energy and vigour across the organisation. Chance reduction risk control strategies fit the bill perfectly.

3.5. Making Risk Based Decisions

Risk is a financial measure of exposure to unwanted probabilistic loss events[8]. It is shown as an annualised cost by using Equation 3.1, which is repeated below.

$$\text{Risk (\$/yr)} = \text{Chance or Frequency of Loss Event (/Yr)} \times \text{Consequences of Loss Event (\$)} \qquad \textit{Eq. 3.1}$$

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 cost of its consequences have ominous implications to a business. In situations involving risk it becomes necessary to identify the scenarios that may happen and estimate individual cost and their probability of occurring.

DAFT Cost can be immediately applied to calculate the full consequential costs of an event. Should the consequential costs be too high, even though the real frequency may not be known, additional protection measures that cut the chance of occurrence are included into the scenario to reduce the possible frequency. By first identifying the cost of failure our risk adverse natures prompt us to take wise precautions when the cost of being wrong is too extreme. Even if the frequency of occurrence can be determined on the day, the nature of risk, with its independent actors all playing unscripted parts, means frequency will not stay the be in future. This implies that basing risky decisions on things staying the same over long periods of time is fraught with danger, as it is highly unlikely that frequency remains unchanged because factors totally unknown and unknowable to the decision maker are forever altering the possibility of things happening. The only certainty with risk is the cost of failure; all else changes with changing circumstances. Controlling risk demands that all the circumstances impacting a risk decision are controlled exactly as envisaged at the time the decision was made. Unless an organisation has the culture and practices to provide a matching level of control, and guarantee its rigorous compliance, the chance of failure will rise over time and eventually the failure will happen.

4. The Accuracy Controlled Enterprise

So far our discussions have been on the variations in all processes and contemplating the sobering disastrous financial effect of the great 60 ‘hidden’ costs of risk and failure. When variation and risk play together businesses tumble, production shuts down, planes fall from the sky. Are we doomed to play a game of chance every time we go to work? Is hope against variation, and luck in risky games, the only tools available to control business outcomes? Unfortunately, for more rather than fewer businesses, that is the case. Process complexity and uncontrolled interaction allows variation and risk to thrive inside their walls. More processes in a business, and the more steps and actions in a process, provide rising power law opportunity for ruin of one type or another.

It was to combat ever-present variation and risk in business and its processes, those quality management systems were developed. Systems such as ISO9001, Six Sigma and the Toyota Production System were created and cultivated to stop variation and reduce risk in every activity done in an organisation, from the shopfloor to the corporate boardroom. But the word ‘quality’ in quality management systems is a misnomer, a warped-lens confusing vision, because ‘quality’ is a concept far too great to envision and explain with one word alone. Hardly anyone ‘gets’ what quality is all about. Of the million companies in the world with ISO9001 certification at the turn of the Twenty-first Century[1], few comments can be observed in newspapers claiming its great worth to any new booming business success. Quality management’s panacea offered to manage business risk seems a wasted effort. Still, the powerful potential of a truly functioning quality management system is easily seen in the market and financial success of companies like Motorola and Toyota. Their good fortunes, following the introduction of quality management systems, screams to the business world that there really ‘is something’ in quality management.

Engendering quality into the use and care of plant and equipment is difficult because ‘quality’ requires so much to be done and to get right in a business’ operations. A quality management system provides control through complying with documented processes. In an operations context that requires overheads for planning production and maintenance, management of resources and equipment, providing continual training and for the analysis of data to identify problems and discover how to solve them. Few operations groups can afford the men and the money to do those tasks as well as they need to be done to get the great worth they can provide. Instead, many operations departments ‘fly be the seat of their pants’. They just want to get the job done, whatever it takes, and get home. But there is one word that fully explains what is needed, whether on the shopfloor or in the boardroom, to gain nearly all the benefits of a quality management system without having to implement and then live under the demands of a quality management system.

The word is 'accuracy'. By being accurate variation is controlled through narrowing its span of outcomes. By being accurate risk is controlled through chance reduction, the best of risk management strategies . No longer is there a need to have a quality management system as the only way to improve product quality. For operations groups, manufacturing groups, process plants and production plants, there is a simpler to understand, easier to implement methodology to minimise risk, control variation and slash their enterprise-wide cost impacts – the Accuracy Controlled Enterprise. The focus in an ACE is not the big-picture product-perfect view of quality. It is just about doing a job, any job, every job, your job, very, very, very well by being everywhere accurate and proving it is before continuing to the next step.

4.1. Plant and Equipment Defects, Failures and Errors

Highly reliable production equipment running at 100% design capacity should be normal and natural. Plant and equipment is procured with the intention that it work reliably at full capacity. Its maintenance is intended to sustain the specified design reliability. Its operation should be as the designer anticipated, and the designer wants reliable 100%-rate production. If under operation equipment performance is not as designed then something systematic is amiss or there are uncontrolled external agents at work. The challenge is to identify what variability is preventing the equipment from delivering the performance it was meant to have and act firmly to stabilise the situation.

Highly reliable equipment is necessary to reduce production costs and maximise throughput. High reliability from operating equipment requires high quality manufacture and maintenance, coupled with the correct operating practices which together deliver the necessary controlled conditions that produce high reliability. When designers make the right choices, and maintenance people do their work accurately to design specification, and operators run equipment as intended by the designer, they can get equipment working so well that it becomes superbly reliable. There is no need to have stoppages to do unwanted repairs if the equipment design is right for the service, it is built accurately, and run accurately Accuracy is defined as "the degree of conformity of a measured or calculated value to its actual or specified value." To be accurate requires a target value and a tolerance of what is acceptably close to the target to be called accurate.

Often the fault for poor equipment reliability lies with the design itself. It can be that the wrong material is selected for the job. Either it is not strong enough for the stresses induced in it or it is incompatible with materials coming in contact with it. Once a design problem is identified the necessary change is made to enable the equipment reliability to rise to the design intent. More often the reason equipment does not meet its designed reliability is because it is installed wrongly, it is built or rebuilt poorly and it is operated not as designed. Usually this happens because people involved in its installation, care and running do not know the right ways. Though most operators and maintainers have some recognised training it can never be enough to competently handle all situations. In those situations where they have not been trained they are forced to use what knowledge they do know to make a decision. If it's the wrong choice and no one corrects them, it becomes the way they solve that problem again in future.

Unfortunately many decisions of this type do not have an immediate bad impact and hence new defects and future failures are introduced into the operation. If there was immediate bad impact it would be good, because the worker would instantly self-correct and get it right. But no, most errors of choice or ignorance do not impact until well into the future. The chosen action was taken and nothing bad occurred. Which meant the operator or tradesman and their supervisor thought it was the right decision, since things still ran fine. This is how bad practices become set-in-place in an operation.

There is nothing wrong with making a wrong decision. Provided it is corrected immediately and nothing bad happens, there was no harm done. Bad things happen when bad decisions are allowed to progress through time to their natural and final sad conclusion. Regrettably there are very few decisions that have instant replay options. If it is important in your company to have low maintenance cost and highly-reliable production equipment then the internal work systems must support that outcome. All work done by operators, maintainers, engineers and managers need to be right the first time.

4.2. Why We Have Standard Operating Procedures

Companies have long recognised that if you want consistent, reproducible, correct results from the workforce they need to work to a proven and endorsed job procedure. A job or operating procedure is a systematic approach to a task that provides clear guidance, sets the required standard and stops variations in work performance. Variability in processes leads to defects and failures.

Variations in work performance arise because human skills, talents and abilities are typically normally distributed. If we were to gauge the abilities of a wide cross-section of humanity to do a task, we would end up with a normal distribution bell curve. Secondary and tertiary learning institutions are well aware that student results follow a normal distribution curve and scale class grades accordingly. A normal distribution bell curve, or Gaussian curve, of a talent in a large human population is shown in Figure 4.1.

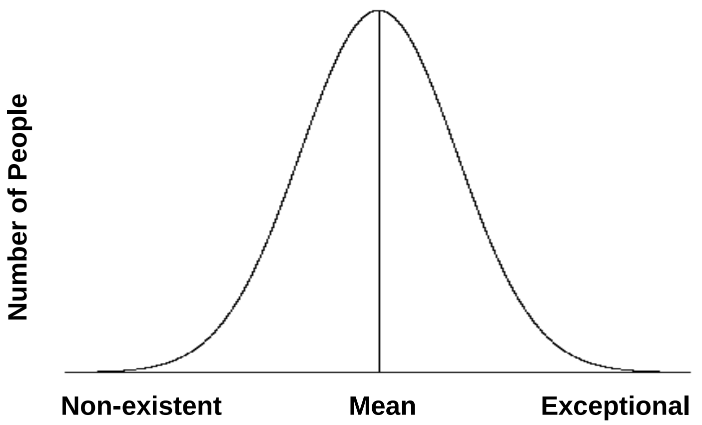


Figure 4.1 Distribution of a Talent in the Human Population

The implication of such a distribution is that for most human skills and talents there are a few exceptionally able people, a few with astoundingly poor ability and lots of people in-between clustered around the middle or mean. If a workplace requires highly able people to make its products and do the maintenance, then from the distribution curve of human talent it will be hard to get many people who are naturally exceptionally good. The ones you do get will cost a lot of money because they are the elite in the industry. Standard operating procedures were created to use people from the around the middle and below ability levels to do higher standard work than they naturally could do unassisted.

The talent distribution curve also explains why the continual training of the workforce is so important to a company's long term success. If the available labour pool is clustered around the mean performance level of a skill, then a good way to improve the population's ability to do the skill is to teach them how to do it better. Training has the effect of moving average performers toward the elite portion of the population as shown in Figure 4.2.

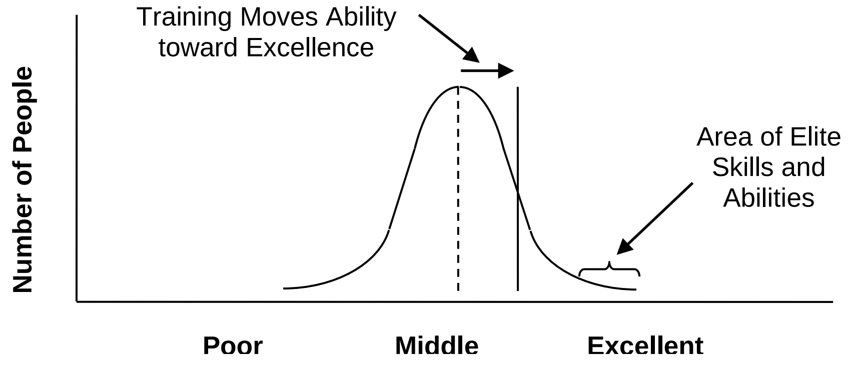


Figure 4.2 The Effect of Training on Developing a Talent

4.2.1. The Cost of Poorly Written Standard Operating Procedures

Since standard operating procedures (SOPs) control the quality of the work performed by people not expert in a task, they are clearly absolutely critical to the proper running of a business. It is also critically important that they are written in ways to promote maximum efficiency (make use of the least resources) and effectiveness (done in the fastest correct way).

Workplace experience indicates that very few companies use SOPs to control production outcomes. When they are available they are not self-checking and do not promote good practice. Usually they record what to do in a task. The better SOPs also explain how to do the task. But most SOPs offer little practical assistance to the user in controlling product quality or the quality of their performance in doing the task. Typically they are glanced over when operators and maintainers start a new job and then thrown to the back of the shelf to never be seen again. That is a pity because they are one of the most powerful learning tools ever developed for use in the workplace.

Of the companies that have SOPs, most were written by an expert in the job. They wrote the procedure already knowing all the answers. So tasks were described with words and statements that assumed prior knowledge. You will often see in SOPs statements such as - “Inspect lights, check switch, check fuse, and test circuit”. And “Inspect steering wheel linkage”. Or in the case of a machine operator - “Test the vehicle and report its condition”. The problem with the use of procedures containing such descriptions is that you must first be an expert to know whether there is anything wrong with what you are looking at. Procedures without the full, correct details require hiring trained and qualified people in order to do what may be a very simple job.

4.2.2. The Best SOPs Can Be Done By the Least Skilled People

Great SOPs are those that ensure work and workmanship quality but do not necessarily need only qualified people to do them. They are written with more detail and guidance and include a target to hit, a tolerance on accuracy and regular proof-tests of compliance so that job quality is guaranteed. In this way defects are prevented from arising and future failures are prevented.

Standard operating procedures can be made into a quality and accuracy control device which has the power to deliver a specific level of excellence every time they are used. Few companies understand the true power of an SOP. Typically they are written because the company's quality system demands it. People mistakenly write them as fast as they can, with the least details and content necessary to get the document approved. In reality SOPs should be written to save organisations time, money, people and effort because if written to their full potential they can make plant and equipment outstandingly reliable by ensuring the elimination of defects which cause stoppages and so boost productivity. For a standard operating procedure to have powerful positive effects on a company and its people it needs clear and precise targets, tolerances and teas measures, which if faithfully met, will produce the required quality to deliver the designed equipment performance. Great production plant reliability and production performance will naturally follow when work is done accurately by using the 3Ts – target, tolerance test - in SOPs.

If we take the "Inspect steering wheel linkage" example from above and apply the 'target, tolerance, proof -test' method, a resulting description might be:

"With a sharp, pointed scribe mark a straight line directly in-line on both shafts of the linkage as shown in the accompanying drawing/photo (A drawing or photo would be provided. If necessary you also describe how to mark a straight scribe mark in-line on both shafts). Grab both sides of the steering linkage and firmly twist in opposite directions. Observe the scribe marks as you twist. If they go out of alignment more than the thickness of the scribe mark replace the linkage (a sketch would be included showing when the movement is out of tolerance)." The procedure would then continue to list and specify any other necessary tests and resulting repairs.

With such detail provided it is no longer necessary to have highly qualified persons to do the inspection. Anyone with mechanical aptitude can do a reliable inspection. This method of writing procedures is the same as used by writers of motor car manuals for novice car mechanics. Car manuals are full of procedures containing highly detailed descriptions and plentiful descriptive images. With them in-hand novice car mechanics can do a lot of their own maintenance with certainty of job quality. The very same logic and method used to write car manuals also applies to industrial production and maintenance procedures. If procedures contain all the information and measures that is necessary to rebuild an item of equipment, or to run a piece of plant accurately, it is not necessary to employ people from the exceptional end of the population to do the job well.

Improving the accuracy in doing a task is achieved through using well-formulated, clearly understood standard operating procedures (SOPs) that contain targets to hit, tolerances for acceptable closeness to the target and tests to prove the work was done to the required accuracy. When you discover high cost consequences that require high cost solutions, the first thing to do is introduce improved SOPs and failure-proof methods to control the work variability and failure risk in order to immediately diminish the consequences. The inclusion of ‘target, tolerance, test’, the ‘3Ts of defect elimination’, in all procedural tasks is the first rule of failure prevention.

4.3. Train and Retrain Your People to Your Standard Operating Procedures

Having a procedure full of best content and excellent explanations for your workforce is not by itself enough to guarantee accuracy. How can you be sure that people comprehend what they read? Many tradesmen and plant operators are not literate in English, nor do they understand the true meaning of all the terms used in a procedure. To be sure your people know what to do and can do it right, they need to be trained in the procedure and be tested. Training is needed before they do the task alone, without supervision, and later they need regular refresher and reinforcement training. The amount and extent of training varies depending on the frequency a procedure is done, the skill level of the persons involved and their past practical experience in successfully doing the work.

Procedures done annually or more often by the same people will not need retraining. Because people forget, those procedures on longer cycles than annually will need refreshment training before they are next done. Training and retraining often seems such an unnecessary impost on an organisation. Managers often say “If the work is done by qualified people why do I need to train them? They have already been trained.” The answer to that question is “How many defects, errors and mistakes are you willing to pay for? What risks are you willing to carry in your operation?" If organisational risk management systems use procedures to protect the organisation from risk it is necessary to continually check and prove the protection layer is in place and operating properly. Training, retraining and auditing actual hands-on performance keeps that protective layer whole.

For example, if there is a flange leaks soon after a piece of equipment was rebuilt, it is a sign that you may need to retrain you people in the correct bolting of flanges. Flanges properly rated for the service which are in good condition do not leak if they were done right. When a repair re-occurs too often on perfectly good equipment, it is a signal that the SOP does not contain targets, tolerances and proof-tests or that training is needed to teach people the correct procedure.

4.4. Making Your Organisation an ACE

A classic example of what great value an accuracy-focused SOP can bring is in this story of a forced draft fan bearing failure. The rear roller bearing on the fan involved never lasted more than about two months after a repair. The downtime was an expensive and great inconvenience. To take it out of the realm of a breakdown, the bearing was replaced every six weeks as planned maintenance. The bearing was also put on vibration analysis condition monitoring observation. After several replacements enough vibration data was collected to diagnose a pinched outer bearing race. The rear bearing housing had been machined oval in shape when manufactured and it squeezed the new bearing out-of-round every time it was bolted up.

You could say that vibration analysis was applied wonderfully well. But the truth is the repair procedure failed badly. If there had been a task in the procedure to measure the bolted bearing housing roundness and compare the dimensions to allowable target measurements, it would have been instantly noticed as having an oval-shaped hole at the very first rebuild. There was no need for the bearing to fail after the first time. A badly written procedure had failed the organisation. Whereas an accuracy-controlled procedure with targets, tolerances and proof-tests would have found the problem on the first repair and it would have been fixed permanently.

Existing ISO 9000 or Six Sigma quality procedures can be converted to accuracy-controlled operating procedures with little development cost. The only extra requirement is that they include a target with tolerances and a proof-test in every procedural task to give feedback and confirmation each task is done right as the procedure progresses.

The problem with targets is that they are not easy to hit dead-centre. It is not humanly possible to be exact. If a procedural task states an exact result must be achieved, then it has asked for an unrealistic and virtually impossible outcome. A target must be accompanied with a tolerance range within which a result is acceptable. There must be upper and lower limits on the required result.

Even the bulls-eye in an archery target is not a dot; it is a circle with a sizable diameter. You can see the bulls-eye in Figure 5.3 is not a pin prick in size. Anywhere within the bulls-eye gets full marks. The target for each task in an accuracy-controlled procedure must have a tolerance.

Figure 5.3 Targets Have Tolerances

A well written accuracy-controlled procedure contains clear individual tasks; each task has a measurable result observable by the user and a range within which the result is acceptable. If this is done with every procedure accuracy control and defect elimination becomes built into the job. With each new task only allowed to start once the previous one is within target, it is possible to guarantee a top quality result when the procedure is followed as written. With targets set in the procedure, its user is obliged to perform the work so that they hit the required target. Having a target and tolerance forces the user to become significantly more accurate than without them. When all the task targets are hit accurately, then the procedure is done accurately and excellent work results.

Once a procedure always delivers its intended purpose you have developed a failure control system. No longer will unexpected events happen when work is performed accurately to the requirements of the procedure. Procedures need in-built accuracy to prevent failure and stop the introduction of defects. To ensure each task is correctly completed the worker is given a measurable target and tolerance to work to. The procedure is done correctly when its individual tasks are all done to within their target limits. Using this methodology in standard operation procedures makes them quality control and training documents of outstandingly high value and accuracy.

The organisations that use sound failure control and defect prevention systems based on proof-tested, accurate work, move from being a quality conscious organisation to being an accuracy-controlled enterprise; an ACE organisation. With that level of accuracy in maintenance, operation and engineering tasks getting outstanding equipment reliability and consistently high production performance becomes normal.

4.5. The Value of Precision

The need for precision and accuracy dominate those industries that use machinery and equipment. It is the single most critical requirement for successful operating performance in manufacturing, processing, transport, shipping, in fact all industries that use machinery. These industries require that their equipment run reliably (no failures or unplanned stoppages) with high availabilities (ready for immediate use) and high utilization (continuously in use) all their working life.

Outstanding reliability, availability and utilization are achieved by being precise and accurate in equipment assembly and use. Precision and accuracy in equipment design, construction, operation and maintenance is sure way to achieve a lifetime of high equipment performance and service with low operating costs. But it does require patience and a dedication to applying simple and practical methods for its achievement.

Man-made equipment and machinery only work well for a long time when they are built and run precisely. Precision means meeting specified standards to within allowed tolerances. Precision requires that the specific standards needed for high reliability are set and continually achieved during design, manufacture, assembly, operation and maintenance. Precision is only achieved by controlling accuracy. Man-made machinery must be built and operated accurately to run reliably. Accuracy is the lifeblood of equipment reliability.

An example of precision is the alignment between two rotating shafts shown in Figure 5.4. If two shafts are meant to be in-line, but they are actually off-set to each other, they will run out-of-true. When these shafts turn they will tear each other apart and cause massive forces to be loaded onto their bearings and coupling. Eventually the bearings, coupling or shafts will be destroyed because of the inaccuracy in their alignment.

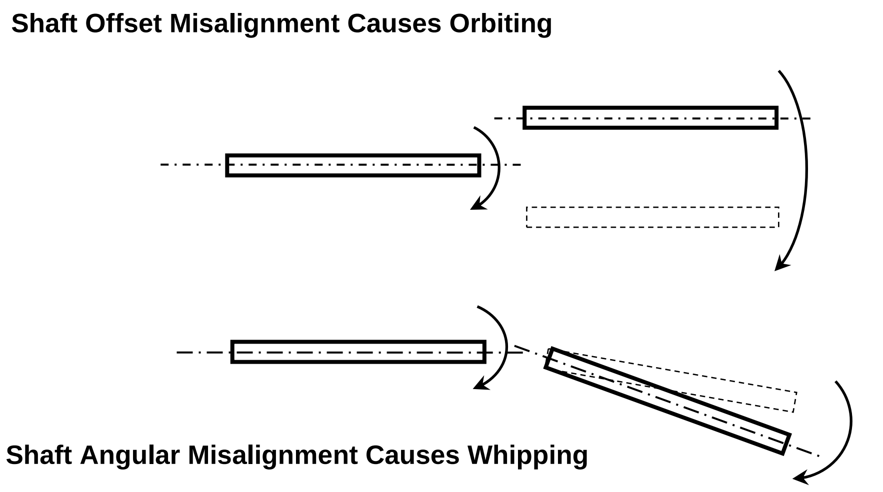


Figure 5.4 Inaccurately Aligned Shafts Destroy Machinery

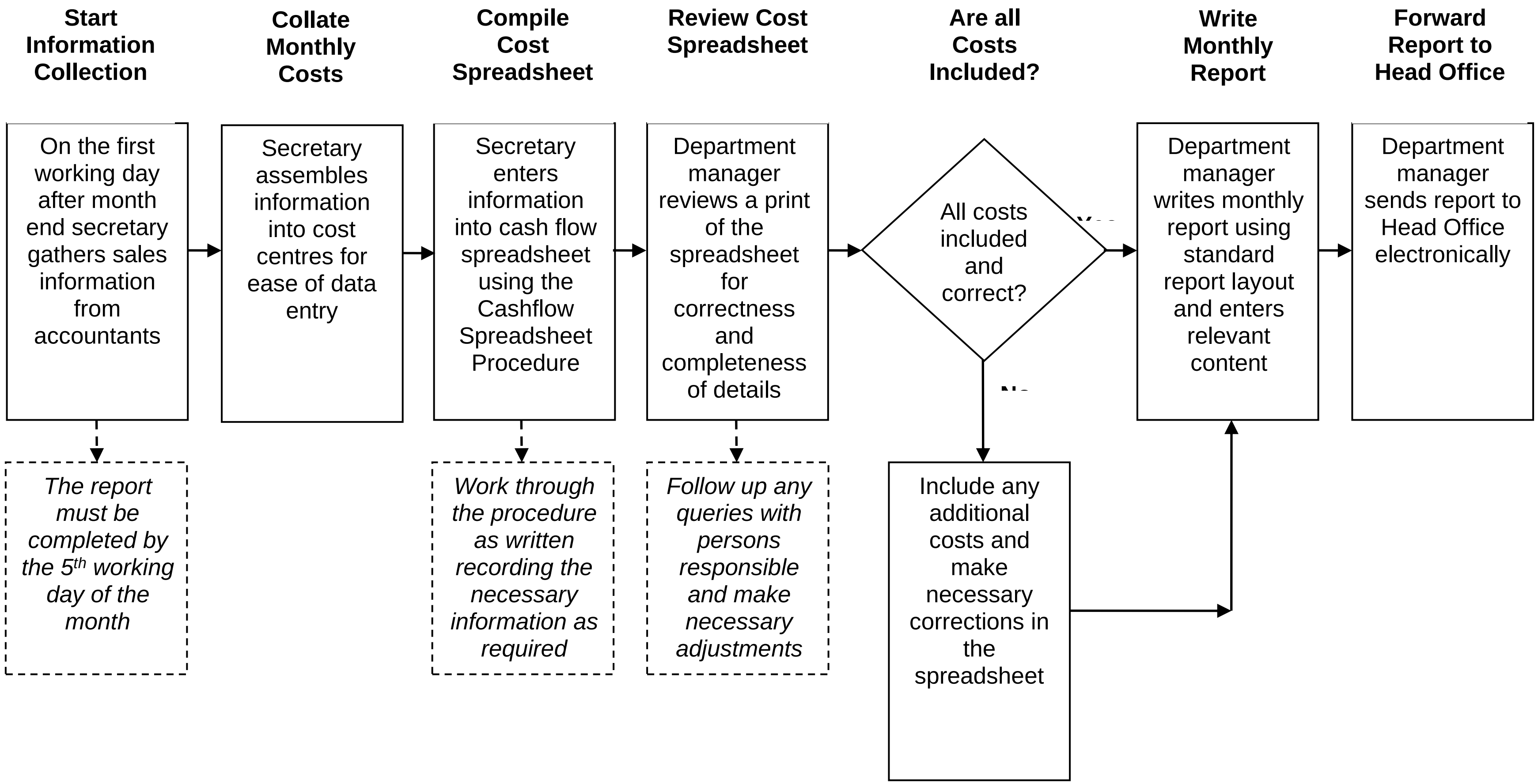
Two shafts in-line must be aligned with sufficient accuracy that will ensure they run without destructive forces being created. When an accuracy standard is set (another name for it is a quality standard) a requirement is established which must be confirmed by measurement. For example an alignment standard for the two shafts in Figure 5.4 is to require their axes to be aligned to within 0.05 mm (0.002") from the far end of one to the far end of the other. The standard specifies how accurate they need to be to meet engineering design requirements. With that information the positions of the shafts can be measured and adjusted until they achieve the stated precision. Introducing accuracy into workplace methods ensures the precision which prevents defects and translates into highly reliable operation with outstanding equipment availability and performance.

The precision principle applies to all operations and business processes. To control a process and to control variations introduce standards and tolerances with measures for how close the process must meet those standards. Set standards for every stage of the process and measure how accurately the operation meets the standards at that point. If the process is controlled to appropriate standards throughout its performance the necessary product quality and throughput specified is automatically delivered. By being everywhere precise you get the end result required. This principle is a sure way to guarantee successful performance. Simply develop appropriate standards with specific targets and tolerances and make sure the real results are regularly measured and compared to the standard. People in charge of the equipment and operation can then adjust their performance, and that of the equipment and process, in a controlled fashion to meet the required accuracy. The standards are the key performance indicators for the process and are used to monitor its quality.

Example 5.1: An Accuracy Controlled Procedure

Accuracy controlled procedures are simple for users but have demanding requirements for writers. Procedure writing starts with drawing a flow map of the business process steps in which the procedure applies and identifying the particular step in the process covered by the procedure. By making it clear where the procedure is used in the business the user identifies its purpose, the people affected by their work and the necessity of it being done thoroughly and correctly. This establishes the right mindset in the user to want to do excellent work in a timely fashion.

Department Monthly Cost Report Procedure



The flow chart is laid out in landscape orientation and formatted as shown in the example for specific reasons. The left to right flow is in keeping with the Western text writing direction and makes the process easy to read. Each process step box is given a brief descriptor and by reading the descriptors across the page the substance of the procedure is quickly understood. Drop boxes can be used below each process step box for added information and explanation. The left to right layout makes it easy to conduct value stream mapping and value contribution mapping in future since the process is drawn across the page as is required for value stream mapping and value contribution mapping.

An accuracy controlled procedure incorporates the 3Ts of defect elimination – target, tolerance, test – in each procedural task to provide accuracy control and allow users to clearly identify the requirements they need to meet and check for themselves that they have met each requirement before going to the next task. Every step in the task is explained in simple detail using both words and images wherever possible. Where the information comes from, where it goes to, and the form it must take is defined and explained in the SOP.

Sales Spreadsheet Procedure

This procedure explains in detail how to create the department's monthly sales summary spreadsheet. The department manager and the cost accountants use this spreadsheet to make their monthly business performance reports. Any errors in the spreadsheet will flow through to the monthly report presented to head office.

This procedure is our current best practice and you should follow it exactly. It is the result of many people's efforts over many years. It is the quickest, best way yet found to do the job. You are encouraged to learn the job exactly as it is explained in this document. If after you have mastered this procedure exactly as it is written, you believe that you know of improvements that can be made, please bring them forward for discussion. You will be allowed to test you ideas and compare them to the procedure. If your suggestion proves to be better, it will become the new way in which this job will be done.

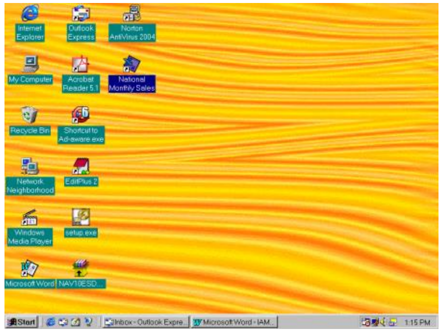
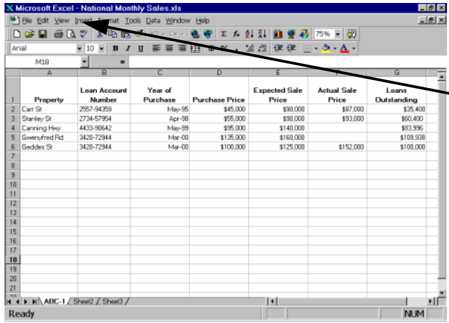
Necessary Equipment and Tools

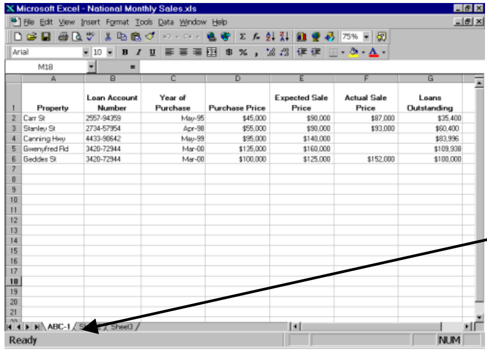
Computer, National Monthly Sales computer file, National Monthly Sales hardcopy file

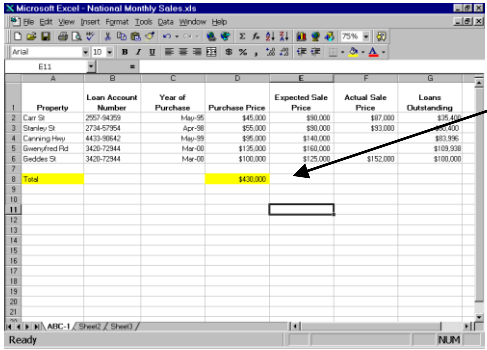
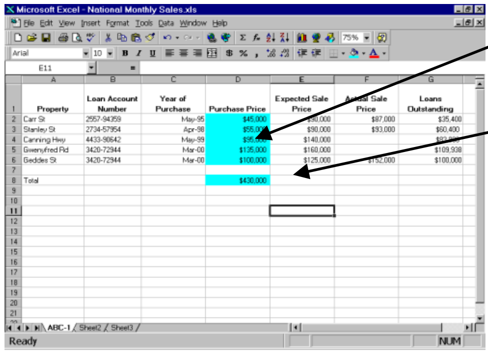
Task Summary

The process of developing the spreadsheet is listed in summary form below. A fully detailed procedure is presented beneath the list. If an issue arises that you cannot solve please see your supervisor.

1. Find spreadsheet
2. Bring up spreadsheet
3. Select work sheet
4. Get hardcopy folder
5. Return with hardcopy
6. Record monthly total
7. Cross check totals
8. Totals don't agree
9. No spread-sheet error
10. Hardcopy checked
11. Update spreadsheet
12. Totals agree

Task Step No.	Task Step Owner	Task Step Name	Full Description of Task	Test for Correctness	Record Actual Result	Initial After Complete
1.	Office clerk	Find spread-sheet	Find the shortcut on the screen called 'National Monthly Sales'. 	See the icon called 'National Monthly Sales'.		
2.	Office clerk	Bring up spread-sheet	Make spreadsheet 'ABC' active on computer by 'double-clicking' the icon. 	Note the name on the spreadsheet is 'National Monthly Sales'.	*(Place spreadsheet name here.)*	

<table>
<tr><td>3.</td><td>Office clerk</td><td>Select work-sheet</td><td>Bring up the worksheet called ‘ABC-1’ to use.

</td><td>See the name on the SOP and actual worksheet is ‘ABC-1’.</td><td>(Place worksheet name here.)</td><td></td></tr>
<tr><td>4.</td><td>Office clerk</td><td>Get hardcopy folder</td><td>Get the ‘National Monthly Sales’ folder in the top draw of the National Sales filing cabinet in the Sales Office.</td><td>Read the file name and see it is called ‘National Monthly Sales’</td><td></td><td></td></tr>
<tr><td>5.</td><td>Office clerk</td><td>Return with hardcopy</td><td>Return to your desk and open the folder to the Total National Sales Report.</td><td>See that the page has the title ‘Total National Sales Report’.</td><td></td><td></td></tr>
</table>

6.	Office clerk	Record monthly total	Total the ‘Purchase Price’ column for the month and put into cell ‘D8’. 	Check cell ‘D8’ has the monthly total.	*(Could also record monthly total here.)*	
7.	Office clerk	Cross check totals	Check that the total for ‘Purchase Price’ in the hardcopy folder and the spreadsheet are the same.	Both totals are the same.	*(Record the total.)*	
8.	Office clerk	Totals don’t agree	If the two numbers are not the same check the formula in the spreadsheet matches the cells that it should. 	Check all individual cells are picked up by the formula in the Totals cell.		
9.	Office clerk	No spread-sheet error	If the spreadsheet is correct, the error lies in the hardcopy file. Report the error by telephone to the Manager National Sales.	Ring the National Sales		

				Manager.		
10.	National Sales Manager	Hardcopy checked	Confirm the totals of individual sales are recorded correctly and ring back the correct individual sales figures.	National Sales Managers advises each sales figure.		
11.	Office clerk	Up date spreadsheet	Correct the figures in the spreadsheet with the correct values and confirm the totals are now correct.	Double check the new total against hardcopy file total.	*(Record the correct total.)*	
12.	Office clerk	Totals agree	If the totals in both documents agree the job is complete. Save the spreadsheet, print a copy for the manager to review, close the electronic file and return the hardcopy file to the National Sales Office filing cabinet.	See spreadsheet is saved and file returned.		

4.6. Senior Managers are the Leaders of ACE

An Accuracy Controlled Enterprise is not the same as an enterprise with a quality management system. Quality management imposes control over the people and equipment that affect the quality of a product. ACE is subtly different because it is about imposing control over individual behaviour. From the most senior person to the least, the philosophy requires that people know what an excellent outcome is in every task they do and they strive to achieve it.

An ACE has clear targets, tolerances and tests for senior managers as well as for the shopfloor personnel. In fact the senior managers show leadership by placing the requirements of ACE on themselves first, and only once they show how the 3Ts of defect elimination required by ACE improve their performance do they take it into the organisation. Unlike quality management systems, where senior managers place quality demands on those below them in the organisation and then monitor their performance from above, the Accuracy Controlled Enterprise focuses on individual excellence and allows managers to lead their people in its adoption. The ‘leading from the front’ required for successful ACE adoption is a very powerful symbol of management commitment to improving the organisation.

5. Value Contribution Mapping

Enterprise asset management is as much about the wise use of money as it is about the wise use of engineering, maintenance and operational management to deliver top performance from production equipment and processes. By fully understanding the costs and money flows in a production operation its managers and employees can make timely and good decisions for the well-being of the business, the shareholders, themselves and their community[i].

Value Contribution Mapping is a process real-time accounting diagnostic tool used to monitor the financial health of a process. Instead of waiting for after-the-fact financial reports delivered days after work has been done, Value Contribution Mapping provides the true costs of operating a process in real-time or whenever desired. Value Contribution Mapping provides a snapshot of the money flows in a process. It incorporates real time accounting and cost data about each step in a process and allows identification of opportunities to improve the efficiency and effectiveness of a process step. With all costs identified it becomes clear where there are excesses and waste. Knowing how much money is being made and lost permits focused and targeted process improvement and process re-engineering to minimise waste and losses. The method shows the moneys spent at every individual step in a process to provide real-time performance indication of operations or business process effectiveness and efficiency and is fundamental for rapidly improving business profitability.

A business should be viewed as a system for supplying the customer's requirements effectively and efficiently[1]. A system implies many interrelated parts working together seamlessly in a coordinated effort to provide an important and necessary function. Maximising profit from a business requires both efficiency and effectiveness from the operation. An effective operations process makes and delivers what the customer wants. An efficient operations process delivers the profit wanted by the shareholders. An important job of managers, economists, accountants and engineers is to develop business systems that reliably achieve this seamless operation to the benefit of the organisation, its customers and the community. This requires an on-going commitment to continually improve and tune the organisation to be more efficient and do its functions faster, better and cheaper.

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[i] Recognition given to Asset Management Council of Australia for use of copyright material

Production, processing and manufacturing systems turn raw materials into finished products through a series of steps that progressively convert them into saleable products. Typically the conversion process takes raw materials and adds inputs such as labour, utilities like power and water, specialist services like engineering and maintenance, supplementary materials like boxes for packaging, along with other numerous requirements to make products customers buy. Production process and service operations can be symbolized by a process flow diagram containing a series of boxes for each conversion step in the process, with materials, utilities, services and labour shown by arrows to represent their flow. Figure 5.1 shows such a symbolic production, manufacturing or service process used to convert raw materials to customer-desired products.

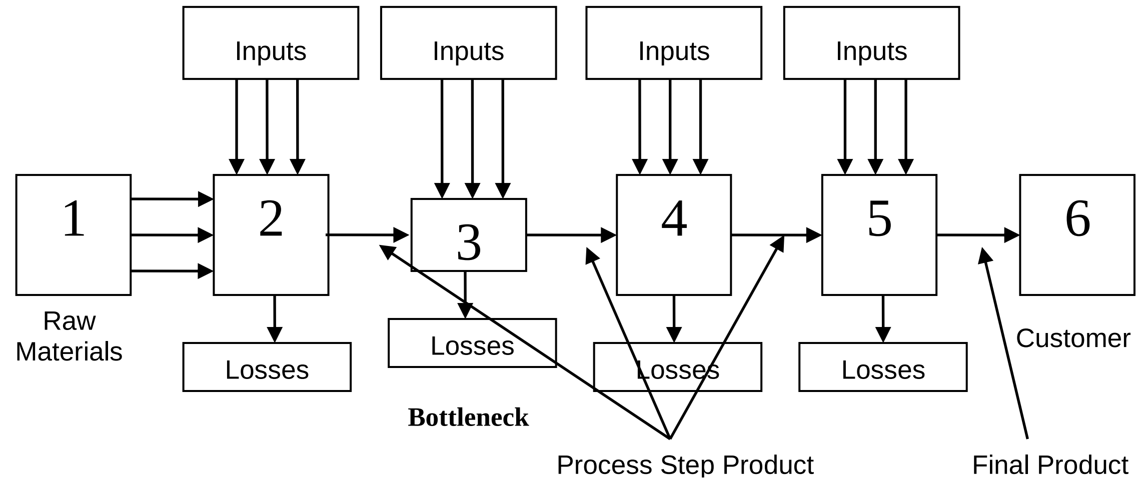

Figure 5.1. A Business Conversion Process

5.1. Properties of Production Processes

In Figure 5.1 raw materials are the direct materials used in the production process. The added inputs include the utilities (power and water) and services (such as boxes for the product, labour man-hours, lubricants for machines, etc) needed to complete the process step. The process steps use these to add value and make the products produced by the organisation. During production the product increases in value equal to the sum of value added in each conversion step. Each value-adding step contributes part of the profit made when the product is sold to the customer. A process step does not produce perfect conversion and some losses occur. Those losses are paid for by the customer and the real value of the product maybe far less than the cost of manufacture.

From Figure 5.1 a few simple properties of a business process can be identified:

i. The process design establishes the process' capability to make the product.
ii. Product quality is determined by the process design.
iii. The bottleneck limits the maximum throughput rate for the process.
iv. The efficiency of operating each process step determines it value contribution.
v. The customer demand rate dictates the manufacturing rate.

A production process should only make what the market will purchase. A production system has inbuilt natural checks and balances that keep a production process in-step with the market for its products. The rate of sale of the product to the customer is naturally controlled by what the customer wants and when they buy. It is important that production does not to make more product than can be sold; otherwise money is tied-up in product and inventory that no one wants.

The amounts of raw materials put into a process are governed by the market demand, the production usage rate and the ability of the business to pay for them. Similarly the added inputs throughout the process are governed by the individual process step needs and the cash flows available to pay for them. Where the customer demand rate is above the process' capacity to make the product, they are brought at the rate that the process can use them and can afford to pay. Market economics and business economics act to regulate and control the production rate. This is the essence of a market-based, capitalist economy – the manufacture of products that people want in production systems that are balanced to the demand.

There is one more issue to consider in a production process - the losses and wastes. The process losses behave differently to anything else in the production process. They are not naturally limited by demand. They are only limited by how much money is available to the production system. Because there are no systematic internal constraints on waste they are actively managed by minimising them during the process design and by managing them to minimal levels during operation.

5.1.1. Bottomless Pits of Losses and Waste

Usually not considered seriously important in business process design are the amounts of losses produced – the wastes. Standard accounting and cost accounting systems do not measure them. The wastes include the obvious waste product and scrap materials commonly associated with production waste. But there are many other types of waste produced. All wastes take money from the profits that could have been made. Other wastes, which are numerous and common but not often noticed, include such things as excess movement, lost heat, lost water, lost energy, excess storage space, excess in-process inventory, excess time, lost time, quality defects, excess forklift pallet hire, excess equipment hire, safety incidents, environmental incidents, excess paperwork, excess manning, and many, many more. Figure 5.2 shows the same process as before and includes all the wastes from the business and production process.

Some of these wastes are identifiable by using value stream mapping analysis, typically time and distance, but their lost cost is not priced using that technique. In order to recognise the cost impact of waste it is necessary to identify the real financial impacts of them on a business through the use of Value Contribution Mapping.

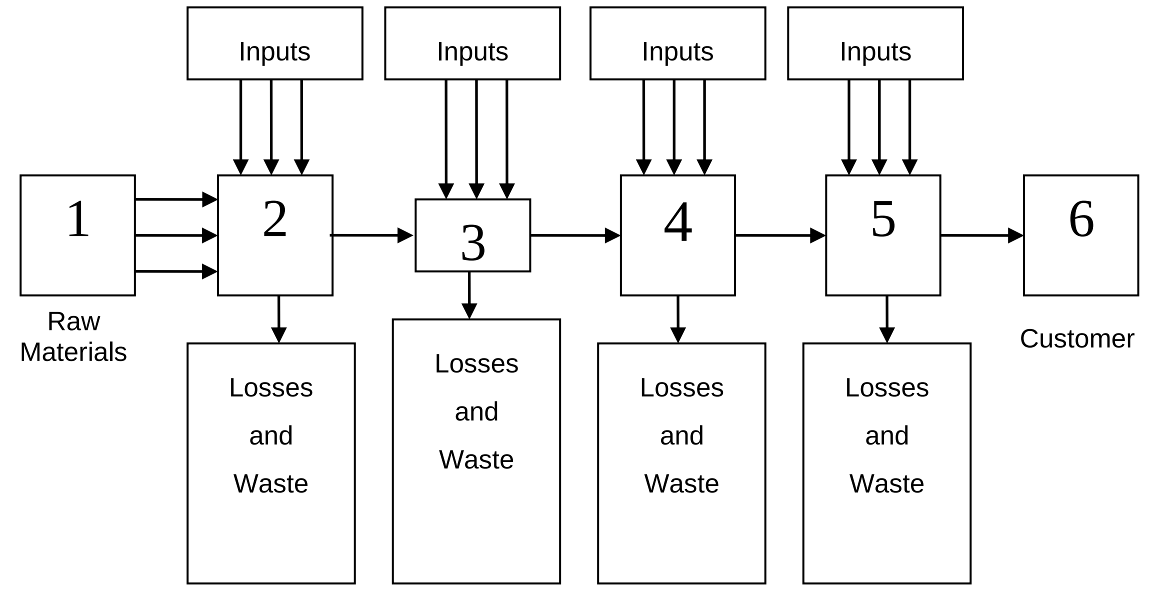

Figure 5.2. Losses and Wastes in a Production Process

The only natural means of waste control for a production system is how much money can be spent on raw materials and added inputs. Since creating waste has no natural means of self-control beyond bankrupting the business, it becomes necessary to develop business control systems that monitor the waste and force its minimisation and eventual total elimination.

There are now two other properties of a process that was not clearly evident before:

vi. Wastes extract effort and profits from a process.
vii. The process can turn raw materials and inputs into waste so that the process makes waste

instead of profit, to the point where waste consumes all the profits.

Based on these seven properties of business processes, a production process can be interrogated to understand how money behaves within it and to identify the costs and wastes that reduce its performance and profit. This analysis process is called Value Contribution Mapping (VCM). Value Contribution Mapping spots all wastes and identifies the financial value lost to the business in order to justify and encourage their rapid elimination.

Once a process is operating, people’s concerns naturally turn to making the product on time. What most people forget to do is to also make it efficiently, while they are meeting the customer’s requirements. The demand to make product on-time often overrides the need to make it cost effectively. This leads to the situation in business where everyone is busy making product, but no one is busy making profit. If this situation occurs in an organisation, the creation of waste instead of profit dramatically rises. VCM is a better way to help manager and engineers collect the cost information needed to operate a production system efficiently and effectively.

5.2. Identifying Value Contribution

Figure 5.1 indicated that there are discrete steps in make a product and delivering a service. Each step has its own raw materials, which is the feed from the prior process step. It has its own added inputs needed to make the conversion. From each step come a ‘product’ and the wastes. Each process step is clearly identifiable from its predecessor and its successor and is self-contained in performing its conversion.

Since each process step is independent of the others it can be taken in isolation and viewed as a whole system in itself. This allows analysis of the process step separately. To make it clear which process step is being reviewed draw a boundary around it on the process flow diagram. An example of segregating a process step for analysis is shown in Figure 5.3.

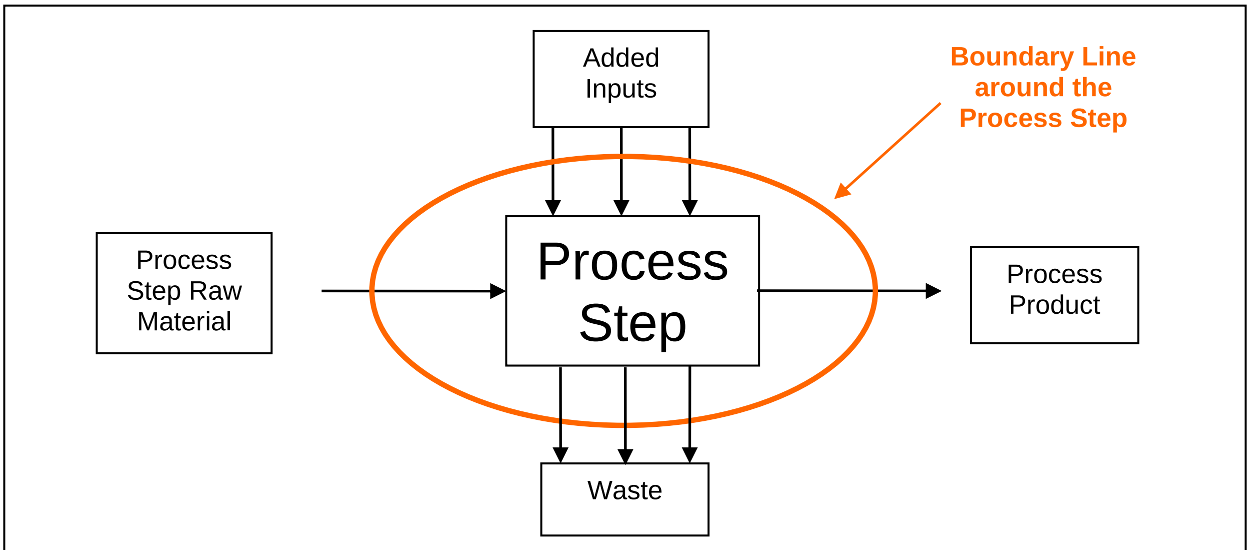

Figure 5.3. Local Process Step Analysis

To determine process effectiveness and efficiency we need a measure. A good measure to use in business is money. Money is the universal language of commerce and most people understand the concept of using money to value an item or service. By using money to measure process product cost, added input cost, cost of wastes and the cost impact from a process step, we can trend the process costs step by step as the product is made. Figure 5.4 indicates the various money flows, both in and out of a production process. By analysing each process step, the true costs of the raw materials, the additional inputs, the wastes from it and the resulting total process step cost contribution to the final product can be determined.

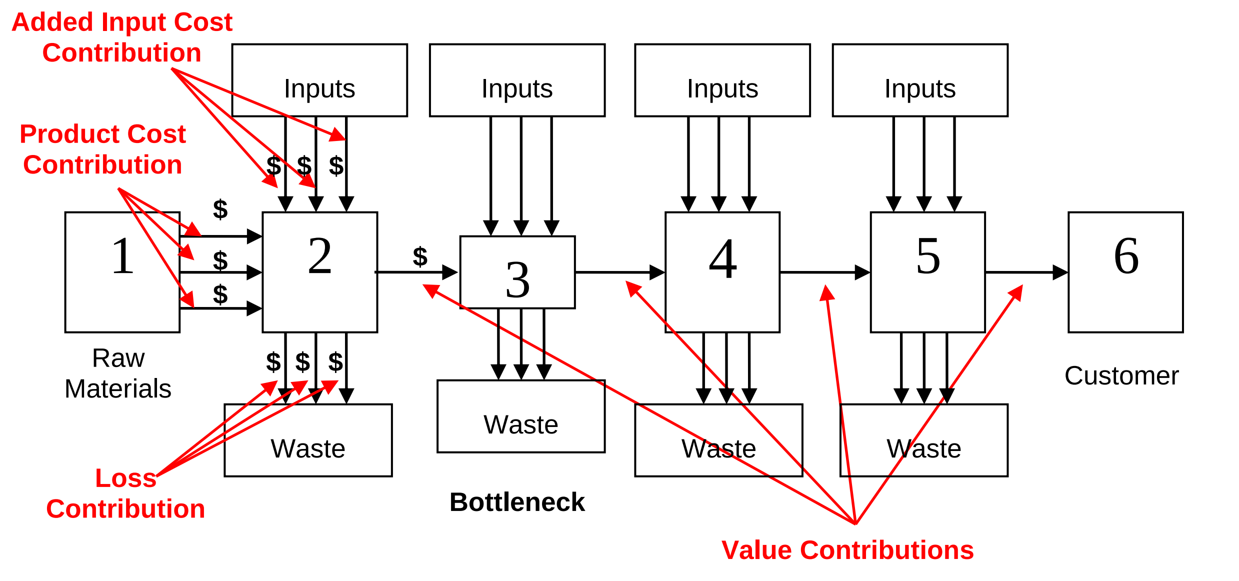

Figure 5.4. Production Process Money Flows

Monitoring the costs and value contributions of each process step provides a means to measure the efficiency of the conversion processes. The more value contribution generated from a conversion step the more financially efficient is the step. By knowing the cost of all inputs and all wastes, the value contribution made to the total profit by each process step can be identified. With value contribution information managers, accountants and engineers can focus on new cost reduction, productivity and process improvements that return the best value for the operation at the least cost to the business.

Figure 5.5 indicates how to identify each money flow associated with a process step. The boundary line makes it clear there is money coming into it from ‘raw materials’ and the added inputs required to make the process conversion. Each process step delivers its own process ‘product’ with its value contribution from the value-adding performed in the step. In addition there are lost moneys that reflect process and operating inefficiencies, wastes and losses.

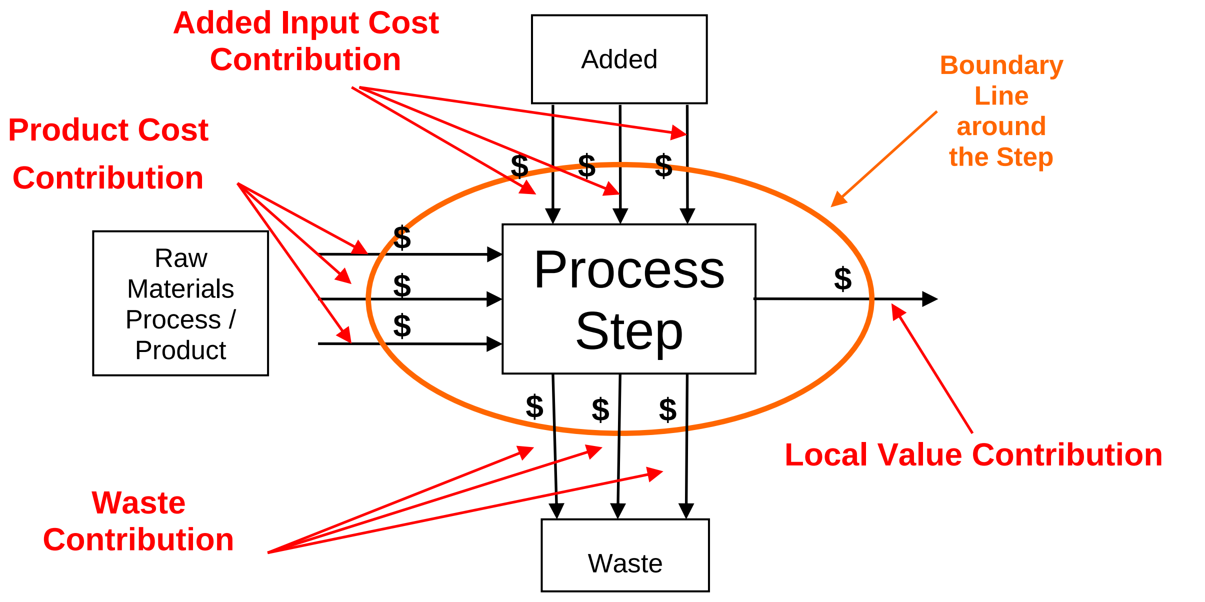

Figure 5.5. Local Process Step Money Flows

In identifying a business as a process of interconnected steps it becomes possible to focus on the financial performance of each step and optimise its performance. VCM uses accountancy to manage operating performance hour by hour by monitoring the costs into, and the value out of, each process step. Figure 5.5 makes clear the importance of cost control in each process conversion step. If so much money is wasted in each step that the customers will not pay what it costs to make the product, there will be no sales and the organisation goes out of business. For products of equal quality it is very likely that the customer will find and use the cheaper producer.

With all the in and out money 'flows' in a process step identified they are used to analyse the profitability of the process step by calculating the costs and losses to determine its value contribution to the production cost of the product. This can be represented by a simple equation.

$$\text{Raw Material Cost} + \text{Added Inputs Cost} = \text{Value Contribution} + \text{Waste} \qquad \textit{Eq. 5.1}$$

Alternately the equation can be written as:

$$\text{Raw Material Cost} + \text{Added Inputs Cost} - \text{Waste} = \text{Value Contribution} \qquad \textit{Eq. 5.2}$$

Strangely, from equations 5.1 and 5.2, it could be said we pay for waste twice, once when we buy it as an input and second when we throw it away as lost value.

5.2.1. Cost Analysis

The power of Value Contribution Mapping is the clear understanding of the real value produced in each production step through the use of visual management to show its money flows. A display of the business process is developed to indicate where the money goes into, around and out of the business. What happens with costs and profits is clear and issues highlighted by the mapping can be addressed.

Activity Based Costing (ABC) is the most appropriate accounting technique to apply when determining process step costs. Standard costing is not suitable since overheads are allocated to direct costs. Rather it is necessary to capture every cost, from the smallest cost to the largest, as it is really spent. A total and true reflection of what happens in each process step during a set period of time is necessary. It may also be necessary to do time and motion studies in the workplace to identify all time and materials used in a process step.

Because the profit stream costing process identifies every cost individually, overheads allocation is not permitted unless there is no alternative. It is preferred that all overheads be identified separately and costed in exact proportion to their usage in each process step. If overhead costs were allocated to direct labour an incomplete mapping of the true costs would result. The accuracy and completeness with which the process step costs are collected will directly determine the effectiveness of the value contribution map as a management control tool. If data is complete and true then good, reliable business-improving decisions will be made to make the operation more efficient and profitable.

The appropriate time period to be used to collect the mapped costs may be an hour, day, week, month and even a year. The time period is dependant on the cycle time for the process step and the size of the time window necessary to identify all money flows for the process step.

Applying ABC permits identification of every cost with its component costs, and even sub-component costs. It is important that every dollar spent in the production of goods is accounted for and shown on the profit stream contribution map.

5.2.2. Collecting Cost Data

The cost data needed to analyse and manage a process is typically generated by the process as it produces its product. The cost of materials, labour, utilities, overheads and services are found on invoices or payslips. What is not normally available are the process costs accurately allocated to the process steps that incurred them. To manage a process step's efficiency it is necessary to cost every one of its inputs, products and wastes accurately.

An approach used to identify the money flows in a process step is to take the process step procedure and work through it. As it is read the process step raw materials, the added inputs, the wastes and the produced product are identified.

As shown in Figure 5.3, a boundary is drawn around the process step to clarify its associated 'flows'. Many of the inputs, wastes and products are shown on the process design drawings, or found in engineering documents, equipment manuals and in standard operating procedures. The data is confirmed by also personally observing the process step for a full cycle of production.

When onsite identify all electrical power supplies to the equipment, all pipes suppling services, all process products into the step, all added inputs into the step, all outputs and wastes from the step. This includes measuring the manpower, management, supervisory and maintenance efforts, times and costs incurred by the process step. It includes measuring forklift movements, vehicle movements, personnel movements, etc. that occur in the time period observed. It includes counting the number of lights and time they are on, how often equipment is hosed down and the amount of water used. All activities are collated and costed in a spreadsheet.

It will be necessary to go as far as identifying minor costs, like rags used for cleaning equipment and the cleaning detergents used. Another example would be to identify the use of personal safety equipment and company brought clothing each operator requires during the time period. Over a year these minor expenses can grow into serious costs that are easily wasted.

Find every dollar that goes into a process step and that comes out of it. Put on the mantle of the crime investigator and look for all the clues to the puzzle. Unearth the truth, the whole and total truth, of where money goes in each process step.

When studying a process step that involves movement of product and/or people, for example storing materials in a warehouse, time the length of the move, measure the distance moved and identify the equipment used in the work. Put a cost to the movement of product and materials so that it can be tested to see if it delivers real value for the expenditure.

All the process costs can be found in the business systems such as payroll, inventory and accounting. Unfortunately they most likely will be totalised costs. The labour will be for a person's total time at work and what is needed is what they spent in the process step. The power bill will likely be for the whole of a building, whereas the cost of lights and power for a machine in that building is required. The purchase of safety gloves will be in batches of dozens at a time but it is necessary to know how many are used by the people working in the process step.

The most accurate approach is to get the real usage of inputs and wastes. For example, the power used by the lights and machinery in the process steps need to be collected for the time period concerned. If that is not possible it becomes necessary to proportion the machine's share of the building's power based on the electric wattage stated by the manufacturers of the equipment used in the process step. By proportioning inaccuracies will be introduced that may eventually cause people to question the final conclusions.

If necessary introduce special means to capture cost information. Time sheets and record-of-use sheets can be developed, chart recorders can be connected to electrical equipment and meters can be installed to measure flows in pipes. When accurate cost control is important to the success of a business spare no effort to discover the total true costs of production.

5.2.2.1. Labour

Direct Labour comes from the time sheets of the people employed directly in the process step being analysed. If the people are used in another process step then only cost time expended in the process step being investigated. The direct labour cost is the pay rate, including on-costs, paid to the people working in the process step, multiplied by the time they spend in the process step during the selected time period costs are being collected for. Their on-costs include such as allowances, superannuation, benefits, etc, proportioned to the period. Do not include allowance for overheads, as they will be separately identified.

Indirect labour costs are the time spent by persons, other than the directly involved people, whose services are needed to ensure the process step is completed. It is necessary to measure and allocate times for indirect labour. This includes such costs as maintenance, supervision, middle and senior management time, inventory and storage personnel, purchasing department personnel, quality control personnel, etc. Identify these costs by interviewing relevant people to determine the time they spend in the process step. During a site inspection watch the process for a full production cycle and observe who interacts with the process step.

The indirect labour cost is the pay rate paid to the indirect people, including their on-costs, multiplied by the time they spend in the process step during the selected time period. On-costs include such as allowances, superannuation, benefits, etc, proportioned to the period.

If a short time period is analysed, say a week, and not all indirect labour is captured, it is still necessary to allocate a proportion of all the indirect labour costs to the time period. In this case take a longer time period, say a month or quarter year, and collect all the costs for the longer period then proportion and allocate them in weekly quantities.

Indirect expenses are those costs incurred due to the presence of the people in the operation. An example is a manager's car and fuel which is paid out of operating revenue. Allocate them in proportion to the hours spent in the process step by the expense owner.

5.2.2.2. Subcontractors

Subcontract labour costs and materials used in the process step need to be recognised and allocated in the same way as employed direct labour. There will be an invoice for the subcontractor's time and materials and the allocation of times and materials for the work done in the process step can be extracted from it.

5.2.2.3. Utility Services

Electricity, water, buildings and such services will need to be measured and allocated to the process step usage during the time period.

5.2.2.4. Management, Engineering, Administration, Supervisory Costs

These costs cover the time managers, engineers, supervisors and administrative support staff spend doing work related to requirements of the process step. For example daily meetings, site inspections, human resources requirements, problem solving process issues, invoicing matching purchases, maintenance planning, etc. All support persons who interact with the process step need their times and costs recorded against the step.

Initially interviews can be held with people to ask them to estimate the time they spend on the process step. If necessary have them keep time sheets to record the actual times spent involved with the process during the time period.

5.2.2.5. Added Input Materials

Direct material costs are for added input materials actually used in the process step. They are the obvious additions of substances into the process step. This includes such things as electricity for motors, boxes for packaging, lubricant for equipment gearboxes, air for pneumatic rams, etc. Typically these materials can be identified as entering the process step in a physical form. The parts of them wasted can be measured and given a value.

These costs depend on the quantity and value of each input material used during the time period. It requires counting the amount of the material used and multiplying by the cost of the added material. Material costs can usually be identified from invoices for the material. Sometimes the added material has been made by the organisation and no invoices are available. In such cases it will be necessary to get an accurate cost for it from the organisation. If none is available it will need to be calculated from the cost of the labour, ingredients, handling and manufacturing charges used to make it.

Indirect material costs are the costs associated with the indirect functions required to perform the process step. Such as paper for recordkeeping, electricity for lighting, a maintenance planner's computer, the cost of forklift hire to move pallets, the building storage space for spare equipment parts, etc. All these costs are real costs incurred to conduct business that supports the production processes and need to be identified.

It is necessary to measure them and quantify them so that they can be given a value. Measurement can be by stopwatch, distance, counters, etc. Their use in a process step needs to be identified and quantified to reflect how much is used in the process step conversion and how much is wasted.

5.2.2.6. Product Costs

The cost of a product entering a process step is needed. An accurate value may be available from the accounting, or production department. If it is not available accurately it will need to be calculated for each prior process step commencing with the start of production.

5.2.2.7. Identifying and Costing Wastes

Direct waste is any unused direct labour or direct materials added into the process which are not fully used in making a product. Even if the added input is gradually converted through a number of process steps, as long as it is fully used it is not waste. Unconverted added input is waste.

For example, in some chemical processes the chemical reaction absorbs only a portion of the mixed ingredients. Those ingredients that are not converted by the reaction are wasted. A laboratory can analyse for the unconverted ingredients and tell how much was unused.

Another example is water used to clean equipment. If the water is not fully used in the process to make product but disappears out of the process, then it is wasted. Leakage out of the process is waste. Spillage from a process is waste. Another example of waste is side-steam materials collected in bags or bins to be disposed of outside of the process.

Indirect wastes are those wastes that relate to the unnecessary use of indirect labour and indirect materials. They are more difficult to identify because they are not easily observable. Examples include wastes related to lost time in meetings, to lost energy, to lost compressed air, to safety equipment thrown away before being fully used, to storing unneeded materials in a storeroom. There are numerous instances of such wastes.

The detection of indirect wastes is through observation. That is why it is necessary to be present during a full cycle of a production process and observe all process steps and their inputs to identify wasted costs, materials and product. Look in the rubbish bins used in the process step area of the business and see what is thrown away. Are lights and air conditioning left on overnight unnecessarily? If required develop and instigate systematic means to spot and record the waste and its value during the period investigated.

5.2.3. Comparison with Standard Costs

Every organisation should have a standard costing system for its products. If there are standard costs available compare them with the costs from the value contribution mapping analysis. Using existing standard costs double-checks the analysis and concerns can be raised and investigated when costs are far from the standard costs previously allocated.

5.2.4. Use of Computerisation and Technology to Capture Costs

The work involved in identifying and costing component inputs, products and wastes for each process step can be large. If a company choses, it can use modern technology and computerisation to capture many of the costs automatically. Labour can be identified electronically by using electronic cards and time clocks. Materials can be identified electronically via electronic tagging or bar coding.

Wastes are difficult to identify electronically and it becomes necessary to conduct site surveys to quantify the percentage of waste and develop a factor to use in calculations. It may be useful to change work procedures and include the recording of waste as standard practice. If waste is not regularly measured it will be necessary to conduct audits periodically to confirm the waste factor allowance and alter the VCM equations as necessary. Introducing counting and measuring of wastes will allow people to identify the causes and address them before they get even worse.

Through the use of Global Positioning Systems equipment, materials, equipment and people movements can be tracked and any time losses identified and addressed.

5.3. The Value Contribution Map

A simplified sample of a Value Contribution Map is shown in Figure 5.6 for a section of a canning line. All the costs are shown cascading to and from the process steps. The time between updating the map depends on the urgency of the situation. If it is necessary to manage changes quickly then more updates are needed than in a stable situation.

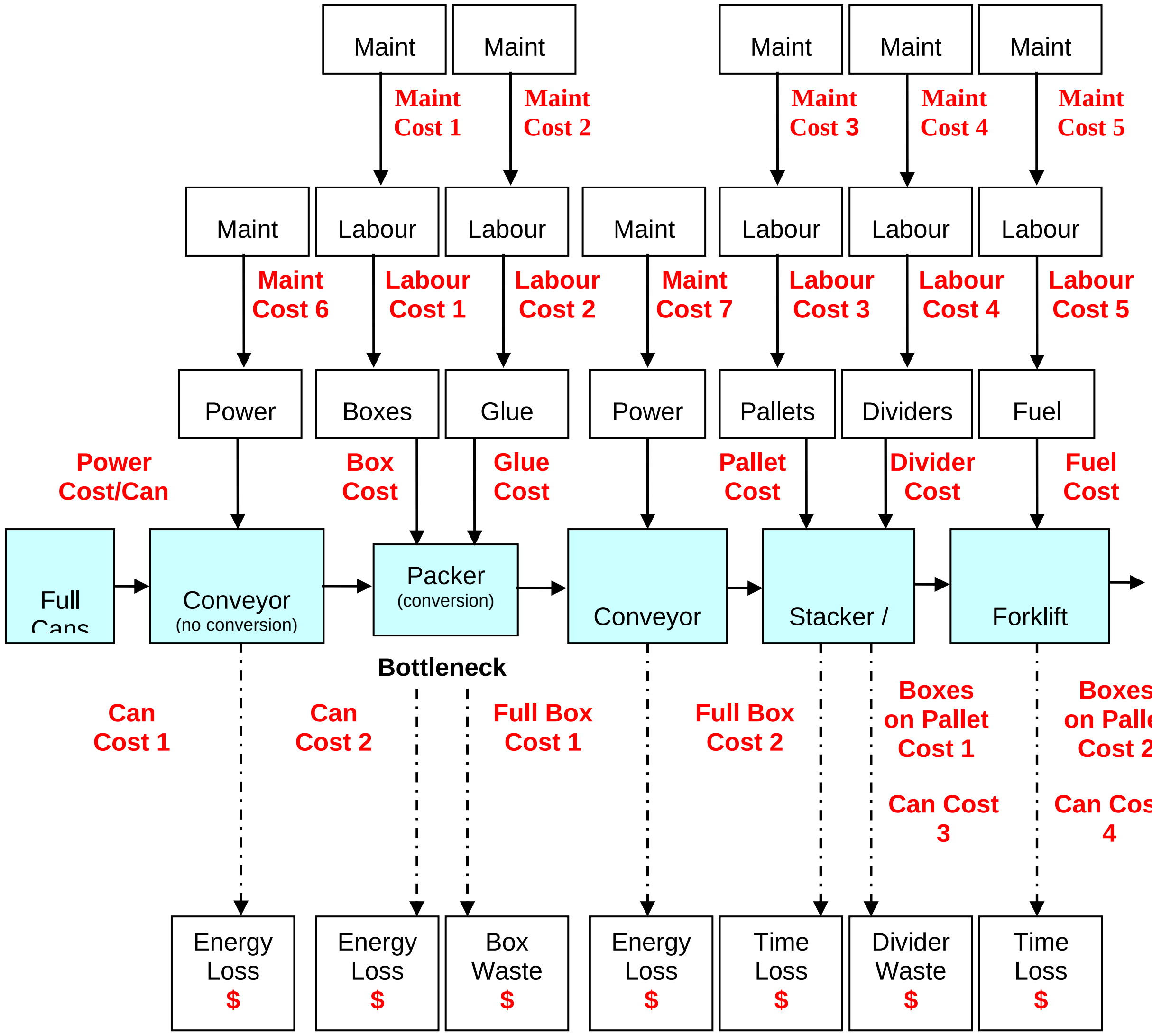

Figure 5.6. Value Contribution Map for a Canning Line

At least every day the value contribution map ought to be updated. If the mapping process can be done electronically it would be useful to do an update it hourly, as this frequency allows powerful control of the operation. With the progress of computerisation, electronic tracking of material and automation of cost information it is possible to have real-time displays of value contribution given to every operator in a business. In some cases it might be necessary to map a particular process step more often than the entire process because of the importance that step has in the operation.

5.4. Performance Measures and Reporting

The problems that are highlighted by value contribution analysis can be addressed by the business management and personnel with new strategies to maximise the value contribution of their processes. After a process step is analysed financially in detail it is easy to understand and appreciate how its many factors interact and impact each other. The accurate costing of inputs, wastes and conversions will identify problems. Through detailed questioning the reasons can be uncovered and the required changes made.

If change is required it is necessary determine what that change will be. The issues will need to be discussed with everyone concerned to fully appreciate and understand the situation's history and reasons for occurring. The new changes will also need discussion, review and analysis for possible unwanted consequences. Finally a decision will be taken and changes will be made. When the changes are introduced they too will need to be measured, monitored and reported.

5.4.1. Profitable Performance Measures

Selecting the right measures to monitor and report will be critical to the success of the change process and to the speed of its implementation. The measures need to be meaningful to the users, truly reflect the situation, are within their control to improve and inspire continued improvement. One of the change strategies will be to introduce performance measures that identify poor efficiencies and the practices that cause them. Performance measures based on the issues identified by the analysis will drive the right behaviours and actions from people. The measures can be graphed and trended to show performance improvement.

Some typical measures to use are listed below. Measures can be developed that are suited to specific circumstances. The purpose of measuring is to know exactly what is happening. Once the current situation is clearly understood an assessment can be made as to whether it is satisfactory or it needs to be changed. When a change is made the effects will be seen in the performance measures. It may take several months for the effect of a change to be observed. Where the measures indicate an unsatisfactory result, a correction is necessary to get on-track.

Usage Efficiency: This is the classic output divided by input. Select the process flows that are important and develop an appropriate efficiency measure for each and trend them over time.

Productivity: These are measures of process performance. They are time based ratios of output during the time period. From the value contribution map select the productivities which are important to measure. Productivity can be measured at the process step level and at the global process level.

Throughput: This measure is a count of what passes a selected point in the production process during a period of time.

Waste Cost: This measure counts the cost of waste in dollars per dollar spent to purchase the original material.

Quality: This is the proportion of production that meets customer specification. It is another measure of a wasteful process.

To get a complete understanding of what happens in a process requires more than one measure. Business processes involve many interactions and may have several variables that affect each other. It may need a number of ratios to identify what is occurring in a process. Do not use any more measures than necessary. Maintaining measures requires time and money, which are then not available for use elsewhere. Experiment with the right measures to apply before deciding which ones to keep and use.

Keep performance reporting simple by using headings to categorise the report and visual means for displaying information. Show trends graphically in a suitable form to make their message clear to users. Use balloon notations in the graphs to highlight issues that need attention. Apply colour and font variations to enliven the report. When a table is required to list details show summary entries and totals for each category. Keep the details for when people ask. Draw people's attention to the conclusions and their implications by providing an executive summary at the top of the report.

5.5. Applying Value Contribution Mapping

The application of VCM is an accounting function requiring engineering precision. The power of VCM is its ability to identify exactly where every dollar is spent and made in a business.

Typically organisations apply the minimum accounting and operating requirements needed to continue in business and have never closely examined the financial performance of their operation. Standard methods of accounting and reporting are too superficial to be used to control production and operations process steps.

Businesses are usually designed to make and get product to customers. Very few are intentionally designed to satisfy the customer and make the best profit from their efforts. So they never establish data collection on what actually happens within their processes, preferring instead to employ supervisors and managers to control and direct the operation. This is thinking left over from before the use of computers. With well functioning VCM in use fewer managers and supervisors will be needed, as the shop floor people can see for themselves how their process is affected by its various inputs and adjust their behaviours accordingly.

Application of VCM is not difficult. It employs regular cost accounting and activity based costing practices to accurately identify money movements throughout an operation. The money movements in each process step are modelled using basic accountancy equations. Once the equations for each process step are developed VCM uses the financial information and data already available in the business to give a snapshot of what is happening to the money flows in the step. The cost equations need to truly reflect the money flows throughout the step. Their development requires engineering precision to capture every cost and waste. By understanding the financial details of what happens at every process step it becomes possible to identify improvements and better practices to optimise each step and make the whole process more productive and profitable.

5.5.1. Process Cost Map

In order to identify the money flows through a process step it is best to start by drawing a cost map showing the money movements and flows occurring in the entire process. An example of a cost map for an actual business is shown in Figure 5.7. The organisation produces bent and straight steel bar used in building construction by uncoiling rolls of different size bar through a machine which then bends the bar to the required shape and cuts it off the coil. The cost map in Figure 5.7 shows the manufacturing process for a single machine and breaks the manufacturing process into its separate steps to show where costs arise during production of each item of bar. The manufacturing process runs horizontally across the page and the costs incurred at each step run vertically into the process flow at the step where they are incurred. The cost map is used to identify every input cost and waste for each step. Realise that every input to a step is itself the result of another process and could also be analysed and monitored by using the value contribution method.

The same approach is used for an entire production line and each machine and production stage is represented by its own box in the flow diagram. The cost map for the whole production process is drawn and if necessary a box is analysed separately for its specific details and the information taken back to the master cost map.

By laying-out the process in a flow diagram it becomes clear which steps incur costs and from where costs arise. In order to have a cost equation that correctly represents the money flows we must include all the input costs and all the outputs, including the product and the waste, for each step. If the actual costs incurred at each step are not available then a well analysed cost estimate based on accurate historical data or by scientifically rigorous observation and recording is required.

Difficulty arises when there is no real data available for individual inputs and none can be collect on-site. In such cases it becomes necessary to allocate costs using standard cost methods and hope they closely reflect the real situation. Figure 5.8 is a simplified version of the cost map in Figure 5.7 where costs are allocated and proportioned for each individual step as advised by the operations management and accounting people in the business.

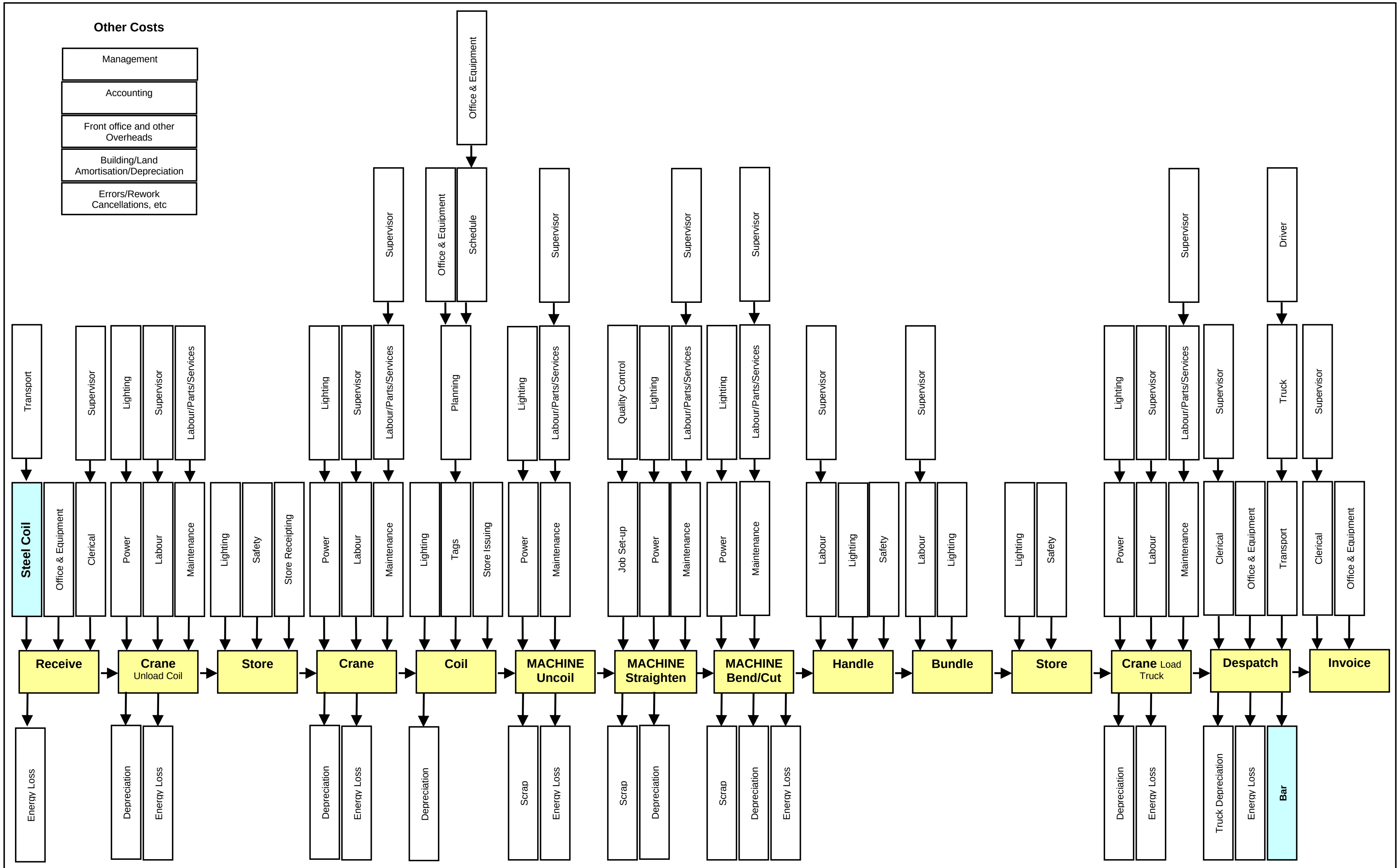

Figure 6.7 Process Cost and Waste Map for a Production Process

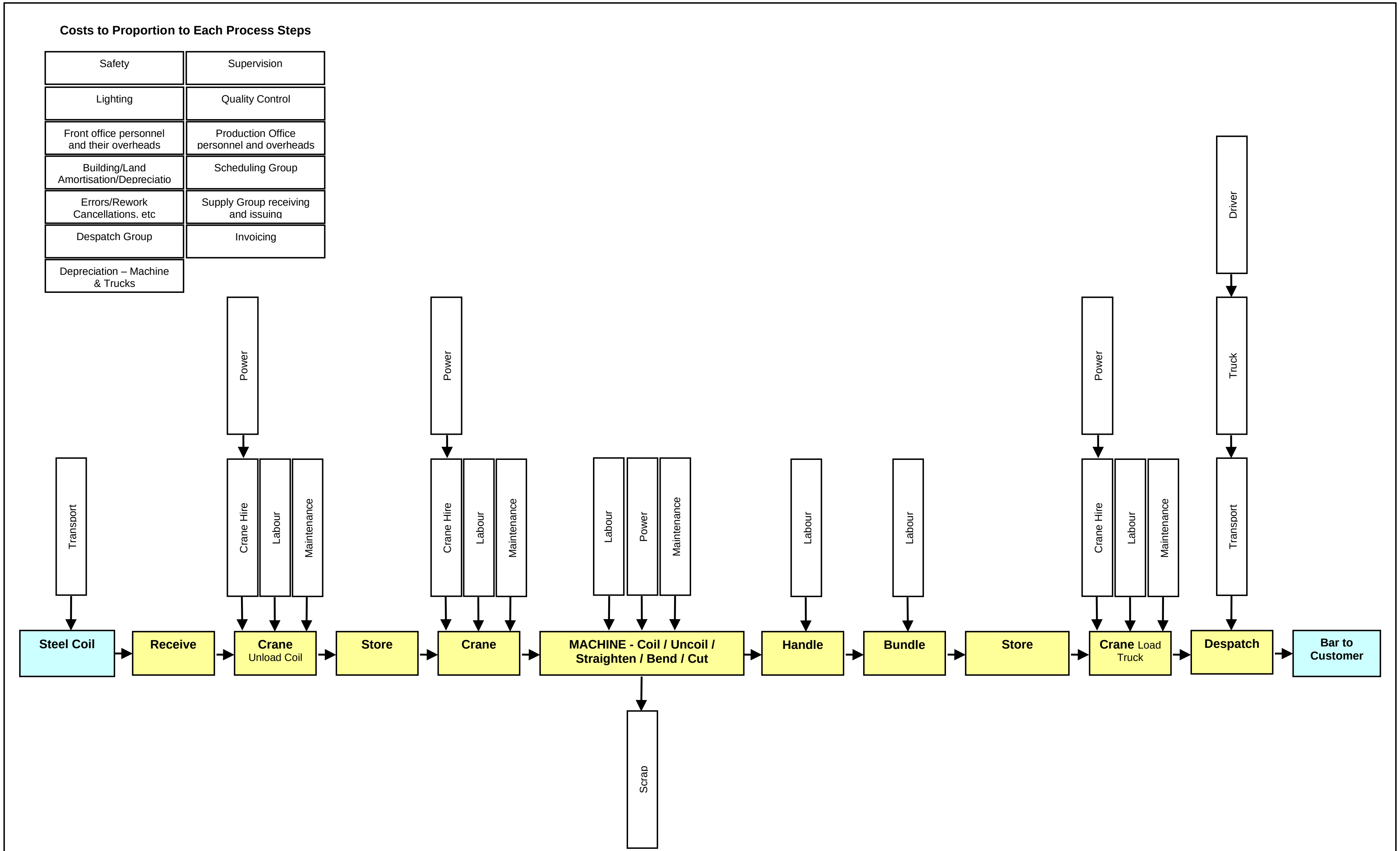

Figure 6.8 Process Cost Map for a Production Process using Allocations

5.6. Developing the Value Contribution Equation

Using the identified money movements shown on the cost map, the costs, wastes and the value-added in each step can be represented by an equation of the type shown in Equations 5.1 and 5.2. The cost of producing product through the whole process is simply the amalgamation of the individual steps. A financial model with such engineering precision permits the monitoring of the real cost of production and allows determination of how profitable it is to do a job. It also identifies and indicates where costs and wastes are excessive and can be reduced or saved so the maximum value can be gained from production.

In the example, each unit of product from by the machine consists of lengths of steel bar either made straight or made with bends and straight lengths between bends. The cost of a work piece depends on its diameter, the length of material used, the number of operations and movements performed on it at each step, and its share of unmeasurable business costs allocated to each step.

The manufacturing cost for each step consists of a range of fixed costs and a range of variable costs along with their respective losses. It is necessary to find the fixed costs and the variable costs for each stage to use in the equation. Typically fixed costs are a constant cost for the business and do not change with the work, whereas variable costs are dependent on the work piece and change as the type of work changes.

To be able to use the equation for every item of work put through the process, it is best to base the costs incurred in each step on factors related to a unit of production (called variables because they vary and change with the work). In other words, the cost equation needs to relate the costs of manufacture to the variables that change with the type of product made. This allows the calculated cost to reflect the real work performed.

The variables for the steel bar production example are:

- Bar diameter
- Work piece total length
- Number of bends in a work piece
- The bend complexity
- The total factory production time for the work piece

Once the cost to produce one unit of work is know then the cost per production run can be estimated by multiplying the cost of a production unit by the number of units to be produced.

Taking each process step one-by-one from the start of the process, the cost map allows easy identification of component costs and wastes. Each step can be assembled into the form of calculation shown by Equation 5.2, and repeated below.

Raw Material Cost + Added Inputs Cost - Waste = Value Contribution *Eq. 5.2*

Applying the equation to the 'Received in Factory' step from Figure 6.8, its value contribution equation is represented by:

Cost of steel coil to make a unit of product + That step's proportion of allocations for one unit of product = Step value contribution per unit processed

For the 'Coil / Uncoil / Straighten / Bend / Cut' step its value equation is:

Value carried from prior step + Labour for the step to make one unit of product + Power used in the step to make one unit of product + Maintenance on the machine caused by one unit of product + That step's proportion of allocations for one unit of product – Scrap from one unit of product = Step value contribution per unit processed

This calculation is performed for each step in the process using a computerised spreadsheet. From the analysis the value-added at each step, along with the impact of its costs and wastes, are clearly identified. If the unit of product is too small to get sensible unit costs then use the smallest multiple of units for which costs and allocations can be reliably and accurately determined.

The entire production line or process can be modelled by adding together the equations for each process step.

Once a process and its steps can be described in mathematical detail it is a simple matter to conduct 'what-if' and sensitivity analyse to identify the critical success factors affecting its optimisation and put into place the best practices to maximise performance and profitability.

Example 5.1: Cost Equation Construction for a Manufacturing Process

This example describes a means to estimate the cost of producing a piece of work through the production process shown in Diagram 6.8. The requirement is to represent the production process by a cost equation so that estimates of the cost of work can be made in order to determine if it is profitable to do a job and to identify where costs can be saved in producing the item.

Each work piece consists of lengths of bar either made straight or made with bends and straight lengths between bends. The cost of a work piece depends on its diameter, the length of material used, the number of operations and movements performed on it and its share of fixed business costs.

The first step is to draw the complete process as a flow diagram showing each stage of production as a separate box on the flow diagram. Within each box briefly name the step with words that describe its function and so it can be identified separately to other steps. On the flow diagram identify every input, output and waste for each step. Figure 6.8 shows the production process and where costs arise during production for the process of the example. The production process runs horizontally across the page and the inputs run vertically into the process flow at the steps they are incurred.

Developing the Cost Equations

It is necessary to identify and differentiate the fixed costs and the variable costs at each step. Typically fixed costs are a constant cost for the business and do not change with the work, whereas variable costs are dependent on the work piece and change as the type of work changes. The production cost consists of the fixed costs and variable costs added together. The basic form of the production cost equation is:

Production Cost = Fixed Costs + Variable Costs.

To be able to use the equation for every item of work put through the process, it is best to base the costs incurred in production on factors related to the work piece itself. In other words, the allocation of costs should be related to variables that change with the type of work piece, so that the estimated cost reflects work piece variety.

Identify the variables that affect the cost of the final product. For example diameter, size, weight, complexity, etc. The variables in the case of the steel bars made in the example process are:

- Bar diameter (available from the design drawings)
- Work piece total length (available from the design drawings)
- Number of bends in a work piece (available from the design drawings)
- The bend complexity (available from the design drawings)
- The total factory production time for the work piece (available from standard costs or a work and motion study is performed to determine typical production times)

For each process step in the cost map write the costs associated with each input and waste identifying it as a fixed or variable cost. Separately write the logic behind developing the cost equation so that there is a reference explaining the equations (see the Appendix at the end of the example). The variable costs will clearly be connected to factors related to the work piece, whereas the fixed costs are independent of the work piece. Once all process step costs are identified collect the fixed costs together by variable and collect the fixed costs together separately. Arrange the collected costs into a summation equation with costs of identical variables added together and the fixed costs included at the end. Look for means to arrange and combine costs and simplify the equation where possible. In this way work through each process step so it has its own equation. The total process is described by the sum of its individual steps.

The example has combined all the individual process steps into one overall equation for the production process. The structure of the production cost equation per work piece for the example is shown below. Note that the numbers in *italics* reference the explanation of the cost in the Appendix.

The cost for each work piece depending on its diameter consists of:

Cost / meter straight	=	Cost of machine power to feed and straighten coil *(2)*
	+	Handling/bundling labour, including on-costs *(3)*
	+	Maintenance of coil holder, rollers, etc due to machine use *(4)*
	+	Steel cost per meter (12mm and 16mm) *(1)*
	+	Coil loading – crane and labour, including on-costs *(8)*

	+	Straightening rollers set-up labour, including on-costs *(11)*
	+	Scrap, including crane movements of bin *(13)*
	+	Finished tag storage - building amortisation & maintenance *(17)*
Cost / bend	=	Steel cost per bend (12mm and 16mm) *(5)*
	+	Cost of machine power to do a bend *(6)*
	+	Maintenance of machine due to use *(7)*
	+	Bends' set-up labour, including on-costs *(12)*
Cost / work piece	=	Scheduling, including on-costs *(9)*
	+	Finished job moving – crane & labour, including on-costs *(14)*
	+	Loading truck/trailer – crane & labour, including on-costs *(15)*
	+	Despatch to customer - paperwork, invoicing *(16)*
Cost / production hr	=	Supervision – Leading Hand, Supervisor, including on-cost *(19)*
	+	Invoice processing, including on-costs *(18)*
	+	Production Planner, including on-costs *(20)*
	+	Senior Management/Accounting costs and on-costs *(21)*
	+	Hire of factory crane *(22)*
	+	Maintenance – crane *(23)*
	+	Maintenance – general costs and building *(24)*
	+	Factory lighting *(25)*
	+	Offices' running costs (Admin Office, Production, Despatch) *(26)*
	+	Safety *(27)*
	+	Quality Control *(28)*
	+	Estimating and quoting, including on-costs *(10)*
	+	Customer disputes and resolution, including on-costs *(29)*
	+	Production Coordinator *(30)*

The cost equation for the complete process for a unit work piece becomes:

Production Cost	**= Cost per m straight**
	+ Cost per bend
	+ Cost per piece
	+ Cost per production hr

Once the cost of one work piece is know then the cost per job size can be estimated by multiplying the cost of a work piece by the number of work pieces required.

Appendix **(Example 5.1)**

(1) Steel cost per meter (12mm and 16mm)

This is the cost of one meter of coil delivered into store. It includes:

all steel mill cost,
all transport costs nationally and locally,
all off-loading forklift use and labour,
delivery documentation processing,
all stores receiving and inventory updating
the cost of storing the coil on-site, such as rates, land tax, site maintenance, etc

Both 12mm and 16mm coils are processed through the machine. The cost is required by meter length.

(2) Cost of machine power to feed and straighten coil

This is the power required to unroll the coil and run it through the straightening rollers. It will vary for each size of bar. The cost is required by meter length.

(3) Handling/bundling labour including on-costs

This is the labour cost to wait and grab, then lift, move to the stack and place each work piece onto its bundle, including the time needed to tie the bundle so it can be lifted and despatched. The time taken depends on the size (length x width) of the work piece. The cost is required by meter length.

(4) Maintenance of coil holder, rollers, etc due to machine use

This cost is from the wear and tear on running parts used to unroll the coil and run it through the straightening rollers. It can be estimated by meter length from the cost of replacement parts (coil holder and straightening rollers) plus the labour to change the parts divided by the total length of coils put though the machine in the time since replacing the last set of roller parts.

(5) Steel cost per bend (12mm and 16mm)

This is the cost of steel required for a bend. Both 12mm and 16mm bends are done on the machine. For a 90^{o} bend this is three-quarter the bar diameter. For an 180^{o} bend it is one-and-a-half times the diameter.

(6) Cost of machine power to do a bend

This is the power required to put a bend in the steel. It will vary for each size of bar and amount of bend. The power is best determined by using a power meter mounted on the machine to measure the power used over a long period of time (at least a week). Alternately a rough estimate can be made from the electric motor size and the length of time it is used.

(7) Maintenance of bender due to machine use

This is the maintenance cost of the bending head on the machine per bend. It can be calculated by the maintenance costs over a period of time divided by the number of bends performed by the bender during that time. The number of bends in a time period can be found from historical records or by site observation.

(8) Coil loading – crane & labour, including on-costs

This is the cost to forklift the coil into the building, lift it by crane to its uncoiling cradle at the machine and return the crane. Labour cost is also included. Because a coil is of known length this cost can be calculated by the meter.

(9) Scheduling, including on-costs

This is the cost to schedule a work piece. It includes the time spent reviewing the drawings, calculating measurements, entering information into the business systems and printing and handling paperwork, including the cost of stationery. From the scheduling process the bar schedules are developed. A cost per work piece can be determined from the cost of time spent per schedule, divided by the number of work pieces in a schedule.

(10) Estimating and quoting, including on-costs

This is an hourly cost allocation for the time and resources taken to estimate and quote a job, multiplied by the time taken to make a work piece. The bigger the job the longer the time taken to do these tasks. The cost can be determined from historical averages of time and resources required provide prices to customers.

(11) Straightening rollers set-up labour, including on-costs

This is the time required to adjust and set the machine to straighten bar and test its performance. This cost can be calculated per meter length by dividing the time taken to set-up with the length of the coil. It assumes that there is one set-up per coil, which is less than actual, as a bar size change can be required a couple of times a day.

(12) Bends' set-up labour, including on-costs

This is the cost to set-up the machine to do all bends required in a schedule divided by the number of work pieces for the schedule and again divided by the number of bends in a work piece. All work pieces in a schedule are identical. An estimate can be calculated from doing workplace time and motion study for several different work pieces and persons and averaging the time per bend. The more complicated shapes involving non-90^{o} bends will require a 'complexity factor' to allow for the longer time these take compared to a standard 90^{o} bend.

The suggested complexity factor is one (1) for 90^{o} bends and two (2) for all other bends.

(13) Scrap, including crane movements of bin

This is the cost of scrap which is presently running at 2% of steel bar throughput, or 20mm per 1000mm. Two crane movements, removing scrap and replacing the bin, are also required in the cost. A more accurate scrap rate allowance can be made for each machine by weighing the actual scrap generated by each machine monthly for a number of months.

(14) Finished tag moving – crane & labour, including on-costs

This cost is for moving each finished tag by crane from the machine to its storage space on the floor divided by the number of work pieces in the tag. Allow one crane lift per tag.

(15) Loading truck/trailer – crane & labour, including on-costs

This cost is for moving each finished job by crane from its storage space on the floor to the transport vehicle divided by the number of work pieces in the job. Allow one crane lift per job.

(16) Despatch to customer - paperwork, invoicing

This cost covers the time spent on each tag by the people in Despatch handling paperwork and inputting into business systems divided by the number of work pieces in the tag. The cost can be collected by counting the number of jobs processed in a period of time by the Despatch personnel and dividing them by the total number of work pieces in the job.

(17) Finished tag storage - building amortisation & maintenance

This cost is that required for the floor space within the building including rates, land tax, building maintenance, etc. The floor space is related to the length of the work piece. The cost can be estimated per meter length by conducting site surveys of the typical foot print of a range of work piece types and dividing the cost of each type by the total length of the steel in the work piece.

(18) Invoice processing, including on-costs

This cost covers the function of creating and processing customer invoices, including rectifying invoicing problems. The cost is estimated from historical averages of processing time and allocated per production hour for a work piece on the assumption that bigger jobs will require more time for invoice processing. The hourly cost is multiplied by the estimated hours a work piece will take to produce.

The time for work piece fabrication is identified from historical records or by site observation.

(19) Supervision – Leading Hand & Supervisor, including on-costs

This is the hourly cost for the leading hand and supervisor multiplied by the estimated hours a work piece will take to produce.

(20) Production Planner, including on-costs

This is the hourly cost for the Production Planner, multiplied by the estimated hours a work piece will take to produce.

(21) Senior Management/Accounting costs and on-costs

This is the hourly cost for senior office staff, multiplied by the estimated hours a work piece will take to produce.

(22) Hire of factory crane

This covers the hourly hire for the cranes in the steel bay allocated by machine, multiplied by the estimated hours a work piece will take to produce on the machine.

(23) Maintenance – crane

This is the cost of crane maintenance per hour, multiplied by the estimated hours a work piece will take to produce.

(24) Maintenance – general costs and building

This is the cost for non-specific machine maintenance in the steel bay, and associated building, allocated to each machine, multiplied by the estimated hours a work piece will take to produce.

(25) Factory lighting

This is the hourly cost for lighting in the production area, multiplied by the estimated hours a work piece will take to produce.

(26) Offices' running costs (Front Office, Production, Despatch)

The hourly cost to run the Administration, Despatch and Production Offices and equipment (power, water, air conditioning, cleaning, stationery, etc), multiplied by the estimated hours a work piece will take to produce.

(27) Safety

This is the hourly cost of safety personnel, safety systems, personal protective equipment, etc, multiplied by the estimated hours a work piece will take to produce.

(28) Quality Control

This is the hourly cost of quality personnel, systems, documentation, etc, multiplied by the estimated hours a work piece will take to produce.

(29) Disputes and resolution, including on-costs

This is an hourly cost allocation for the time and resources taken to resolve disputes on a job. A cost can be estimated using historical data.

(30) Production Coordinator

This is the hourly cost for the Production Coordinator, multiplied by the estimated hours a work piece will take to produce.

Calculating Crane Lift Cost

The cranes are used to move job bundles about the production floor and for unloading/loading transport vehicles. Each lift requires the hoisting motor and each movement requires the drive motor. To calculate the cost of a lift it is necessary to determine the power used by the motors while lifting the load and moving it from where it started to where it is finally placed.

The weight of the load is variable and can be up to 5 tonne. However normal practice is to load transport vehicles in 1-tonne loads for ease of site off-loading. To simplify and standardise the situation for each machine in the production line a typical weight for each lift will be determined from site observation. This will then be used in the production cost calculation for the relevant steps.

6. Creating Plant and Equipment Wellness Quickly

This book started with an introduction that recognised organisations want Engineering Asset Management and Operational Excellence (EAMOE) change performed quickly. Too few organisations are successful at adopting and imbedding EAMOE, yet the pace of operational change and turn-around is accelerating. Clearly there is great incongruence and mismatch between what is wanted by organisations and what is being achieved.

A great part of the problem is related to the difficulty and complexity of the methods and tools currently used in operational improvement programs. They require new learning or development of specialist skills and few organizations can spare the time and afford the resources necessary to incorporate the use of the new methods and tools throughout the organization. The lack of suitable tools and methods to help people make a rapid transition without requiring much cost and time has stopped the successful introduction of EAMOE throughout industry. This book was written to address the clash between the reality and the requirement of operational improvement and provide advice and some of the appropriate tools that are needed.

Organisations need simple methods that are easy to introduce and sustain but which quickly provide higher reliability, availability, safety, morale, quality, and customer satisfaction while delivering lower operating costs. If operational change is required within six, nine or twelve months there just is not enough time to introduce complex and demanding methods. The techniques of Plant and Equipment Wellness are designed to address the needs for simple, low cost implementation with little time commitment.

A Plant and Equipment Wellness program starts with the introduction of Defect and Failure True (DAFT) Costing for all operations equipment and process failures, along with the use of Design Options and Costs Total Optimisation Review (DOCTOR) for all plant changes and new installations. These risk management tools highlight to everyone the vast costs and losses involved when failure occurs and heightens awareness for the need to control the consequences of actions and decisions. It stops people rushing into things without planning and preparing.

The second step in a Plant and Equipment Wellness program is to introduce accuracy controlled procedures throughout the organisation for every task that affects plant and equipment wellness. Only world best practices will be allowed for those people that design, use, maintain, repair and purchase the organisation's materials, parts and equipment. This is done to start the defect elimination and failure prevention process throughout the company and ensure from that day onward that no defects will again enter the organisation. By introducing precision in thought and action the plant, equipment and process reliability will rapidly rise as defects are stopped.

Step three is to introduce visual monitoring of all variables in all processes that impact plant and equipment reliability. This includes production, maintenance and engineering where the monitoring is used to identify excessive variability and risk of performance degradation so appropriate actions can be taken before problems arise to affect equipment. Trend charts with action levels and key performance indicators are used liberally to understand and control the processes impacting equipment reliability. This is where the operators and maintainers take on ownership of plant and equipment performance.

The final phase of a Plant and Equipment Wellness program is speeding-up the accountancy process to real-time speed of production. As soon as a purchase order is raised the cost impact is electronically reflected in the costs of production. Every hour spent on a task is reflected in the production cost displayed on the screen. The cost and location of wasted materials, utilities and resources is identified. The flow of money about the production process is used to monitor production health and well-being and give instant feedback on the effects of actions and decisions. Real-time, on-line accounting acts to galvanise action to control costs. Bleeding production losses are halted and sutured through the use of timely and accurate information to rein in costs, wastes and losses. Instant feedback allows the financial impact of failures to be immediately seen by all the organization. Waste is stripped from the production process – lost time, scrap, over-use, material losses, etc – and value is maximised. This capability to see all production and process costs at real-time production speed transfers responsibility for high performance to the workforce and creates ownership within employees to optimise the operation.

The needs of change management are also recognised and a well-planned, thoroughly prepared and communicated change process is applied for each phase undertaken.

Such a four-stage approach uses a small number of world-class improvement practices interwoven with the organisation's existing methods. It causes little disruption yet rapidly incorporates best practice into everyday activities. The results include:

- The making of timely, correct, fact-based decisions.

- The introduction of accuracy and precision into every activity to eliminate defects and failures.
- Improved and sustained plant and equipment reliability.
- A massive reduction in exposure to risk.
- Improved financial performance through greater productivity and value contribution.

A Plant and Equipment Wellness program addresses all five concerns affecting plant and equipment wellbeing – control of process variability, the prevention of failure, risk control, the need for accuracy and value building business processes – while providing a simple, easy to adopt, low cost methodology every organization can immediately gain from.

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