Chapter 13: Selecting Reliability Strategy

Equipment is not reliable because you maintain it. Maintenance has only a little to do with getting high equipment reliability. All industrial operations in the world maintain their equipment, yet the vast majority suffer from poor plant reliability. Even doing condition monitoring or preventive maintenance according to a planned schedule will not deliver highly reliable machines. High reliability is mainly attributable to factors other than the maintenance you perform on your equipment.

The maintenance normally undertaken to care for operating plant arises from the following:

1. Core maintenance activities required by the equipment design
2. Core maintenance activities required by the business process in which the equipment is used
3. Additional maintenance activities resulting from equipment failures

Nowhere in the list is the business imperative to deliver high reliability. Reliability is not a result of maintaining and repairing your equipment. Every maintenance intrusion produces downtime—the opposite of reliability. The right maintenance focus is producing uptime. You want your maintenance crew to focus on creating and sustaining the ideal conditions for the health and well-being of all vital equipment parts so that they don't need maintenance.

There's a story that came out of the power generation industry on the east coast of Australia about a power station's decision not to overhaul a steam turbine for more than five times longer than recommended by its manufacturer.

It passed that three years after a new electrical power generation set was installed, its manufacturer knocked on the power plant manager's door to let him know it was time to do the recommended overhaul. The manager asked his plant maintenance engineer's opinion. They looked at the operating performance data, the trends from the inbuilt condition monitoring sensors, and the equipment's maintenance history and decided not to do the overhaul because there was nothing wrong. The manufacturer told the plant manager the warranty was voided, and he would wait for a call to repair the breakdown when it happened.

Three years later, without a call during that time, the manufacturer returned to the power generator to advise that it was now time to do the overhaul. The plant manager and maintenance engineer looked at the last six years of operating performance data, the trends from the inbuilt condition monitoring sensors, and the equipment's maintenance history and decided not to do this overhaul again because there was nothing wrong. Three years later, the manufacturer returned and was sent away. Then again three years after that, and again after that. It was 17 years before the turbine was overhauled for the first time, and that was only after there was evidence that an overhaul was necessary.

When you have a successful plant reliability strategy, your maintenance program prevents the causes of equipment failures. Once the focus is on creating healthy parts inside of assets instead of caring for sick assets, a different list of maintenance work results.

1. Core reliability activities required for failure-free equipment
2. Core reliability activities to optimize equipment performance in the process in which it is used

3. Additional reliability activities to eliminate all equipment failures

Maintenance Is a Risk Control Activity

Removing perceived operating risk is seen by some as sufficient justification to do maintenance.[1] Maintenance tasks are initiated in the belief that doing maintenance will prevent a risk. Condition-based and preventive activities are wrongly founded on the question, "How can my machine fail?" Maintenance will end up carrying out inspections and intrusive actions on perfectly healthy equipment. This approach to maintenance selection wastes resources, effort, and money. If instead we ask the question, "What failures will my equipment actually experience?" The answer will be, "Fewer than those that you think might happen!" Not all the systems and components of the equipment shown in Figure 13.1 will fail, although they could.

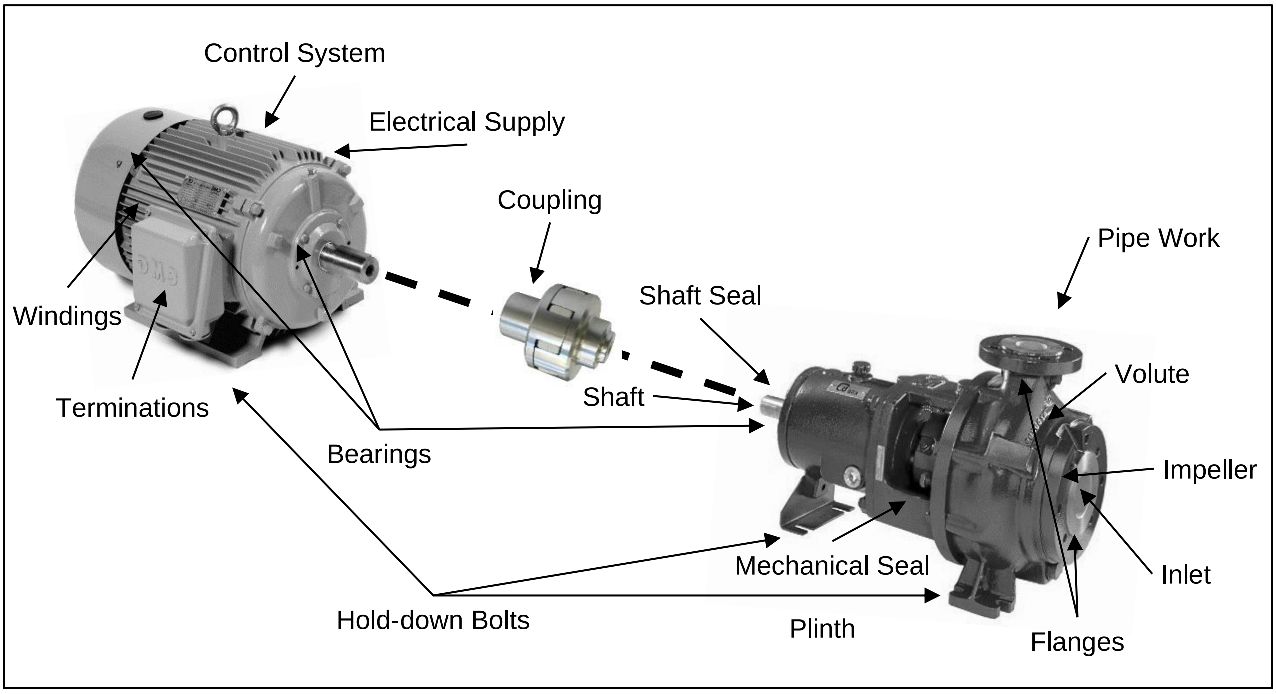

Figure 13.1—Equipment Can Fail in Many Places and in Many Ways

Because a maintenance strategy developed from an "all that may fail" approach primarily focuses on imagined failures, the maintenance performed does not match what is required to prevent the real causes of risk. Figure 13.2 shows what happens in the maintenance management system when real risk is not considered during the maintenance strategy selection process.

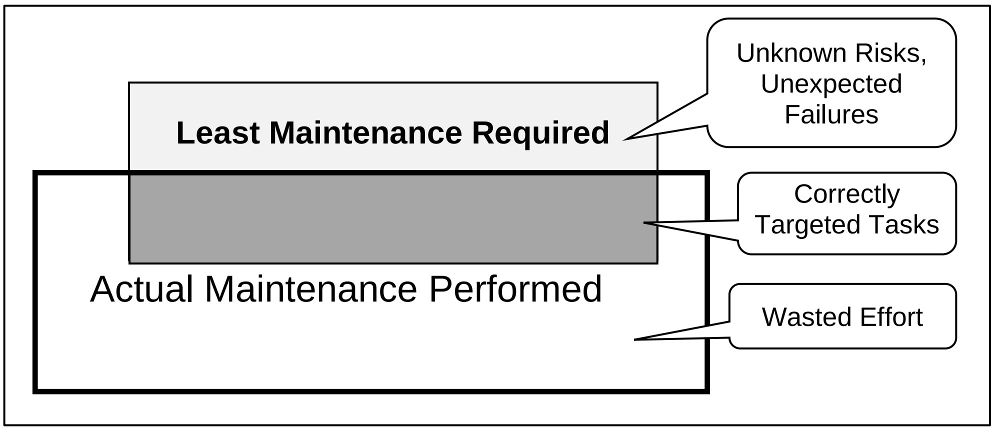

Figure 13.2—Doing the Wrong Maintenance Is Wasteful

It is the actual threat that is the essential element in choosing the management strategy and actions to address operating risk and workplace safety. The requirement to assess where operational risks come from cannot be left undone because it is those failure events that occur that will put life and the business in danger. The expenditure of maintenance dollars on operating risk management (e.g., condition monitoring, process control, etc.) needs to be directly related to the probability of failure events and their consequent effects. This is how to be sure your maintenance expenditure gets the best return for the investment.

Standard risk assessment methodology applies to all risk situations. The risk management phases as normally applied to plant and equipment maintenance are shown in Figure 13.3.

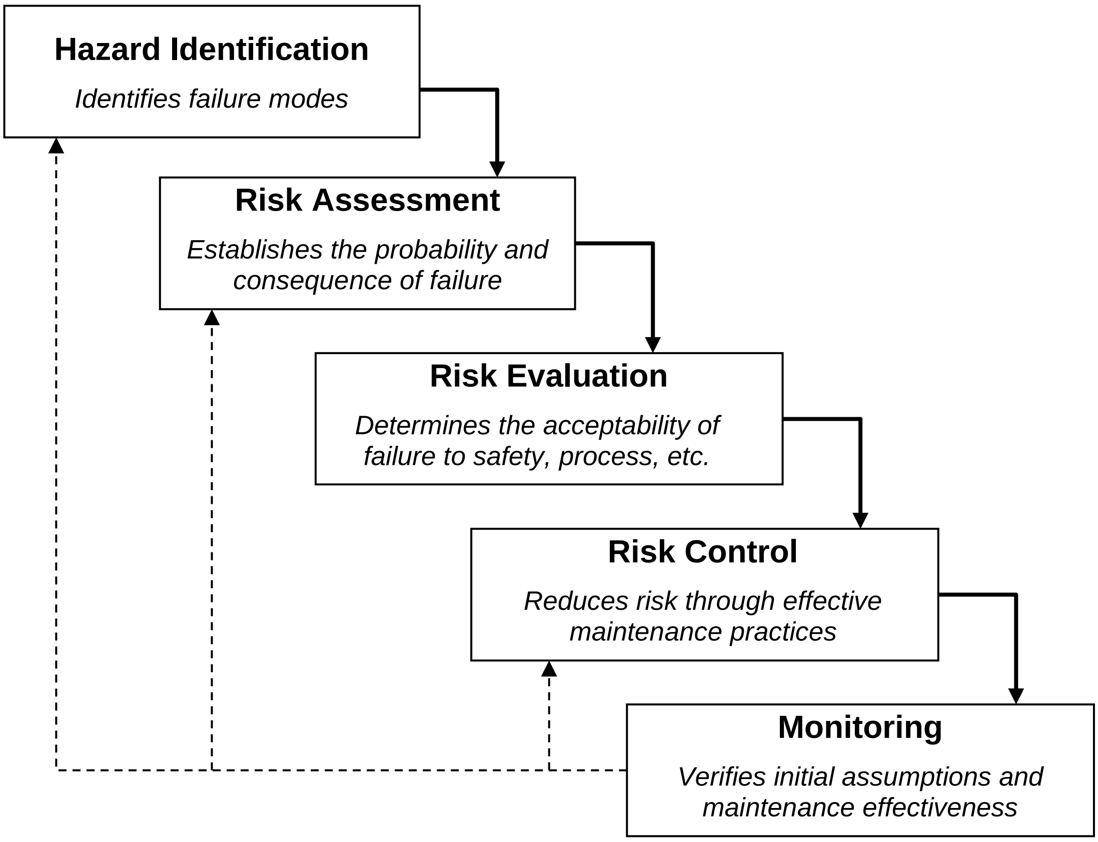

Figure 13.3—The Application of Risk-Based Principles to Maintenance

This risk review approach to maintenance activity selection aims to identify the ways in which an item of equipment may fail. Then, depending on the criticality of the asset, consider whether it is possible to detect and measure how the failure process develops (from which predictive maintenance arises), or consider its previous failure history and use hindsight to identify whether age fatigue or normal use will lead to failure (from which preventive maintenance arises). Those failures having no operating, safety, or environmental effects are allowed to run to failure (from which breakdown maintenance arises) and then repaired.

Frequently, reasonable judgments based on experience can be made without the rigor and expense of exhaustive risk analysis. Sometimes a formal math-based quantitative risk assessment using event probabilities is necessary, and decisions are made based on those outcomes. This is often the case in statutory-related risk management.

The decision tree shown in Figure 13.4 is typical of the experience-based maintenance activity selection processes generally used in industry. If the answer is that no evidence of failure is detectable, then, depending on the criticality or risk, either planned preventive maintenance, functional tests, or breakdown maintenance is applied. If the answer is yes and the criticality justifies the cost, then condition-based maintenance will be applied. If the answer is yes but criticality does not justify it, then planned preventive or breakdown maintenance is chosen. The approach thus far requires that every item of plant (system, machine, component) be reviewed, criticality considered, and a decision made about the maintenance it will get—repair on failure, scheduled replacement, proof test, or condition-based failure detection. In most operations, the maintenance performed is aimed at failure detection (condition monitoring) and failure correction (repair before failure). As a result, maintenance activities are focused on the equipment's current failure state—even though such activities are not effective at preventing failures from arising in the first place.

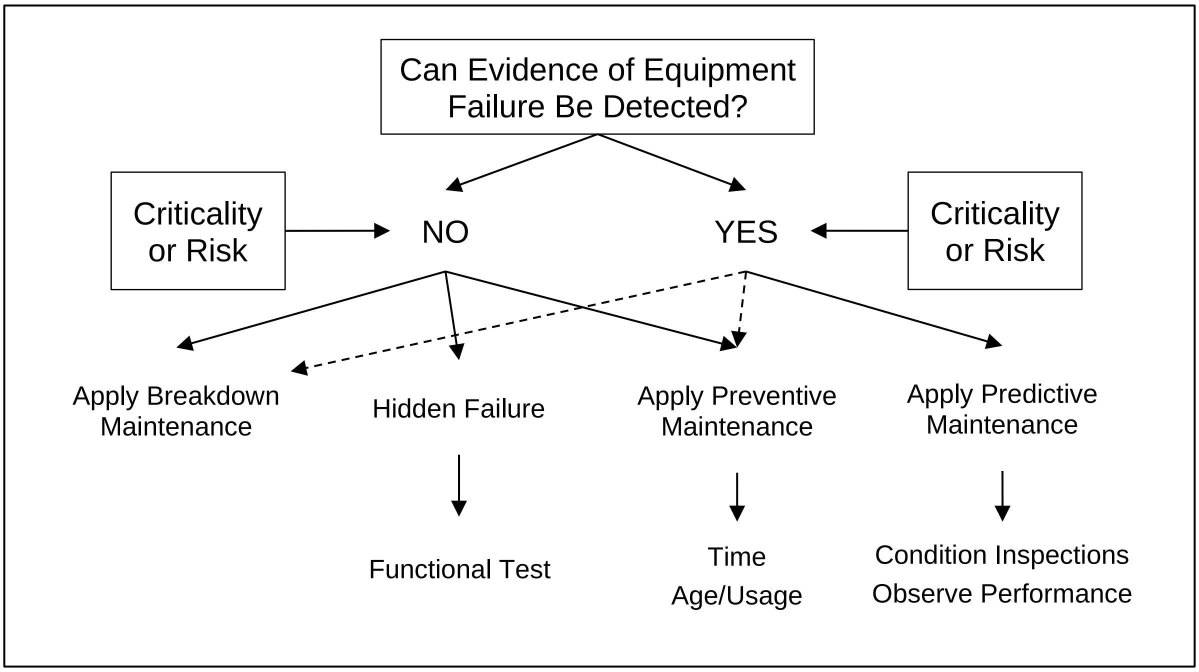

Figure 13.4—Common Risk Decision Tree for Maintenance Tasks

Targeting maintenance to critical operating equipment failures focuses on failure detection strategies that identify when a risk of failure exists. Because maintenance is better aligned with risk, the maintenance management system delivers the outcome shown in Figure 13.5. A good proportion of the activities undertaken will reduce risk, but not all equipment problems will be prevented, and significant proportion of the maintenance effort will continue to be pointless.

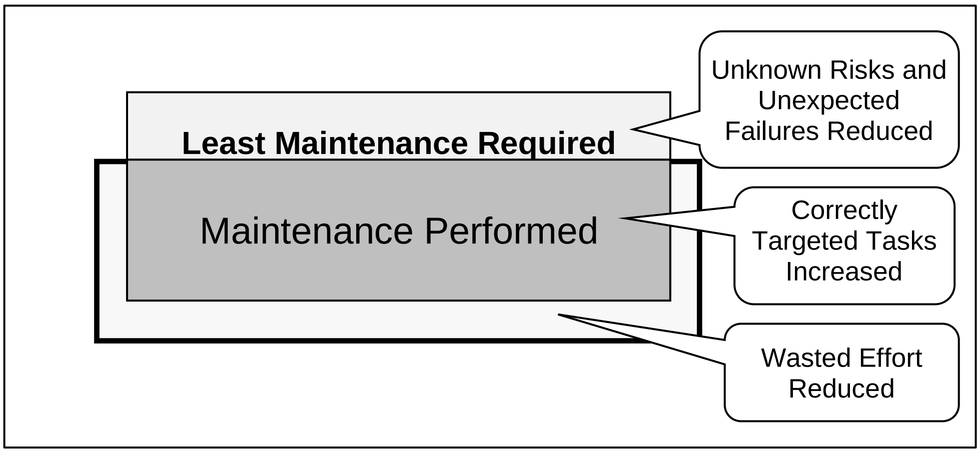

Figure 13.5—Failure Detection Focus Minimizes Maintenance

<u>The Failure Prevention Focus of Plant Wellness</u>

The Plant Wellness Way takes a different approach to protecting plant and equipment—it asks, “What needs to be done to keep component microstructure healthy and in full strength condition?” The risk assessment is done early in the life cycle, as indicated in Figure 13.6, and is used to identify the necessary risk management activities that must be introduced throughout an equipment component’s lifetime to ensure the least operational risk when the equipment is in use.

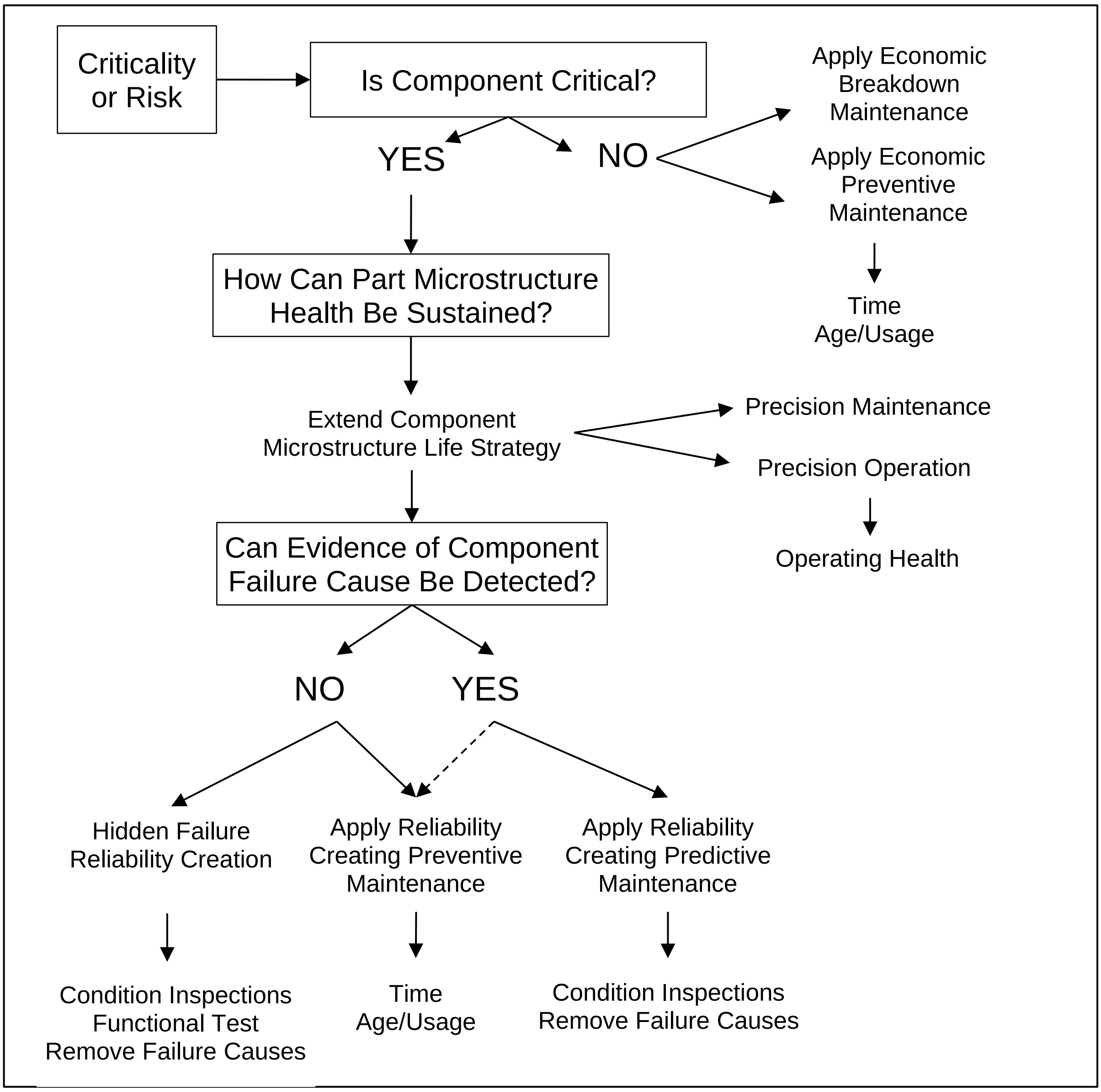

Figure 13.6—Risk Decision Tree for Plant Wellness Tasks

Using a life-cycle defect elimination and failure prevention strategy focused on ensuring the endless health of components gives you a maintenance management system with the outcome shown in Figure 13.7. Now maintenance proactively prevents risk and eliminates its causes. Every task brings operational benefit by improving uptime and maximizing throughput from highly reliable machines and equipment.

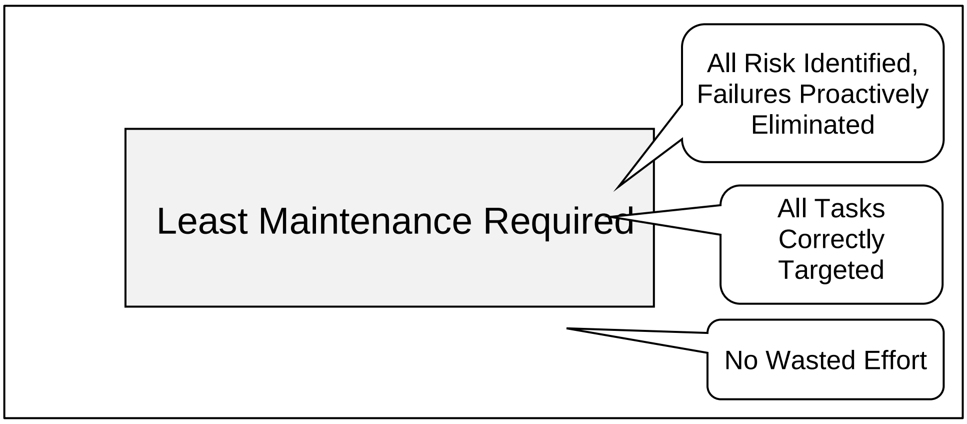

Figure 13.7—Maintenance Minimized to Sustain Equipment Health

Maintenance Cannot Deliver World-Class Reliability

Figure 13.8 is representative of the maintenance strategies available and the plant uptime they can achieve in a continuous process plant operation. It hints at the answer to getting highly reliable plant and equipment. Point A, near to 90% availability, can never be reached in reactive operations. These unfortunate businesses are doomed to always have costly maintenance and poor production performance. A combined strategy of preventive, predictive, and planned maintenance might achieve around 90% availability. These businesses will get better production performance and lower maintenance costs because their maintenance efforts are well coordinated with production needs. Of the standard methodologies currently available combining reliability growth, precision maintenance, and defect elimination strategies brings the greatest operating profit margin. Point B shows that availability—and, by implication, equipment reliability—has little to do with how much money you spend on maintenance. It is the choice of strategy that matters most. For identical maintenance costs, the strategy selected has the greatest effect on production and maintenance performance. Because the Plant Wellness Way starts with a fully designed and established life cycle long and business-wide “system of reliability” it is unlike any existing maintenance strategies and produces exceptional productivity almost immediately.

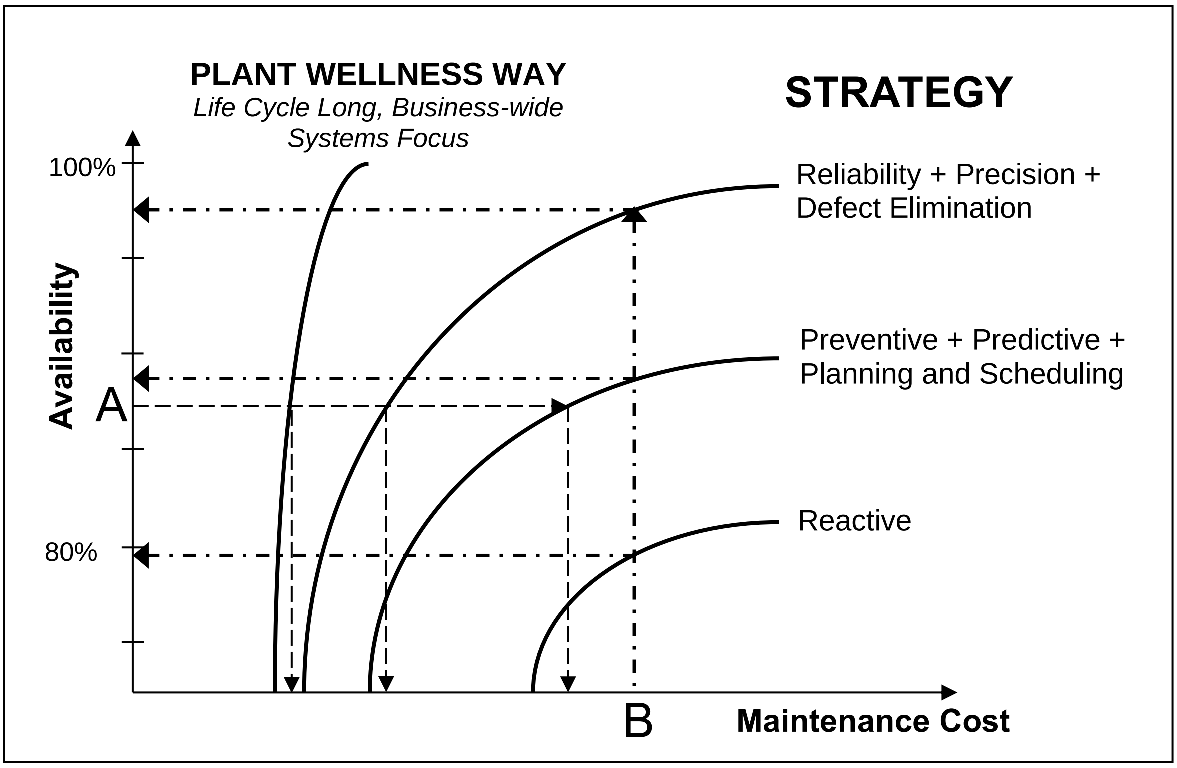

Figure 13.8—Availability and Maintenance Cost is a Result of Asset Management Strategy

Figure 13.9 highlights that the Plant Wellness Way also gets you to world class performance far faster than any other viable strategy. The Plant Wellness Way produces highly reliable plant and machinery because it is a holistic business system containing the best methods and the most effective solutions by design. It proactively identifies and removes operational risks from throughout the life cycle to get utmost equipment reliability, plant availability, asset utilization and minimum production unit cost from the start. The Boardroom decision to use Plant Wellness Way as a company's asset management and reliability creation methodology ensures its business processes and reliability practices quickly create and bring lasting maintenance and operational success.

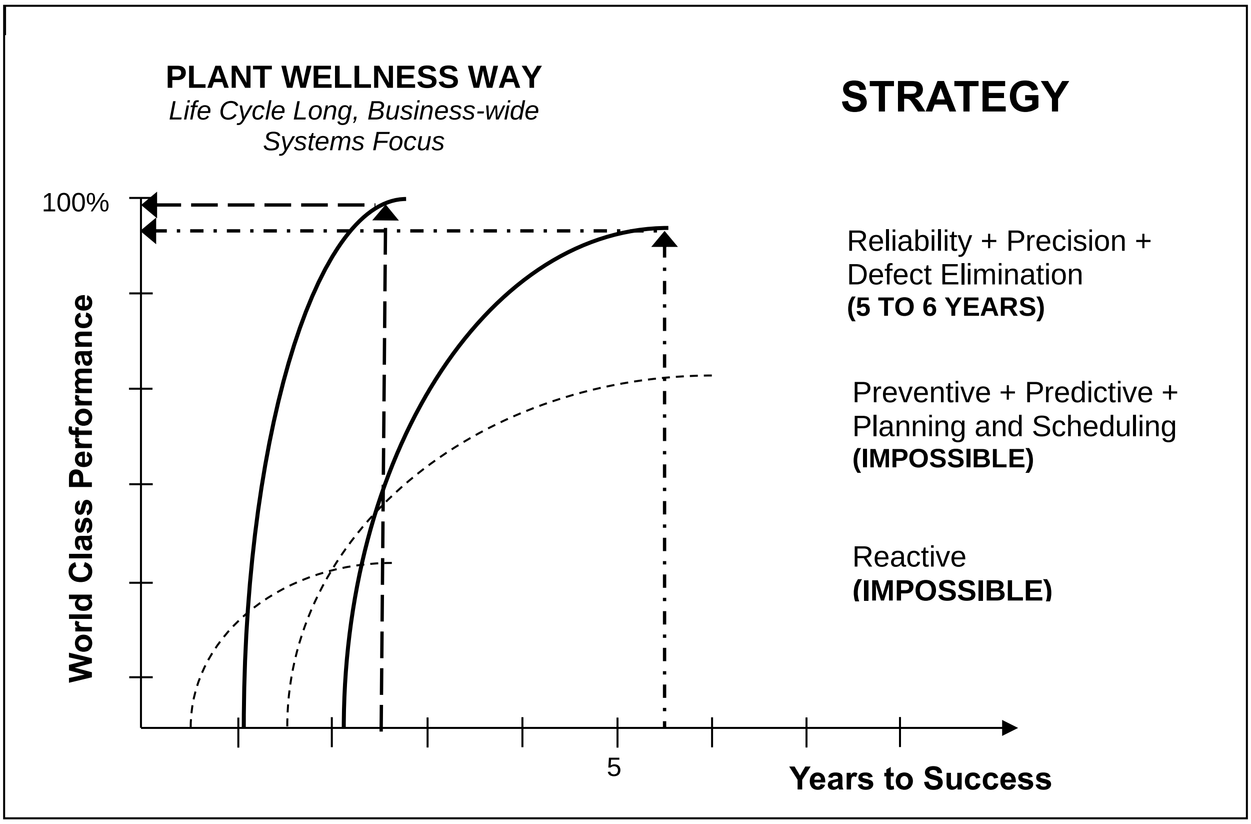

Figure 13.9—Speed to World Class Performance is a Result of Asset Management Strategy

Table 13.1 lists the number of days of lost production in a continuous operation for different values of availability. To go from a reactive operation with 80% availability to a site with 90% plant availability means halving the number of days lost to downtime. To go from 90% to 95% availability requires downtime to be halved again. To get to 99% availability from 95% means gaining back a further 14 days of downtime. It is impossible to halve current downtime losses using a company's current processes. The downtime that an industrial operation suffers is the result of the processes it uses. Halving your downtime requires using life cycle and business processes that inherently produce the necessary uptime. To go from 80% availability to 90%, then to 95%, then to 99%, means a total replacement and rebuild of the vision, systems, paradigms, knowledge base and skill sets used in a company. For each jump in availability the organization must first develop, and properly use, the right reliability creation and asset management processes with the capability to make and sustain the next jump. Only when an organization recreates itself and builds effective processes to achieve each level of success can the subsequent results be gained.

For Continuous Operation Plant		
Availability (%)	**Downtime** (days/yr)	**Uptime** (days/yr)
80	73	292
85	55	310
90	37	328
95	18	347
98	7	356
99	3.7	361.3
99.5	1.8	365.2
99.9	8.8 hrs	364.7

Table 13.1—Downtime versus Availability (Uptime)

Reactive maintenance is an easy but disastrous business decision for an organization to make. It leads to poor equipment utilization, much production downtime, and high operating and maintenance costs. Unless your products sell at high premiums and you can easily afford the excessive operational costs of using reactive maintenance practices, your business will continually struggle with high production losses and unsatisfactory operating profit.

Combining preventive, predictive, and planned maintenance is expected to lead to higher plant availability and improved operational performance. This maintenance strategy involves being prepared and organized to do necessary rectifications before there is an equipment breakdown. Replacing parts with new ones before they fail can bring higher equipment availability from the restored equipment service life. This approach minimizes plant downtime and reduces equipment maintenance costs by preventing unplanned production loss. But planned outages stop the production of saleable product. If there were no outage, product would have made. Maintenance shutdowns and turnarounds may be planned and scheduled to minimize lost production time, but the total cost includes the lost opportunity to make more operating profit.

Another drawback of planned and scheduled maintenance is the work performed may not actually be effective in lifting plant availability. You can have a good and efficient maintenance planning and scheduling process, yet the work done on an asset is shoddy, wrong or damaging to component health. Excellent maintenance planning and scheduling that makes efficient use of resources and production time is a necessary requirement for getting high plant availability, but it cannot create reliability. The maintenance maybe planned and scheduled but it is the precision quality of the work performed that causes the equipment to be reliable.

The reliability growth, precision, and defect elimination strategy is not really a maintenance strategy; it's a reliability creation strategy. You embed reliability growth, precision quality, and defect prevention practices into a plant reliability management system that extends across the asset operating lifetime. That choice leads to the use of practices and methods that produce outstanding plant and equipment availability because assets are never allowed to fail. You use effective, economic preventive, predictive, and planned maintenance activities focused on sustaining asset health and not on finding faults to fix. The Plant Wellness Way also delivers effective operating plant reliability management strategies and requires good maintenance planning and scheduling to be done, but its focus on component microstructure health creates a life cycle long system of reliability where operating risk is eliminated in every phase of the life cycle and not only in the operating phase.

Plant Maintenance That Makes Operating Profit

All the maintenance strategy options shown in Figure 13.8 involve using your maintenance crew, but only one uses tactics that rapidly lead to outstanding equipment reliability and world-class production performance with the least equipment maintenance costs. The Plant Wellness Way life cycle component health focus is the key difference between it and the other maintenance strategies, which are all asset level focused. It recognises that maintenance plays a small part in equipment reliability and brings into play all the other necessary elements needed to get failure-free operation. High reliability is dependent on the robustness of the engineered design, the quality of parts manufacture, the precision of workmanship used during assembly, the accuracy of installation during construction, the exactness of maintenance reassembly, and the stability of the operating envelope. World-class maintenance is only a sixth of what you need to do right.

To get utmost operating profit from your production assets, you need to take a life-cycle profit optimization perspective. This makes you consider the entire life cycle to get greater operating profits. Once an operation is in production, you only have stress reduction and degradation prevention options. But with a life-cycle profit focus, you make sure everyone across the lifetime of your assets maximizes operating profitability. You get the project group to create outstanding equipment reliability in your operation, you get your suppliers to do all that they can to create lasting reliability in your plant and equipment, and you get your maintenance and production crews to do work that brings the most operating profit.

Maintenance is a risk management strategy wrongly applied by organizations when it is used for consequence management to fix equipment and correct initiated failures. When maintenance is used to limit losses and costs, it becomes an expense to be minimized. If instead maintenance is used to reduce the chance of failure by proactively preventing defects so that equipment reliability rises, it becomes a profit-making activity. Now the maintenance effort removes problems and results in a lower-cost operation and higher productivity. Maintenance used to eliminate failures makes money.

Physics of Failure Reliability Strategy Analysis

Figure 13.10 shows how the Plant Wellness Way is used to select an effective strategy mix for proactive risk reduction of equipment parts. Operating criticality determines which equipment component failure brings too much risk. For these parts, you identify the causes of their material-of-construction destruction with a Physics of Failure Factors Analysis.

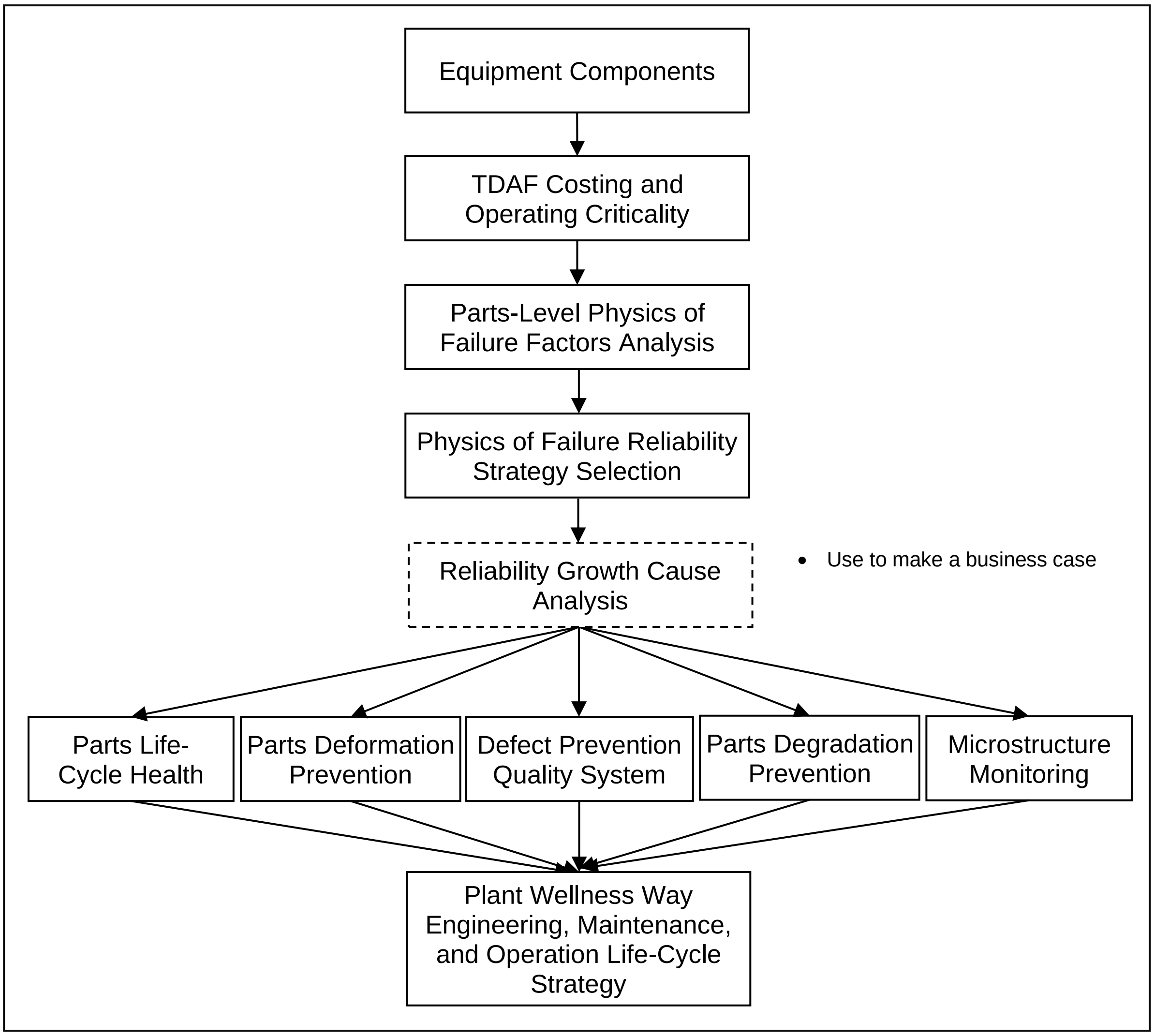

Figure 13.10—Developing Plant Wellness Strategy for Risk Management

A Physics of Failure Reliability Strategy Analysis takes the POFFA failure causes for each critical component and identifies how to get exceptional lifelong equipment reliability by preventing all the causes of failure. With Physics of Failure Reliability Strategy Analysis, you choose chance reduction strategies and defect elimination solutions to prevent failure mechanisms and embed them into your business and plant life-cycle processes. By doing so, you develop a coherent, complete, and standardized strategy to get utmost reliability from the parts throughout your facilities, equipment, and infrastructure.

In doing a Physics of Failure Reliability Strategy Analysis, all of the causes of microstructure failure are addressed with the right plans and the right actions at the most appropriate places in the component's life cycle. The plans are implemented by introducing necessary changes and practices into a company's processes, workplace procedures, and supply chain vendor management. Planned maintenance work orders detail the breakdown, preventive, predictive, and precision maintenance activities needed to control the level of equipment risk. Engineering and maintenance activities incorporate the failure prevention, defect elimination, and precision tasks that stop failure causes. The operations group procedures contain activities to reduce and control variation so that stable operation below microstructure threshold stress levels is standard practice. Equipment makers, suppliers, and service providers deliver quality machinery and workmanship. In this way, everyone reduces operating equipment risk by staying within the constraints of an asset's Physics of Failure limits.

Once developed, your reliability creation strategy and plans are transformed into effective actions that are approved by all key stakeholders and embedded in documents across the operation. The stakeholders are the board, senior executives, finance, engineering, operations, procurement, and maintenance department managers and their work team supervisors. They review the equipment reliability plans and include anything else they feel is necessary. Meetings are held with relevant workplace groups to explain and discuss the plans and the roles the groups will play in their achievement. Providing avenues of communication and opportunity for discussion helps gather support from the people who need to endorse or implement the new strategies.

Life-Cycle Tasks, Work Procedures, and Critical Spares

The Physics of Failure Reliability Strategy Analysis develops mitigations to eliminate the causes of component risk. Risk reduction strategy selections throughout the equipment life cycle are permitted. These include choosing the specific work quality controls to be applied during a critical part's construction; selecting condition monitoring inspections; specifying particular component health maintenance; picking the most economic preventive maintenance option; choosing equipment replacement policies and timing (i.e., replace with new on failure or near end of life); justifying critical spares holding; and stipulating breakdown recovery strategies for the part.

Preferred mitigations are those that significantly remove the frequency of equipment parts overload stress and stress accumulation. These are most effective at reducing the risk of failure.[2] Other acceptable abatements include those that substantially lower the opportunity for a defect to occur and those that make a component far more robust and durable in service. Less favoured solutions are those that only reduce consequences, although they, too, are used when they clearly save substantial amounts of money and effort.

During manufacture, precision work and component quality are crucial to eliminate defect creation. On installation, precision and work quality are vital to prevent distortion. During operation, low-stress operating practices are used to minimize degradation. When parts are stored, apply top-class stores management practices to retain reliability. Procedures for each asset need to be written down, specifying the reliability creation activities to be done by operators and maintainers and stipulating the precision quality methods to be used. All work orders are to be fully and accurately planned. The work orders contain the risk reduction and reliability creation activities and quality standards needed to keep risk levels low and reliability high. They are scheduled to be done before the chance of failure rises above a low risk level and put into the computerized maintenance management system so that details are never forgotten. All work orders are done when due, so you get the maximum risk control benefits and production successes from your reliability creation strategy.

Because you are creating highly reliable equipment, you can expect a marked decrease in the range and number of critical spare parts you need to keep on hand once the plans are properly implemented. Critical spares are kept because their availability lowers your risk. During a breakdown, they ensure that you can recover and return to operation most quickly. They are also used for proactive replacement of a severely aged working part. The correct critical spare stocking practice is to let the economics of carrying a spare drive the holding decision. You should only buy a critical spare and store and maintain it if that is the least expensive TDAF cost choice.

A useful precaution against error and misunderstanding when choosing mitigations for high and extreme risk levels is to gather a team of competent people knowledgeable in the situation. Team agreement is best when revising event frequency or likelihood for catastrophic scenarios. A group decision that is well debated and discussed benefits from the “wisdom of crowds” for arriving at a good and reliable consensus.[3]

Gradually, you build a proactive engineering, maintenance, and operational strategy with the practices that deliver highly reliable equipment. No longer is there mystery as to what maintenance to do and why it must be done, or why plant and machinery are only operated in specified ways that minimize stress, or why limits are set for production process variables to reduce microstructure degradation. Now the type and content of engineering, operating, and maintenance done in your operation matches those needed to maximize reliability, productivity, and business success.

Verifying Business Benefits

To accept that a suggested improvement is effective, it must be unquestionable in its ability to reduce risk levels by a substantial percentage over what would have been the case without it. Proposed risk controls need to be proven that they will be effective. The prevention strategies identified to limit the chance of failure and any actions chosen to minimize the consequence of failure need to reduce risk to the required level. Estimating the extent of risk reduction can be done using a table formatted with the headings shown in Table 13.2. If necessary, tests and trials can be conducted on equipment to confirm the stress reduction gained by a suggested mitigation. Measurements such as reduced electrical power use, lowered equipment vibration levels, decreased operating temperatures, and other appropriate indicators of lower stress can be used.

Ref No.	Equipment Tag No.	Equipment Description	Failure Event or Causes	Estimated Original Risk ($/yr)	Engineering, Maintenance, and Operational Activities to Reduce Risk	Years Equipment Remaining in Service or Expected to Be in Service	Current No. of Historic Failure Events Due to Cause (/yr)	No. of Failure Events or Expected Due to Cause after Risk Reduction	Annualized Likelihood of Failure Event after Risk Reduced (/yr)	TDAF Cost of Failure Event ($)	Estimated Remaining Risk ($/yr)
1	2	3	4	5	6	7	8	9	10	11	12

Table 13.2—Equipment Risk Reduction Layout

Many maintenance activities only add cost to a business and do not actually profit the business by making equipment reliable. If doing a maintenance activity does not reduce operating risk, then the work is a waste of time and resources with no business benefit whatsoever. A maintenance activity must reduce the cost of failure or the frequency of failure—preferably both. To show the benefit of a risk reduction decision, a calibrated risk matrix like that in Figure 13.11 is used to test a mitigation's value to the organization. On the matrix, you show the current TDAF cost risk if the part fails, and then you show the new risk, presuming that the selected Physics of Failure Reliability Strategy Analysis mitigations are in place and properly done. Provided that an improvement substantially reduces an event's frequency or substantially reduces its consequent cost, it will show up as a real business benefit on the risk matrix. Once a mitigation proposal is proven financially sound, it gives you strong reason and justification to make the necessary changes in your business processes and practices.

Likelihood of Equipment Failure Event per Year				TDAF Cost per Event		$30	$100	$300	$1,000	$3,000	$10,000	$30,000	$100,000	$300,000	$1,000,000	$3,000,000	$10,000,000	$30,000,000	$100,000,000	$300,000,000	$1,000,000,000
Event Count per Year	Time Scale	Descriptor Scale	Historic Description			C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
						1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9
100	Twice per week	Certain		L13	2	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11
30	Once per fortnight	Certain		L12	1.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5
10	Once per month	Certain		L11	1	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
3	Once per quarter	Certain		L10	0.5				3.5	4							7.5	8	8.5	9	9.5
1	Once per year	Almost Certain	Event will occur on an annual basis	L9	0					3.5							7	7.5	8	8.5	9
0.3	Once every 3 years	Likely	Event has occurred several times or more in a lifetime career	L8	-0.5												6.5	7	7.5	8	8.5
0.1	Once per 10 years	Possible	Event might occur once in a lifetime career	L7	-1												6	6.5	7	7.5	8
0.03	Once per 30 years	Unlikely	Event does occur somewhere from time to time	L6	-1.5												5.5	6	6.5	7	7.5
0.01	Once per 100 years	Rare	Heard of something like it occurring elsewhere	L5	-2												5	5.5	6	6.5	7
0.003	Once every 300 years			L4	-2.5										3.5	4	4.5	5	5.5	6	6.5
0.001	Once every 1,000 years	Very Rare	Never heard of this happening	L3	-3											3.5	4	4.5	5	5.5	6
0.0003	Once every 3,000 years			L2	-3.5												3.5	4	4.5	5	5.5
0.0001	Once every 10,000 years	Almost Incredible	Theoretically possible but not expected to occur	L1	-4													3.5	4	4.5	5

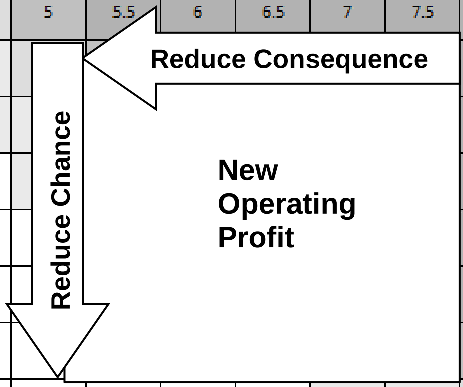

Figure 13.11—Prove Maintenance Strategy Brings Value to Your Business

Documenting Your Plant Reliability, Maintenance, and Operating Strategy

The development of a strategy starts by stating the outcomes required. The outcomes may not be easily achieved, but by continually improving your process designs, they will be realized.

Set the Business Objectives

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

- Halve current plant maintenance costs as a share of replacement asset value by adopting the Plant Wellness Way methodology.
- Reduce breakdown maintenance costs to less than 5% of total maintenance cost for the plant by making defect elimination a part of maintenance.
- Double the time between planned shutdowns and turnarounds by operating the process and its equipment for least degradation.

Plant Wellness Maintenance Management Strategy Process

Figure 13.12 is a flowchart that summarizes the maintenance management issues addressed during Physics of Failure Reliability Strategy Analysis. Operational risk control strategy is developed for each critical equipment. Taking one asset at a time, you identify all its threats to your operation's success and eliminate them. Failure cause after failure cause is removed from critical assemblies and components. It takes effort and time to do such detailed risk assessment and risk control selection, but the thoroughness protects your business by greatly reducing the chance of catastrophe over the operating lifetime of an asset. Once a reliability strategy to get the utmost operating profits is set, it is vital to fully execute the risk reduction activities.

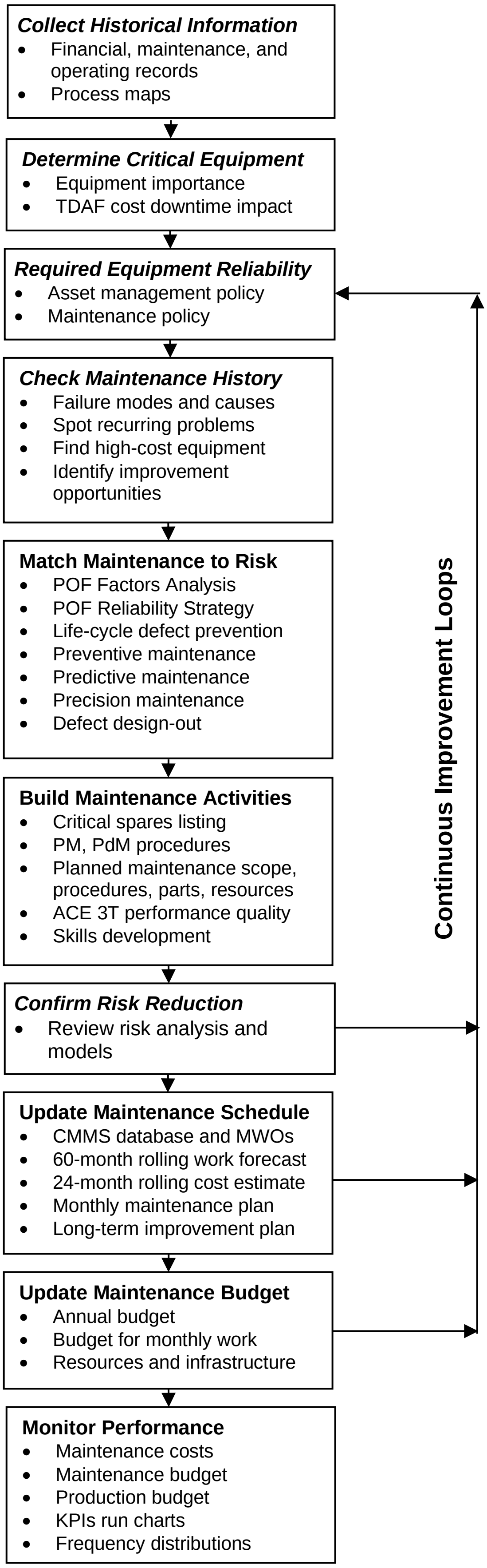

Figure 13.12—Turn Plant Wellness into Planned Maintenance

<u>Example Equipment Risk Reduction Strategy for a Pump-Set Bearings</u>

Developing a maintenance strategy to prevent the failure of a centrifugal pump-set starts by drawing a process map for the equipment. Each of its assemblies is then analysed by using Physics of Failure Reliability Strategy Analysis. During the analysis, a maintenance strategy is developed that delivers high reliability for all components. An example of the final operational risk reduction strategy for a pump's bearings is shown in Table 13.3. If the proposed operational and maintenance activities are carried out properly, they will ensure that the pump bearings have a long, failure-free life. The precision maintenance laser alignment removes the chance of overstressing parts, and the inspections remove the risk of unknown environmental and operational degradation. The likelihood of a bearing failure on the risk matrix goes from "likely" to "very rare" and the criticality goes from high to low.

Operational Risk Reduction Strategy for Centrifugal Pump Bearings								
Equipment Tag No.	**Current Failure Events**	**Failure Events Frequency**	**TDAF Cost of Failure**	**Risk Reduction Activity**	**Improvement Expected**	**Frequency of Activity**	**Cost/Yr**	**Failure Event Reduction**
Pump 1	Bearings fail	2 years	$35,000	Laser shaft alignment to precision practices every time the pump is installed	A precision alignment is expected to deliver 5 years between bearing failures	Every strip-down	$200	Failure interval likely to be greater than 5 years
				Oil and wear particle analysis every 1,000 hours of operation	Oil and wear particle analysis can indicate the start of failure several hundred hours prior the event	1,000 hours or six months	$600	Failure will be prevented by a predictive planned condition monitoring task
				Visual inspection by the operator each shift of the oil level in the sight glass	Visual inspection of the oil level ensures the bearings are always lubricated	Every day shift	No cost	Failure will be prevented by operator condition monitoring
				Operator physically touches pump bearing housing each week to feel for changed temperature and vibration	Touching the bearing housing will identify problems before they cause failure	Wednesday day shift	No cost	Failure will be prevented by operator condition monitoring**Error! Bookmark not defined.**

				Motor load monitoring using process control system to count overloads	Monitoring the electrical load will identify how badly and how often the equipment is stressed by overload	Continuous with monthly report to operations manager	$100	Poor operating practices will be identified, and personnel trained in correct methods
				Pump performance monitoring of discharge flow and pressure using process control system	Monitoring the pump performance will indicate gradual changes of pump internal clearances affecting service duty	Continuous with monthly report to operations manager	$100	No direct impact on reducing risk of pump failure, but identifies performance drop and allows planned maintenance to rectify internal wear

Table 13.3—Example Equipment Operation and Maintenance Strategy Development

Contents of an Asset Maintenance Strategy and Plans Document

A document recording all of the outcomes and recommendations from your life-cycle reliability strategy will be required so that all stakeholders can review your strategic asset management plans. Typical issues in a life-cycle reliability strategy document are listed below. If there are other specific needs required in your operation, add them into the Physics of Failure Reliability Strategy Analysis. The development of strategic asset management plans is a large undertaking. But without them, maintenance and operations fly by the seat of their pants, everything becomes guesswork, and the business is run too much by luck rather than by good management. Without a sure strategy and plans to achieve your asset management and maintenance policies, vast amounts of production time and money will be wasted. With a Physics of Failure Reliability Strategy, you have the best chance of becoming a top performing operation. Turning your company into a world-class leader is a job worth doing well.

Contained in each of the following sections is an overview of the range of issues and plans that your life-cycle asset management and maintenance strategy document should address.

Asset Management and Maintenance Visions

Why you do physical asset management or maintenance and how they help the business.

Asset Management and Maintenance Policies

What your business aims to achieve with asset management and maintenance, how it is to be done, who will do it, what is expected for the organization in the long run.

Production Performance Envelope

What daily plant availability is needed to meet production output? What is the average and the peak production rate to sustain the required output and not compromise production asset reliability? What is the minimum daily quality rate required to meet production plans? What is the uptime needed for each piece of plant to deliver the required total plant availability? How much can you afford to spend on maintenance and repairs? Typical headings under which these questions are answered in your strategy and plan document include those noted below.

- Production performance required
- Production costs required
- Process reliability analysis (chart your production process to identify its reliability weaknesses and likely performance problems)

Risk Assessment of Operational Assets

What can go wrong with your equipment, what will it cost, how often does it happen? Risk analysis is done using the "Operating Criticality" spreadsheet with the TDAF costs as the consequence value.

- Equipment used, description, and service duty (i.e., each asset used and its duty)
- Financial and throughput impact on production of failures in each equipment item
- Operating criticality (prioritize the importance of the equipment to sustaining production)
- Assembly level criticality (e.g., foundations, base frame, pump, coupling, motor, power supply)
- Physics of Failure Factors Analysis at the part level to identify the ways in which equipment parts can fail

Production Risk Management Plan

How maintenance is used at the parts and assembly level to reduce production risk at the equipment level. The related decision making is part of completing a Physics of Failure Reliability Strategy Analysis using the worksheet provided in the spreadsheet accompanying this book.

Precision Maintenance Standards

The specific engineering values of world-class maintenance quality and accuracy needed to deliver outstanding plant and equipment reliability (mechanical, electrical, instrumentation, structural, civil, etc.)

Precision Operation Standards

The quality and accuracy needed to run plant and equipment to meet operational performance at least degradation and least maintenance costs (mechanical, electrical, instrumentation, structural, civil, safety, environmental, etc.)

List Equipment on Preventive Maintenance

The equipment and parts to adjust, and those requiring replacement of wearing parts.

- List of equipment and their assemblies done as shutdown, as opportunity-based preventive maintenance, or as time/usage scheduled preventive maintenance
- Precision standards when performing preventive maintenance

List Equipment on Predictive Maintenance

The equipment and parts monitored to detect impending failure and restore before failure.

- What condition monitoring will be used?
- Where will the condition monitoring be done?
- How will it be decided when it is time to maintain or replace?
- Who will competently do the condition monitoring? (i.e., subcontract, in-house maintainer, in-house operator)
- Who is the competent person responsible for receiving the report, understanding its information, and acting on it?
- What will be done when the condition has deteriorated too far?

List Equipment to Rebuild

Those equipment, assemblies, and parts that are to be repaired.

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

List Equipment to Replace

Identify the equipment and assembly parts that always should be replaced and not repaired. The TDAF cost of a breakdown often justifies installing new equipment rather than taking the chance of keeping and reusing old, tired equipment that will cause an unplanned production stoppage.

- Assemble and part numbers replaced new and the criteria when replacement occurs
- Routable spares and the number of times used before disposal and replacement with new
- Precision standards new equipment must meet
- Precision standards to meet on installation

Critical Spares List

The vital equipment, assemblies, and parts you must always have available on site.

- Equipment or parts to be carried on site
- Equipment or parts to be carried by a local supplier
- Stores management standards to protect the integrity of each type of spare

Records Management

Indicate all the engineering, operating, maintenance, and procurement documents needed. Specify the necessary documented maintenance history to be kept of equipment and parts usage to identify future reliability improvement opportunities.

- The engineering, operational, and maintenance documents to keep
- How documents are to be kept current and safe
- What records are to be made and kept during each equipment life
- What analysis of records will be required and the information to be provided by the analysis?
- How records and documents will be controlled, and their content kept correct and current

Maintenance Performance Monitoring

Identify the monitoring and measuring to be undertaken to ensure that maintenance is delivering the reliability, availability, quality, and cost that the production plan requires. These measures often become Key Performance Indicators (KPIs) in business reports.

- Definition, formula, and data sources for each measure
- Plant-level KPIs (e.g., availability, unit cost of production, quality rate, maintenance cost proportion of production cost)

- Equipment-level KPIs (e.g., uptime, quality rate, production rate, maintenance cost)
- Personnel KPIs (e.g., hours spent developing skills, employee satisfaction)
- Maintenance process performance KPIs (e.g., daily work order completed per trade type, backlog of work, percentage planned work, percentage scheduled achievement)
- Maintenance improvement KPIs (e.g., number of procedures written to ACE 3T standard, number of design-out projects started, number of design-out projects completed)
- Reliability prediction KPIs (e.g., number of work orders spent improving reliability, reliability improvement graphs such as Crow-AMSAA plots)
- Plant wellness index audit (annually measure the capability of the organization to create and sustain high-reliability plant)
- Specify the run charts to be kept and the frequency distribution curves to be plotted

Maintenance Resources Required

Identify all manning, infrastructure, equipment, and support services needed to resource the production risk management activities known as maintenance.

- Necessary maintenance equipment and technologies
- Necessary stores capacity and stores internal operating methodologies
- Necessary engineering and maintenance knowledge
- Necessary trade skills and competence
- Necessary numbers of people by trade type/service
- Location of people for most efficient operation of maintenance activities
- Necessary computerized maintenance management system capabilities

Cost–Benefit Analysis

Prove and confirm that the cost of doing maintenance will return value to the business.

- Annual maintenance cost versus the cost of failures prevented (the risk analysis will provide the TDAF costs that will be incurred by the business if equipment fails)
- Annual maintenance cost versus the cost of lost production output if plant availability does not meet production targets (production and equipment history is used to determine the numbers of production slowdowns and stoppages in an average year that did not need to happen)
- Maintenance costs as a proportion of operating costs

Rolling Five-Year Maintenance Program

To provide focus and drive reliability improvement, indicate exactly when and what is to be done during the next five years for each item of plant to deliver maximum production productivity.

- Work orders by type performed on each equipment item and the benefits provided
- Schedule of work orders for each equipment
- Reliability improvement projects planned for each equipment item

Rolling Two-Year Maintenance Budget

Develop a believable budget that will deliver the risk control that production needs. Using a rolling two-year forecast allows inclusion of the savings from future improvement initiatives. Two years is a believable period for anticipating changes and planning reliability improvements. Beyond two years, forecasting becomes unrealistic because one cannot anticipate the impacts of a continually changing world.

- Maintenance cost by equipment
- Maintenance cost by plant
- Maintenance cost by type
- Maintenance cost per period
- Costs estimates to do equipment improvement plans

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

FOOTNOTES

1. Thanks to Peter Brown, Industrial Training Associates, Perth, Western Australia, for the use of his concepts.

2. David J. Smith, *Reliability, Maintainability, and Risk*, 7th ed. (Boston: Elsevier, 2005).

3. James Surowiecki, *The Wisdom of Crowds: Why the Many Are Smarter than the Few and How Collective Wisdom Shapes Business, Economies, Societies, and Nations* (New York: Doubleday, 2004).