III.PHYSICAL ASSET OPTIMIZATION FOUNDATION PRINCIPLES

"… this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth. … But in a very real sense, it will not be one man going to the moon-if we make this judgment affirmatively; it will be an entire nation. For all of us must work to put him there." John F. Kennedy

Asset optimization is business oriented; profit centered and directed to attaining greatest lifetime effectiveness and value from physical production assets. The process begins at design and continues through procurement, installation and operation. It includes maintenance and finally ends at removal from service and disposal.

Asset optimization includes safety, environmental and social responsibility, institutional values and culture, organizational structure and reporting, process, practice and technology. Activities and improvements are prioritized for the specific business and operating conditions. They are implemented opportunistically within a value matrix to gain greatest return from increased production capability and effectiveness and optimized spending. Metrics that link to business and financial objectives are employed throughout the asset optimization process to establish objectives, identify opportunities and measure progress.

Information and management systems must be integrated and capable of effective mining to identify performance gaps as well as convey current status, predicted asset lifetime and capacity, effectiveness of operating, management and logistics processes. Asset optimization requires that maintenance is a vital part of production, partner of operations and managed as a core business activity to gain maximum asset effectiveness and return.

BASIC REQUIREMENTS

The following ingredients are essential to ensure the success and best possible contribution of asset optimization:

- Total understanding of the necessity and benefits for optimizing the performance and effectiveness of the physical asset base including the contribution of essential value to mission compliance, increased profitability, availability, production output, quality, and reduced cost.
- Forceful, energetic top-level leadership totally committed to the program and its success.
- Ambitious, optimistic, and achievable objectives established at working levels.

  To gain the ownership and commitment essential for success the people who are going to do the work must identify specific opportunities for improvement and develop the fulfillment plan.
- Financial prioritization of improvement initiatives for greatest value and contribution.
- Organization, practice, and technology changes implemented to address specific requirements.
- Activity-based accounting to accurately assess real costs and value.
- Layered metrics to measure and ensure compliance with interim and final objectives.
- Information structure to monitor and display performance.
- Rewards for results and value created.
- Commitment to continuous improvement and identification of additional opportunities for improvement.

Ensuring Success

The asset optimization program must be driven top down, led middle out and accomplished bottom up. Some have called this process "Shared Leadership".[122] Business conditions, specifically value creation and increasing profit, are the basis for prioritization and provide the sequence for implementing improvement initiatives. The process requires a clear understanding of the principal factors that determine and drive profit.

Successful asset optimization typically requires:

- An organizational culture shift to initiative, ownership and, accountability.
- A streamlined administrative organization.
- Improved coordination and communications.
- Commitment to reducing the need for and the cost of maintenance.
- An optimized mix of processes practices and technology to accomplish the objectives.

Important actions necessary to derive maximum value and profit include designing for reliability and maintainability and eliminating root cause problems. The latter includes actions such as upgrading materials, improving the quality and integrity of basic requirements (lubrication, integrity checks) and providing better operator and craft training. Systematic elimination of minor deficiencies before they lead to major damage and interrupt production is the key to optimum asset optimization. Few would argue with a statement that fire prevention is far more cost effective than fire fighting.

OPTIMIZATION PROGRAM PRINCIPLES

Obtaining the desired product at minimum cost is the goal of all manufacturing and production processes. As illustrated in the financial model contained in Chapter VI, a production process requires numerous contributing elements. In addition to raw materials, these include electricity, fuel, water, people, logistics, administrative and technical support, training, and services such as waste removal.

Dealing with, controlling and optimizing the lifetime cost of ownership requires an understanding of what the actual life really is and how the operating environment, operations, and maintenance of the plant affect the bottom line.

Are mission effectiveness and value determined by production availability (capacity), market conditions (demand), operating (conversion) and maintenance costs? Typically it will be some combination of two or more of these. The answer is vitally important, because it establishes the prioritization of opportunities within an asset optimization program, as well as the basis for deployment and allocation of resources. Safety is always a paramount consideration. Regulatory (environmental) factors have a strong effect, as do product and work quality. In the following sections some of these philosophical issues will be examined enroute to a description of the process itself in Chapter IV.

As stated, an asset optimization program necessitates safety and environmental excellence and leads to improved institutional values and culture, organizational structure, process and equipment reliability, increased operating efficiency, improved operability and maintainability, effective work and logistics (supply chain) management and optimized spending. Institutional cultural issues that must be addressed during an asset optimization program include values, behavior, ownership and communications. Additional issues include a multi-skilled team workforce compared to the more common functional workforce; decentralized compared to centralized organization; core competencies that determine the necessity of in-house or a potential for outsourced work; personnel qualifications and training.

> *For the purposes of this handbook, core competencies are defined as those that involve critical business or proprietary information, must be fully aligned with business decisions, deliver a direct contribution to the dominant value driver and cannot be obtained from multiple sources. Any aspect of the business operation that delivers a strategic business advantage must be considered a core competency.*

Asset optimization takes a holistic overview of the asset procurement; installation and lifetime care process. It defines the entire process from top to bottom. This leads to a prioritized view of equipment cost versus durability, compatible operating requirements, best practices for lifetime care, and similar issues. Those responsible for asset utilization and optimization have a vested interest in the success and continued viability of the organization. Soliciting input from reliability professionals may lengthen a decision process to some degree; however, a mutually agreeable consensus will increase the likelihood that all potential problems will be identified, an appropriate risk assessment will be made, and the final decision will optimize risk and costs.

Business Driven

Although most of the processes and practices necessary to assemble an effective asset optimization program are readily available, many organizations are not yet realizing its full value. One reason appears to be inadequate communications between reliability professionals and senior management. (The term reliability professional is used within the handbook in its broadest sense to include all involved in the asset optimization and care process). Many reliability professionals express frustration, believing that their past and future contributions to corporate success and profitability are endangered by management decisions that focus solely on short-term cost reductions. Seen from management's side, a narrow focus on physical achievements and technology rather than business constraints, priority and results may inhibit the necessary dialog.

Corporate executives and financial managers argue that customers, shareholders, and boards of directors are the primary driving force behind cost reductions. In the past, profit margins and excess capacity were typically sufficient to allow reliability professionals to pursue narrow goals without much discipline or requirements to demonstrate real value. With both profit margins and excess capacity being squeezed, future investment for productivity-improving technology and practices must be supported with compelling financial justification. As a result, reliability professionals must learn to speak business in order to translate results into financial terms that are credible and appealing to executives and senior management — executives are not going to make the translation from business to technical reliability!

Asset optimization is a business process. There are permanent cost reductions, value, and profits to be gained through visionary, enlightened, transformational change. Maintenance can be controlled, planned, and optimized for maximum value. Maintenance cannot be deferred too long or ignored; deferred costs will reappear in the future, greatly multiplied in both financial terms and impact. The familiar "pay me now or much more later!"

The choice is clear. Lead with asset optimization or wait until it is imposed by the same competitive pressures that forced adoption of modern manufacturing practices such as Lean, Just in Time (JIT) and Statistical Quality Control (SQC).

Profit and Results Oriented

Asset optimization is a results oriented lean process, rather than being activity and task protective. Opportunities, prioritization and measures of performance are financially based. Profit center, rather than cost center, principles direct the entire process. It incorporates and builds on the best attributes of Six Sigma, Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM) and others — assembled and optimized to gain greatest value within specific plant conditions and business / operating objectives.

Profit Centered Management

The need for asset optimization that differs from past practice is apparent to many professionals.[70] Cost-centered management; the traditional method of asset care is directed to compliance with an operating budget. It is activity and task protective, risk adverse and contains structural disincentives for optimization. Everyone knows the reward for under budget performance in a cost center! In contrast, profit-centered management advocated within asset optimization is value and results oriented; encourages investment, and accepts added operating costs in order to increase value, improve efficiency and take advantage of opportunities. A profit center rewards agility and initiative and demands ownership, responsibility and accountability. A premium is placed on optimization. Investments and added costs are evaluated from the standpoint of results and return. A profit center is certainly healthier and better suited to asset optimization in a complex process or manufacturing environment.

Asset optimization focuses on profitability and value gained over a lifetime of operation. The principles require seeking improvement opportunities prioritized by value. Opportunities mentioned previously include improved safety, reliability, production output, quality and capital effectiveness. Reducing cost by replacing or modifying equipment that is operating inefficiently is an often-neglected opportunity to create value. In addition to reducing operating costs, changes to improve efficiency often also improve reliability.

Specific examples in the equipment area that can have very attractive returns include:

- Assuring that operating conditions match design specifications.
- Extending life by upgrading to corrosion resistant materials.
- Considering replacement with higher efficiency equivalents.
- Installing sealed bearings and / or bearing isolators to ensure contamination-free lifetime equipment lubrication.

- Eliminating failures caused by pipestrain induced casing distortion and shaft misalignment.
- Self-venting seal housings.[86]

A facility has a pump improvement program in place that calls for installing a standard suite of reliability enhancing modifications whenever a pump is repaired. [129]

There are dozens of such opportunities in every industry — all must be prioritized by financial return.

An oil refinery increased profit tenfold simply by focusing on opportunity rather than cost.[129]

Within the concept of asset optimization, maintenance (asset care) shifts from keeping individual equipment operating to optimizing reliability, ensuring process and system integrity and effectiveness.

Directed to Gaining Maximum Value from Operations

Insisting on maximum value over least cost is a long-term commitment that requires a top to bottom change in organizational culture. This is a concept that is difficult to establish as the normal way of conducting business.

Return on Investment (ROI) and Net Present Value (NPV) are two conventional ways to calculate the relative value of projects and decisions in order to objectively determine maximum value. (NPV and ROI are lagging indicators, Chapter IX, results of profit center activities that indicate success only after the fact!) Framing operational issues and schedule impacting asset care decisions in value terms is a profit center mentality and greater challenge. For the typical organization trained to think of minimizing costs, the concept of maximum value may be unfamiliar. The profit center, value concept of reducing costs as a percentage of operating hours or production output in units — MW, pounds, tons, barrels, etc. — is quite different and leads to greater value than cost reduction. It automatically considers opportunities for increased production, yield, quality, and efficiency. The financial model and process presented in Chapter VII may be of assistance.

Within the financial model, benefits from improved practice and technology are translated into financial terms so that decision makers can identify and will support the initial and sustaining investments to gain maximum value.[34]

An industry leading company reports full access to cost and spending information through their ERP system. This has led to a worldwide corporate drive to establish cost per unit output as a KPI for all facilities. From a reliability perspective the organization is being asked for an investment in time, effort, resources (human and technical) and money to gain a return in terms of:

- *Improved safety and environmental performance*
- *Increased production due to improved plant availability*
- *Reduced maintenance cost*
- *Improved overall efficiency and effectiveness*

All have a positive effect and will lead to a more profitable organization. The company advises that organizations that can obtain effectiveness information such as cost per unit output, and more importantly a trend over time, will have an excellent indicator of the effectiveness of the improvement program.

Benefits of improved equipment management that are driven by asset optimization and translate into real financial value include:[34]

- Reduced safety incidents, elimination of industrial injuries, improved environmental compliance.
- Increased utilization, availability and production rate.
- Improved quality.
- Maximum conversion effectiveness — optimized cost.
- Minimum failures, scheduled and unscheduled outages.
- Reduced O&M costs.
  - Reduced energy usage
  - Eliminated maintenance actions, reduced maintenance costs.
- Reduced spare parts inventory (increased capital effectiveness).

Unifying Partnership between Maintenance and Production

By definition, asset optimization imposes broad requirements and demands results that are well beyond the capacity of any single functional area. Perhaps asset optimization is best viewed as a unifying link between Production, Production Planning, Process Control and Maintenance that requires all functions fully aligned. Asset optimization provides the production capacity needed to assure that mission requirements can be met safely at optimum output, quality (yield), efficiency, and profitability.

These concepts are illustrated in Figure 3.1. Note that revenue, asset utilization and cost are the three prime contributors to corporate / mission effectiveness, expressed as RONA and ROCE.

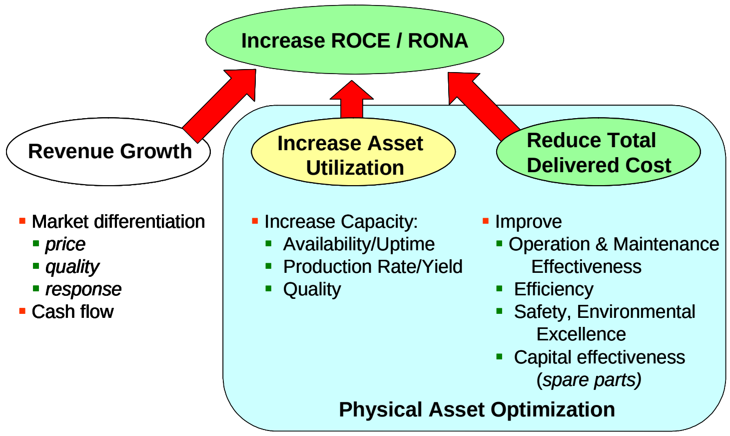


Figure 3.1 Physical Asset Optimization Focuses on Results

Costs Controlled by Reducing Requirements for Spending

Every company that produces a product, with the possible exception of Ferrari, must operate within cost constraints. From industry benchmarks and other data all companies know what costs are necessary to meet overall profitability objectives. They are also well aware of cost metrics for individual activities such as asset care (maintenance) and work management. In other words, industry benchmark costs define how much maintenance is affordable for a given business and level of production. If affordable maintenance is less than what seems necessary to keep the means of production operable, a plan must be developed and placed into effect to increase reliability and reduce maintenance requirements. The real question is not how much maintenance is considered necessary, but rather what is affordable for a given business. Again, this clearly points to a conclusion that eliminating failures — and the need for spending — is the only way to reach cost objectives.

Eliminating Defects — the Key Imperative of the Physical Asset Optimization Process

A reliability oriented culture of excellence that views defect elimination as a prime opportunity for improvement is the key imperative to increasing asset effectiveness and reducing spending. Eliminating defects addresses all the consequences of failures. Focusing solely on labor cost — as many do who are fixated on costs — immediately limits improvements to the labor component of a typical repair — approximately 50% of the total cost in North America! By eliminating defects, costs — both labor and material — are safely and permanently eliminated. Eliminating defects leads to corresponding reductions throughout the organization, including cutbacks in idle capital used for redundancy, work-in-process inventory, and spare parts. Negative cash flow caused by failure events is minimized, operating availability and production effectiveness increase. Supporting processes such as work management gain in quality and effectiveness due to the ability to concentrate resources and improve planning.

Risk Assessment, Management and Control are Essential

Risk Management, consisting of threat identification, assessment, prioritization and mitigation is an essential part of the process used by industry leaders to minimize surprise events. It is proactive in nature, and directed to identifying threats long before occurrence. Industry leaders understand that risk is not simply consequences, but probability of the failure event *multiplied by* consequences if the failure occurs. Risk Management involves taking solid action to reduce probability or consequences — optimally both.

Industry leaders identify risk and recognize and mitigate problems that have not yet happened. The rest wait until failure symptoms occur to take action thereby risking costly “surprises”. Three events are illustrative:

A refinery recognized that the lubrication and seal oil system on a vital compressor that could shut down a major part of the facility did not meet current design standards or practice. Controls were antiquated and many felt that the automatic start system for the spare lubricating oil pump was unreliable. Although there had never been a failure or outage attributed to this vital system, most with knowledge considered it a serious event just waiting to happen. Eventually the decision was made to replace the entire system. The task was thoroughly planned. A replacement was engineered, procured and installed successfully during a scheduled turnaround.

Two pumps in hot hydrocarbon service were normally operated in parallel as a process reliability measure. The two pumps had flat head vs. flow characteristic curves and, in parallel, operated in a risky low flow regime. Both pumps had historically experienced high rates of bearing failures. The threat was well known. The plant depended on periodic vibration readings and an assumption that changes would be noted in time to recognize a problem and shut a pump down prior to failure. Eventually, a multi million dollar failure occurred when deteriorating conditions were not recognized quickly enough to avoid catastrophic failure and a resulting fire.

A third facility requiring 120 percent capacity, decided to operate two 100 percent centrifugal pumps in parallel. The rationale was that at 60 percent each the pumps should be “loafing” and hence more reliable. They knew about but didn’t consider the risks inherent in low flow operation, the possibility that slight differences could cause one pump to assume more than half load, starving the other even further and the potential consequences of a low flow induced failure. An engineer stated that plant policy was not to consider risk in the economic analysis of projects to mitigate the effects of changes in operating procedures. Since without considering risk the cost of reduced equipment life was quite low compared to the gains from increased production, permanent corrective action couldn’t be justified. A failure to consider risk when changing operating conditions is irresponsible.

Industry leading companies utilize risk ranking, described in more detail in Chapter XIII, to ensure that attention and effort are focused on the greatest threats and potentially most rewarding opportunities. The risk ranking process must be formulated such that only about 10% to 15% of total equipment and system assets are in the highest risk category. With a greater percentage of equipment in the highest risk category there is basically no prioritization or assurance that efforts are applied to the most needed areas. As a result, corrective efforts are diluted.

In one case a facility conducted a “criticality” assessment, to identify systems that were critical to production. The criticality assessment, ignoring actual operating history, identified approximately 1,600 systems out of about 2,200 total systems as critical first priority for application of RCM. After about a year of effort by a dozen or so reliability professionals, optimized programs had been developed and implemented for approximately 200 systems — 13% of the total considered most critical. At that point the program was more or less abandoned due to priorities, demotivated participants, diminished resources and uncertain returns. Did the 200 analyses that had been completed cover the highest priority / risk systems or address the most threatening potential problems with greatest value recovery? No one knew — that issue hadn’t been addressed.

PROGRAM OBJECTIVE

Maximize Return on Assets through an Optimum, Sustainable Lifetime Strategy

Asset optimization focuses on the lifetime cost of ownership, which includes design, procurement, and installation. As an example, over a full lifecycle the acquisition cost for typical rotating equipment may be 10 to 15 percent of the total cost, lifetime maintenance may be as low as 5 percent with operating cost typically comprising as much as 85 percent.[25]

A systems approach to the lifetime cost of owning physical production and manufacturing assets provides a means for managing every cost element at the margin to gain the highest returns on both new and existing assets. The objective is to maximize the revenue and related profit-generating potential of each and every physical asset.

Visionary manufacturers have shifted awareness from the here and now to an extended time horizon. Physical asset management strategies based on total lifetime ownership have become a fundamental extension of competitive awareness.[(25)]

Asset optimization provides the basis for collectively optimizing investment, resource allocation, and spending decisions to gain greatest lifetime return. The emphasis is on achieving maximum sustainable lifetime effectiveness from design, procurement, and installation through operation, maintenance, and eventual replacement or de-commissioning, Figure 3.2.

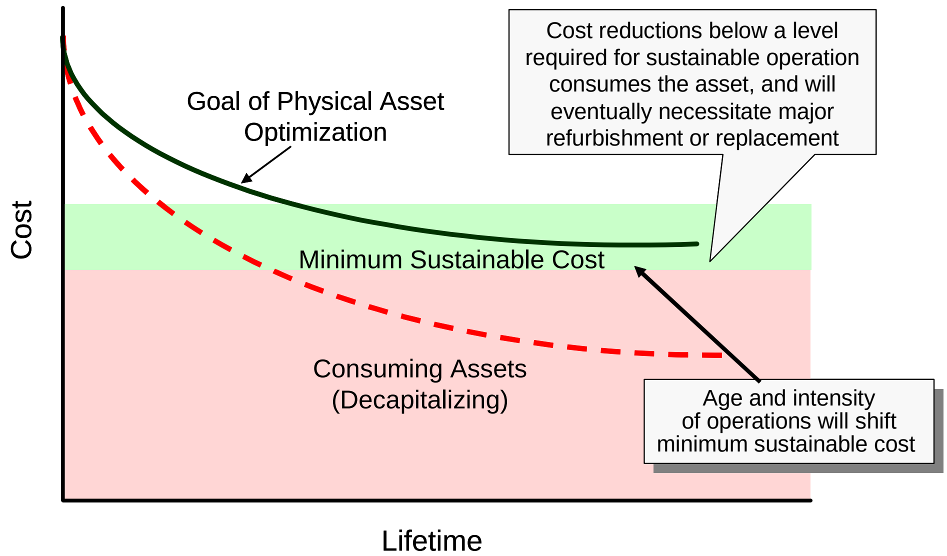


Figure 3.2 Sustainable Equipment Asset Optimization

As illustrated in Figure 3.2, the type and tempo of operations may raise or lower minimum sustainable costs. For example, operating above nameplate production rates may stress equipment and shorten lifetime. Likewise, shifts in operation to different raw material or fuel may accelerate corrosion rates and wear. Within the asset optimization process the trade-offs are known and demonstrated with a positive ROI.

As another example, a decision not to paint and / or preserve a structure for corrosion protection may require replacement of the structure long before its designed end of life. Examples are readily apparent in nearly every major cold weather city. Cracks in concrete bridge abutments are allowed to persist. Water enters the crack, freezes and the crack expands. Eventually the crack reaches reinforcing steel, the combination of water and road salt causes corrosion and the deterioration accelerates. The section of concrete breaks off exposing the reinforcing steel to even greater corrosion. Ultimately the entire abutment will have to be replaced long before the end of design lifetime simply because a small amount of time and / or funds weren't made available to seal small cracks!

This example is all too typical. Cost reductions are often gained by deferring sustaining maintenance on capital assets. Probably few — if any — decision makers attempt to assess the risk of deferred maintenance[(7)] or calculate the Net Present Value (NPV) of their decisions. Many don't want to be bothered; others are focused on expediency rather than economic value. The penalties for deferring activities such as painting, sealing cracks, correcting steam and air leaks, and repairing damaged insulation are gradual and spread over time. The negative impact on operating budgets and the real costs and consequences of such decisions do not become apparent until production is affected or a major failure occurs. With a bit of luck the imperative for action won't be blamed on the individual responsible for the neglect.

The following cases demonstrate that maximizing profitable operation requires a program for predicting lifetime and reliability improvement achieved by correcting defects while operating alternatives are available.

One company lost 40,000 pounds of steam per hour during cold, wet weather as a result of defective insulation. When the loss began to affect production output, the obvious action of launching an effort to locate and restore defective insulation was ignored in favor of a capital project to install an additional boiler.[129]

Another company eliminated lubrication rounds as a cost savings measure. After approximately six months, valves, dampers, and moving equipment began to stick, requiring expensive maintenance and, in some cases, replacement.[129]

A third company determined that over lubrication was the cause of most motor bearing failures. Instead of optimizing the lubrication process for individual bearings they decided the best course of action was to cease lubricating motor bearings altogether! [129]

In all cases the asset optimization process considers the tradeoffs and value gained to construct the most effective and profitable lifetime asset management strategy for operational requirements. Within the balance, knowledge of current life expectancy, the rate of consumption and real cost under a given set of operating conditions are critical elements of maintaining maximum lifetime effectiveness.

Figure 3.3 illustrates the lifetime profile of typical operating and production assets ranging from process and manufacturing facilities to individual equipment. Shaded areas above the breakeven line represent the ability to meet mission requirements and profit. Interruptions, losses, and restrictions that prevent full compliance with mission requirements are shown as shaded areas below the breakeven line. Note that both the horizontal and vertical scales in this figure have been greatly exaggerated for the purposes of illustrating the concepts.

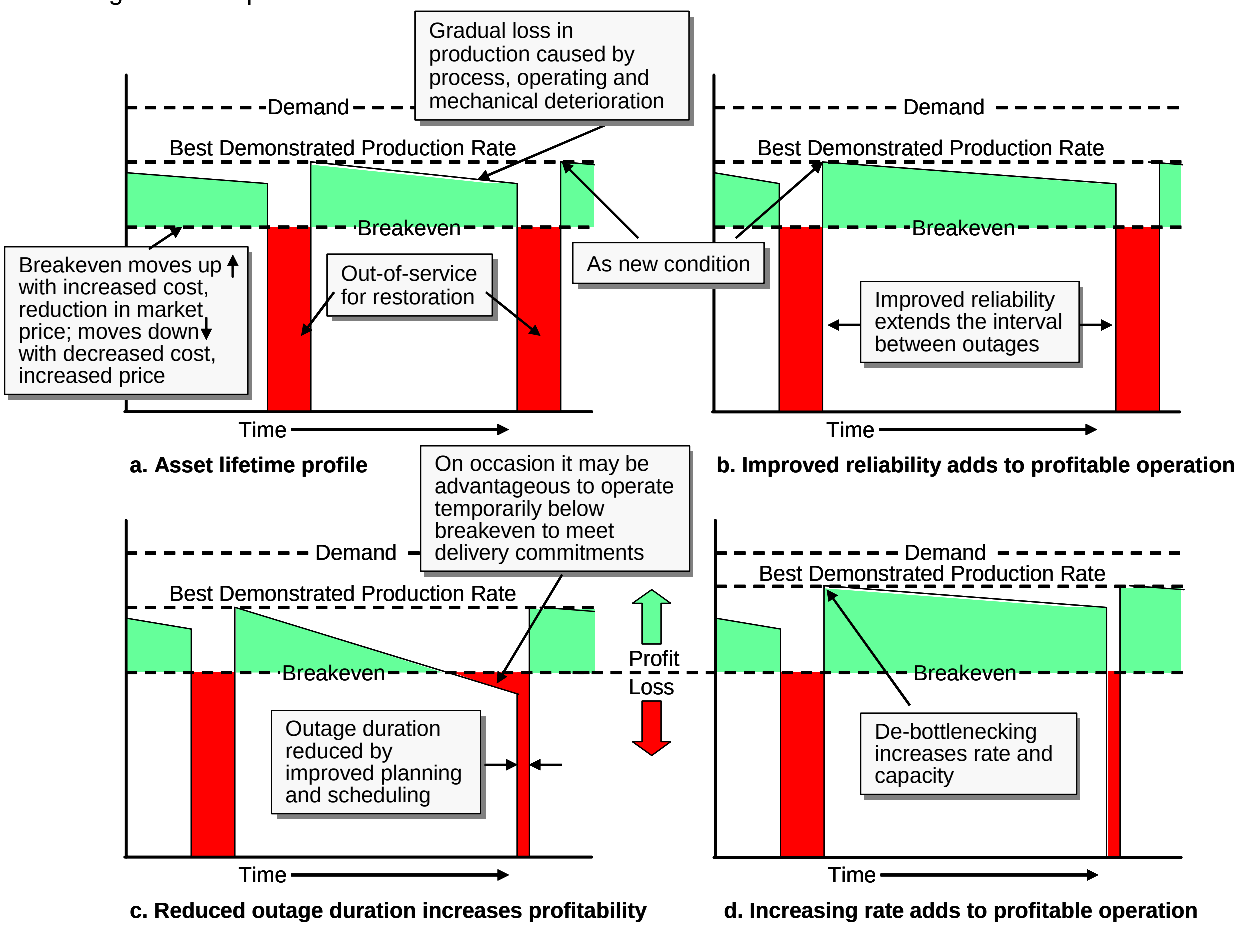


Figure 3.3 Intervention Improves Asset Effectiveness[129]

A gradual loss of profit and operating readiness can be caused by a variety of defects. These include deteriorating efficiency (greater cost), corrosion, heat exchange limits, mechanical constraints such as speed restrictions resulting from excessive vibration, valve leakage, declining catalyst activity (applicable to the hydrocarbon industry) and a host of other problems acting alone or in combination. Improved design, care in installation, proper operation, and maintenance all contribute to extended life and asset effectiveness. However, every asset must eventually be removed from service for restoration. The only questions are how often and for how long.

Three methods that can be used to increase profitable operation are illustrated in Figures 3.3b, c, and d.

Increasing reliability by eliminating life-shortening defects extends the time between restorative outages, as shown by Figure 3.3b. Profitable operating life, illustrated by the area above breakeven, increases. Shortening the duration of restorative outages reduces the non-service time that subtracts from asset operating life, effectiveness, and profit, as shown in Figure 3.3c. Within industry, objectives to double the interval between planned restorative outages (overhauls / turnarounds) and halve the duration of an outage are not uncommon. One Operations Superintendent stated an objective of doing away with planned outages altogether by doing more restorative work during operation and accomplishing restorative tasks during unplanned shutdowns that occur due to events such as power interruptions.

Figure 3.3c also illustrates operation with reduced capability below breakeven for some period of time. This type of operation at reduced capability is occasionally necessary to ensure successful mission completion, meet operating and delivery commitments, and preserve valuable customer relationships.

> *A manufacturer faced with heat exchanger degradation determined that while production could be maintained, the loss of efficiency resulted in significant unprofitability. Question — halt production to repair the exchanger or continue at a loss to fulfill customer JIT requirements? The manufacturer concluded that customer good will had greater value than temporary unprofitability and continued to supply product at a loss until delivery requirements had been met.*

Figure 3.3d shows how increasing rate and capacity by removing bottlenecks will increase profitable operation, as indicated by the shaded area above breakeven. In this case, de-bottlenecking is defined as removing process, operating, quality, and mechanical impediments to full operation — reducing the "hidden plant" described in Chapter IX.

STRATEGY BEGINS AT DESIGN

A 1997 article in *Maintenance Technology* stated that over 60 percent of equipment lifetime maintenance costs were caused by preventable errors during design, procurement, installation, operation, and maintenance, Figure 3.4.[108] Over 20 percent of these lifetime maintenance costs were due to design engineering and construction errors that could be avoided by appropriate design-related decisions.

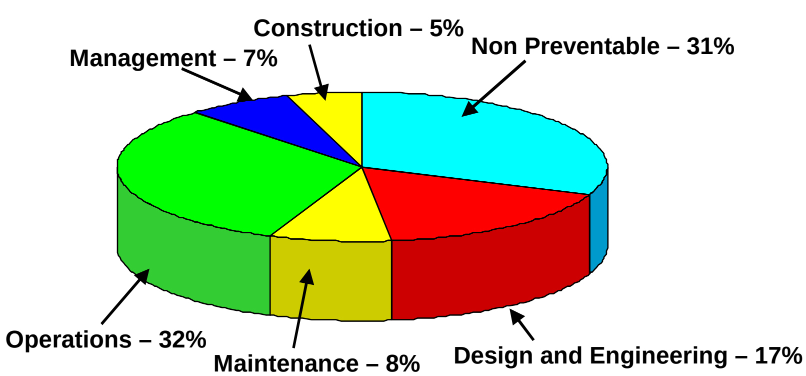


Figure 3.4 Division of Maintenance Costs by Origin [108]

In most facilities, rigorous design specifications are applied to critical equipment — typically large, unspared machines and other equipment whose loss interrupts production. Because of this scrutiny, critical equipment is usually quite reliable. It is designed with exceptional attention to detail, installed with great care and subjected to close attention and surveillance throughout its life. As a result, critical equipment typically operates for lengthy periods without attention or problems. Based on grouped lifecycle costs, critical equipment may be less expensive to maintain when compared to small general-purpose machines. Although the cost of any given maintenance “event” is typically much less for general-purpose equipment, the population is far larger and may consume more lifetime costs than critical machines. Chronic, repetitive problems that wouldn’t be tolerated on critical machines may be allowed to exist on smaller, spared equipment simply because they were designed that way! When lifetime costs are examined in detail it becomes obvious that chronic, repetitive failures, many caused by design defects and basically ignored, are a major opportunity for improvement.

> *System Reliability, Availability, and Maintainability (RAM), including component life and ease of repair, are inherent characteristics that originate at design and strongly influence the lifetime cost of ownership. Lifetime costs must be assessed more fundamentally during the design process. Good design eliminates or minimizes problems, including the opportunity for operating mistakes. The process must ensure that improvements and problems solved on existing equipment are incorporated in the design of new equipment. Compromises to reduce cost often result in facilities and equipment that are difficult and costly to operate and maintain. Once a system has been fielded, no improvement of RAM performance can be achieved without significant expense.* [45, 59, 62, 129]

Return on capital necessitates that new manufacturing facilities are designed with reduced operating margin and redundancy. As stated earlier, return on capital has necessitated as much as a 50 percent reduction in investment for capacity.[129]

An incident that occurred in a new plant illustrates where design can go astray.

> *Two deep-well pumps were installed to maintain level in a water storage tank open to atmosphere. The length and flexibility of the deep-well column caused the pumps to be highly unreliable with failures occurring nearly every month. Specifications disclosed that the design required pumping the tank empty when filled with ammonia-saturated water. While this condition could occur, it was extremely unlikely and could be accomplished with a portable pump if required. Plant personnel concluded that the installed pumps should be designed for normal conditions rather than unlikely, extreme conditions. The deep-well pumps were replaced with conventional in-line pumps. These pumps performed satisfactorily for years without any failures.*

Design Defects Identified and Eliminated Throughout Asset Lifetime

A reliability evaluation involves statistically estimating lifetime reliability.[29] When design and other intrinsic defects are present during the operating lifetime, gaining sufficient reliability to meet production goals through maintenance alone may be prohibitive in terms of costs.[22] Intervention required for effective equipment management will range from relatively simple inspections on equipment with high intrinsic reliability to comprehensive Preventive, Condition-Based and Proactive Maintenance on complex, critical systems and equipment.[68]

> *Asset optimization demands the elimination of design defects as well as defects introduced through fabrication, construction, installation, operation, and maintenance due to design weaknesses. Fundamental reliability-enhancing strategies including a reliability risk analysis are useful at design to ensure that in-service performance will meet lifetime expectations. Requirements must be incorporated in the design process.*[22] *See also Chapters VIII and XX.*

Maintenance and other support strategies are important, but they can only preserve the reliability that is built-into the asset.[22] A maintenance-only focus can consume inordinate resources when activities attempt to compensate for design or systemic weaknesses that are more effectively and efficiently addressed or eliminated in other ways.[22] Industry-leading reliability-driven organizations recognize that defects due to faulty design and installation must be eliminated This includes reduced lifetime brought about by off-design operation. In some cases components must be modified and materials upgraded. In others such as the pump example mentioned in the previous section, the equipment must be replaced altogether.

Correcting design deficiencies is a prime objective of asset optimization. There are opportunities to reduce spending by hundreds of thousands of dollars in most facilities by eliminating design defects; for some it may be in the millions! Far too many organizations accept serious design defects simply because “it has always been that way.”

> *In more than 40 asset optimization workshops conducted worldwide since 1997 nearly every participant cites major and continuing availability and cost problems due to uncorrected design deficiencies as a real concern.*

Maintenance Avoidance / Prevention

Courtesy Heinz Bloch

Maintenance Avoidance / Prevention is becoming a key component in the effort to gain greatest asset effectiveness. Maintenance Avoidance is based on the principle, stated earlier, that a large percentage of maintenance requirements for specific equipment are determined by its design. It is noteworthy that many of the world's most profitable companies share these beliefs. They know that avoiding maintenance by applying solid design, operating, repair and upgrade practices is more effective and less expensive than performing maintenance. That thought process starts at the inception of a plant with the knowledge that building-in maintenance *avoidance* is smarter than attempting to optimize maintenance on assets that are not optimized in design, Chapters VIII, XX.

The most profitable best practices companies:

- Know that it makes economic sense to justify, specify, buy, properly install and operate the right equipment to begin with.
- View every maintenance event as an opportunity to upgrade. They will understand measures available to upgrade and will pursue upgrading whenever the measure is cost-justified. That requires training, grooming and nurturing of talent. To translate: It requires long-range thinking.
- Practice root-cause (failure) analysis.
- Have low tolerance for repeat failures and will not accept "mystery explanations." Translation: There is accountability.
- Always pick the "ripe, low-hanging fruit" first. They make absolutely sure they have the "basics" right. Only then will they invest in sophisticated "icing-on-the-cake" or high-tech approaches.

Maintenance prevention focuses on initial design and design improvements throughout life to improve reliability and reduce requirements for maintenance.[124]

PROCUREMENT DIRECTED TO OPTIMIZING LIFETIME COST

Procurement based on low initial cost is false economy if unreliability, inefficiency, excessive maintenance and diminished quality quickly consume the initial price advantage.[25] Measures during lifetime to reduce cost of replacement parts and labor often result in reduced production availability and output and increased long-term costs. Relaxing material specifications, purchasing equipment sized to barely meet specifications, and challenged designs are examples of how savings at procurement can cause enormous losses during operation.

> *A number of years ago several chemical companies decided to purchase two-section turbo compressors, despite the fact that prior designs had all included an additional third section. Procurement savings were in the millions of dollars. In every case, design problems delayed startup for months. And this was just the beginning. The compressors proved highly unreliable in service, shutdowns were frequent, repairs difficult, expensive and time consuming. With production losses of $250,000 or more per day, the companies quickly consumed the procurement savings and lost considerably more.*

The time lag between decision and results may mask procurement problems. For example, visualize the sequence of events following a decision to purchase lower cost components that turn out to have a significantly shorter service life compared to the components they are replacing. At least two years will elapse from the time the replacement components arrive, are installed, and begin to fail before a pattern emerges. (Whether the pattern will be recognized at all may be questionable.) Assuming the failure pattern is recognized, there must be some record of the change, why it was made, conditions prior to the change, and expected return. Otherwise, the failure pattern may continue without anyone recognizing the deterioration from prior performance.

Some companies utilize site and corporate experience to select equipment based on highest efficiency and lowest lifetime cost.[25] A few apply offsets to quoted prices that compensate for the lifetime cost of ownership.[129]

Quality Installation is Essential

Quality installation is equally important to optimized lifetime cost. Industry leaders rigorously apply equipment installation specifications that include foundation preparation, base-plate leveling and grouting, pipe flange and shaft alignment, oil system flushing, pipe and separator cleaning.

A 1996 paper described conditions in a chemical plant about five years after commissioning. Pumps were experiencing a high failure rate attributed to coupling misalignment. The failure analysis disclosed that the problem was due to inadequate grouting that caused pumps to quickly go out of alignment during operation. The difference between the low-cost grouting used in the installation and "best-practice" was calculated to be approximately $1,500 per pump. The added cost to perform the installation correctly during construction would have paid for itself in about eight months. The cost to correct the problem during operation had multiplied about sevenfold.

Correct Operation must be Assured

The 1997 *Maintenance Technology* article referred to earlier, Figure 3.4, stated that 32 percent of maintenance expenditures were caused by avoidable operating errors.

A leading manufacturer determined that 28 percent of their maintenance costs were caused by abuse and poor operating practices.[129]

Avoidable operating errors include those caused by difficult, unusual, or easily forgotten operating procedures. Many potential operating problems can be prevented by simple modifications. Posting special startup requirements near a start switch may avoid problems caused by forgetting infrequently used procedures. Drilling an internal vent into pump seal cavities to ensure that vapor cannot collect, warp seal faces, and produce dry face contact at start is an example of a modification that will prevent failures and reduced reliability during operation.[86] Maintaining a positive pressure on bearing cavities located in areas of high moisture to prevent lubricant contamination is another.

Following a series of failures, one company found that warm up lines required and called for by start procedures at least ten years old had never been installed and no one had ever mentioned the discrepancy.

Improve Operating Efficiency

Electricity consumed during operation often comprises 50 to 80 percent of a motor's total lifetime cost. With a reasonable mean time between repair (MTBR), the operating cost of a typical mid-size pump will be about four times the maintenance cost. Stated another way, a 5 percent improvement in operating efficiency will offset 20 percent of the average maintenance costs. Considering these figures it is essential to maintain the highest possible lifetime operating efficiency of driven equipment by assuring operation is close to Best Efficiency Point (BEP).

In addition to power savings achieved by improved efficiency, facilities with a large number of pumps have reported substantial savings in maintenance costs by correcting off-design performance. In addition to operating less efficiently and consuming more electrical energy per delivered flow, a pump operating off-design is likely to experience reduced reliability due to factors such as internal turbulence, cavitation, recirculation, and off-design pressures.

Off-design performance is identified from equipment design conditions: temperature, differential head, speed and power. Match design conditions to the actual conditions observed on operating instrumentation (flow is usually unavailable). Many will be close to design parameters; some will be off; and a few may be way off. Begin with those that are farthest off design performance. How does power delivered based on motor current and speed compare to power required from pump curves? Conduct an economic analysis on corrective actions including replacement. Several organizations have gained substantial added profits from this simple process.

Optimized Maintenance is a Necessity

Optimized maintenance is an essential part of asset optimization. Maintenance, life extension, corrective and repair work accomplished on physical assets, has a broad range of technical and conditional requirements. Maintenance must produce quality results and, at the same time, be highly effective with a minimum of wasted time and effort. Maintenance people must be motivated, have a high sense of initiative, ownership, and commitment to quality and improvement. They must be flexible and adaptable to change, often under circumstances that demand the application of a wide range of competency, skill, and technique.

Maintenance must be sustaining with the following characteristics:

- Broad based but focused
- Oriented to improvements, eliminating the cause of failures, not simply repairs and fixing
- Directed to minimizing the cost of unreliability and downtime
- Emphasis on an organizational culture of initiative, quality, ownership and reliability

Maintenance within asset optimization must be anticipatory. A minor defect is usually controllable and easy to correct. Left unattended, a minor defect can lead to an unexpected major failure with costly side effects that may impact safety, quality, and production. Early recognition and correction, avoiding failures that impact safety, production, quality, and the environment, is a key objective of asset optimization. As stated earlier focus on fire prevention, minimize fire fighting!

By following the practices and recommendations of industry leaders, maintenance managers can demonstrate that their activities add to the financial success and profitability of the organization. Good maintenance ensures that the organization is able to provide high quality products and services that are delivered on time. Dynamic maintenance practices and programs support the products and services delivered by the organization and will be a positive influence on financial health and the organization's future. This is especially true for organizations that aspire to the standards defined by the Malcolm Baldrige Award, the International Standards Organization (ISO), North American Maintenance Excellence (NAME) award and other national and international organizations that recognize excellence in all aspects of business.

Stability, predictability, order, organizational efficiency, maximizing advance planning and implementing a reliability improvement program that will reduce the need for maintenance are a few of the necessary characteristics when optimizing the maintenance process.

Key elements that should be incorporated to gain an effective maintenance program include:

- The balance of cost versus value; initial versus lifetime cost must carefully considered at every step of the process.
- The combination of reliability and economic analyses assures focus into areas with the greatest value and return

  Reliability is an inward goal — thinking in terms of profitability will lead to optimum reliability.
- Every activity must have associated measures of performance (KPI's). Without measures of performance there is no way to establish an objective. Without an objective there is no way to gauge progress and know when you have arrived.
- Utilize predictive technologies wherever possible, including the determination of preventive intervals.
- Apply improved methods to gain greater task and work effectiveness.
- Design improvements, technology and surveillance must all be considered to alter failure probability and consequences (risk).
- Form cross-functional, multi-discipline, action teams to seek out and implement permanent improvements.

Many practitioners speak in terms of Maintenance and Reliability — M&R. Perhaps it would be better to reverse the sequence to Reliability and Maintenance — R&M — signifying that improving reliability leads to better and less maintenance.

The asset optimization program includes provisions that ensure maintenance requirements are designed out, see Chapter VIII and XX, and those that cannot be eliminated altogether are made as easy and inexpensive as possible to accomplish. The order is very important. First, design maintenance out, then address maintainability, and finally implement a program of defect elimination.

A Canadian Coast Guard Officer inspecting a cruise ship observed a timer-initiated, automated cleaning system for galley range grease filters designed to eliminate labor-intensive requirements for manual cleaning and a potential fire hazard when manual cleaning was neglected or deferred. (129)

A 1986 EPRI report stated that predictive or condition-based maintenance can potentially reduce overall, non-fuel O&M costs for a power generating utility by 5 to 10 percent and reduce fuel consumption by 1 to 2 percent. A power generating utility recently reported documented average savings of over $2 million per year during the last three years resulting from maintenance, availability, and heat rate improvements gained with predictive maintenance.

A second power generating company reports that maintenance expenditures are approximately 65 percent of non-fuel O&M costs.[7]

P/PM Technology, a now out of print technical journal devoted to practical applications of maintenance technology, reported that the savings gained from predictive maintenance represent only 10 percent of the total potential of long-term programs where the need for and the cost of maintenance is reduced. As much as 90 percent came from increased availability and production output.

In companies where maintenance costs may exceed annual net profit, optimization is mandatory.

Maintenance is a key component and contributor to success of the asset optimization program. Maintenance, when optimized for greatest effectiveness and value utilizing asset optimization principles, ensures the capacity necessary to meet production commitments and contributes significantly to site financial performance. Within asset optimization maintenance is viewed as an investment in future profits achieved through capacity assurance, improved throughput, quality and reduced operating cost. In short, optimized maintenance is essential to asset optimization and site profit.

As previously mentioned, many corporate directors and financial executives view the maintenance function strictly as a business cost required to repair equipment, structure and buildings. Few think of maintenance as a profit center source of significant business value. Those who regard maintenance as a business cost rather than a value added activity should ask themselves how much value would be produced without maintenance? In too many cases, when expenses must be curtailed, the maintenance budget is the first to cut, and the last to restore. Incentives to increase effectiveness, replace inefficient equipment, and invest in new technology (which often incur installation and training costs) are often rejected strictly on the basis of cost.

A facility that had historically experienced chronic problems with DC variable speed drives replaced one unit with an AC variable frequency drive as an experiment. Despite a demonstrated payback in approximately nine months, further replacements were rejected on the basis of capital prioritization. Had the facility been a bit more creative the local bank would have gladly financed additional replacements.

Maintenance must be considered as the activity delivering immediate and future assured capacity — without maintenance there won't be any capacity. (Minimum costs to sustain assets have been discussed earlier see Figure 3.2)

There is another cost issue. A manufacturing or production facility must be able to operate successfully within a level of maintenance funding that is affordable for the specific business conditions. The issue is how much maintenance a business can afford — not how much is needed. If the need appears to be greater than what is affordable, a program must be pursued to reverse the situation. This is discussed in more detail in Chapter IV; benchmarks are discussed in Chapter IX. A manufacturing or production facility must be within a few percent of the costs of industry leaders if it is to remain competitively viable.

There are five essential actions that must be accomplished to improve maintenance effectiveness:

1. Develop and implement a prioritized reliability improvement program specifically targeted to reduce the need for maintenance. This is the only way to achieve a permanent, maximum, sustainable reduction in spending.
2. Formulate and implement comprehensive Preventive and Condition Based Maintenance programs.
3. Embed an effective maintenance work management, planning and scheduling process.

4. Demand organizational discipline to follow established processes and procedures.

   If Standard Operating Procedures are not written and religiously followed to include a strictly followed process for identifying and implementing improvements, practice and performance will slowly degrade.

5. Develop a comprehensive stores management program that optimizes stocking levels, procurement, storage and issue.

It is essential to recognize that within the asset optimization process the sequence in which improvements are implemented is based on a value assessment process that prioritizes their potential value and effectiveness based on actual conditions, potential value, resource availability and probability of success.

For example, if a Planning and Scheduling process is in place and is somewhat effective, beginning an improvement initiative with an effort to increase reliability may create the greatest value in the least time. If reactive, break-in maintenance is far too high, beginning with Preventive Maintenance (PM) and Condition Based Maintenance (CBM) implementation, especially the latter, may be the most effective action to increase value. Similarly, if data, institutional knowledge or a simple audit discloses a large number of lubrication induced failures and / or a lubrication program that is below standards, bringing the lubrication program up to best practice should be initiated without delay.

If resources are available, several improvement initiatives can be started simultaneously. The management challenge is greater, but so are the rewards and speed of success.

Maintenance — A Core Management Responsibility

Within asset optimization maintenance must be a full participant in business decision-making and productivity reviews. Maintenance experience must be incorporated in key business process decisions — such as constructing or modifying facilities, acquiring new equipment, cost reduction initiatives, and changing manufacturing processes and tolerances — not simply notified as a new decision is being implemented. Maintenance involvement at the beginning helps ensure that lifetime optimization issues are addressed to avoid availability and operating problems, production bottlenecks, and sub-optimal maintenance costs.

Industry leaders integrate the maintenance function into all levels of their organizations' management review and decision-making process. This ensures that cost-effective business decisions are made with full input from all organizational elements. For the foreseeable future business emphasis will be on availability, throughput, quality, production cost, speed of delivery, and effective service support. When maintenance is not consulted, operating costs may be greater than expected, equipment reliability and / or performance may be less than required, and maintenance and repairs may take longer and cost more than they should. Unfairly, maintenance is usually blamed!

By integrating asset optimization into the organizational decision process, potential problems are anticipated; availability and reliability concerns can be discussed and understood by all. When this routinely happens, the organization is well on its way to maximum effectiveness. Reliability professionals provide a critical assessment of problems and future needs associated with system upgrades and/or equipment replacement.

The Maintenance Function

The maintenance function within asset optimization is illustrated in Figure 3.5. In broad terms maintenance actions are originated in two ways: unplanned, reactive maintenance and planned maintenance. The best practice benchmark, detailed in Chapter IX, is 85 percent to 90 percent planned.

> *Planned maintenance is defined as work that is fully planned and scheduled some time prior to initiation — generally one week.*

Referring to Figure 3.5, corrective maintenance may be planned or unplanned (emergency, break-in). Time based (PM), condition based (CBM) and proactive maintenance are always planned and hence far more effective in terms of labor utilization (wrench time).

> *In some organizations time and condition based maintenance are combined under Preventive Maintenance (PM). In this handbook PM is strictly time-based maintenance.*

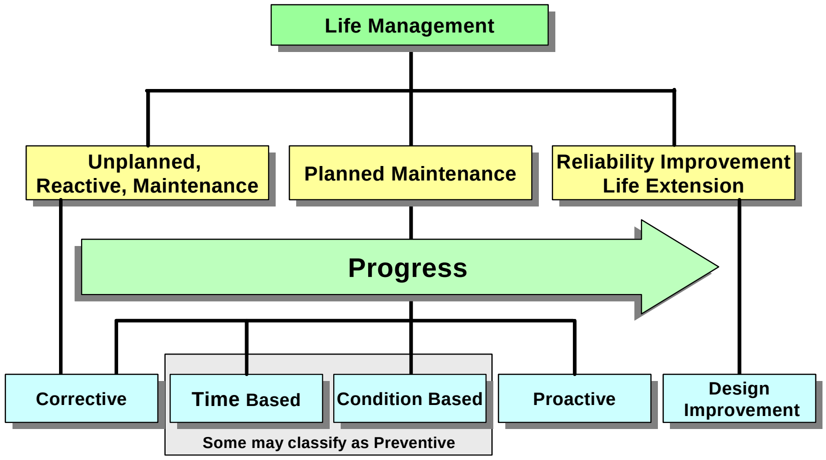


Figure 3.5 Maintenance Hierarchy

Maintenance progress is achieved within asset optimization by moving from unplanned, Reactive Maintenance toward planned Preventive, Condition Based, Proactive and Life Extension. The gain in effectiveness as the maintenance process moves from reactive to Preventive and Condition Based is discussed in greater detail in Chapter V.

Reliability improvement, in many cases a joint responsibility of maintenance and engineering, is targeted to eliminate the need for maintenance and hence spending for both labor and materials. The necessity for eliminating maintenance and requirements for work will be explored in detail in the next section.

The Maintenance Process

Among leading corporations, maintenance is considered an integral part of production and part of the process generating business value. Its importance to the timely, efficient, and effective creation and delivery of an end product is fully recognized. The process is well defined, as illustrated in Figures 3.6 and 3.7.[129] Just as a car needs tires, an effective and profitable manufacturing process must have an effective and well-run, maintenance program. The principles expressed in this section apply regardless of whether maintenance is a function within manufacturing, a stand-alone process composed solely of company personnel, outsourced to a third party or some combination of the three.

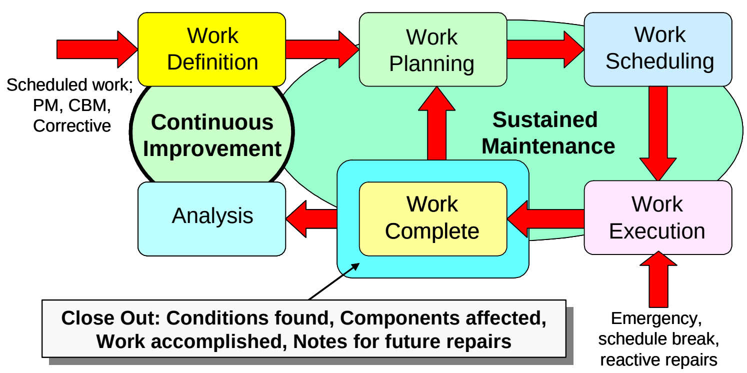


Figure 3.6 The Basic Maintenance Process[129]

Referring to Figures 3.6 and 3.7, every facility accomplishes the Work Identification, Planning, Scheduling and Execution cycle in some form. Within the worst performers the entire cycle is primarily reactive. In a reactive facility, planning, limited to parts and tools required, is hastily and inefficiently accomplished by a first-line supervisor or a craft mechanic upon receipt of a work order. Mechanics or the first-line supervisor are generally responsible for safety checks and production line-up to accomplish the work as well as locating parts. In many cases, craft mechanics must be moved from a partially completed task to another higher priority task with significant loss of time and effort caused by the shift. The first line supervisor is constantly juggling priorities and people in an effort to keep the facility operating and satisfy production.

This brief description does not adequately describe the chaos, wasted time and effort of reactive maintenance. Suffice to say reactive maintenance is a horribly inefficient and ineffective method that simply attempts to keep a plant operating — there is no time to think about improvements, making tomorrow better than today.

Figure 3.7 illustrates the maintenance process showing areas in which improvements will affect expenditures and availability along with measures of performance. This is addressed in detail in Chapter IX.

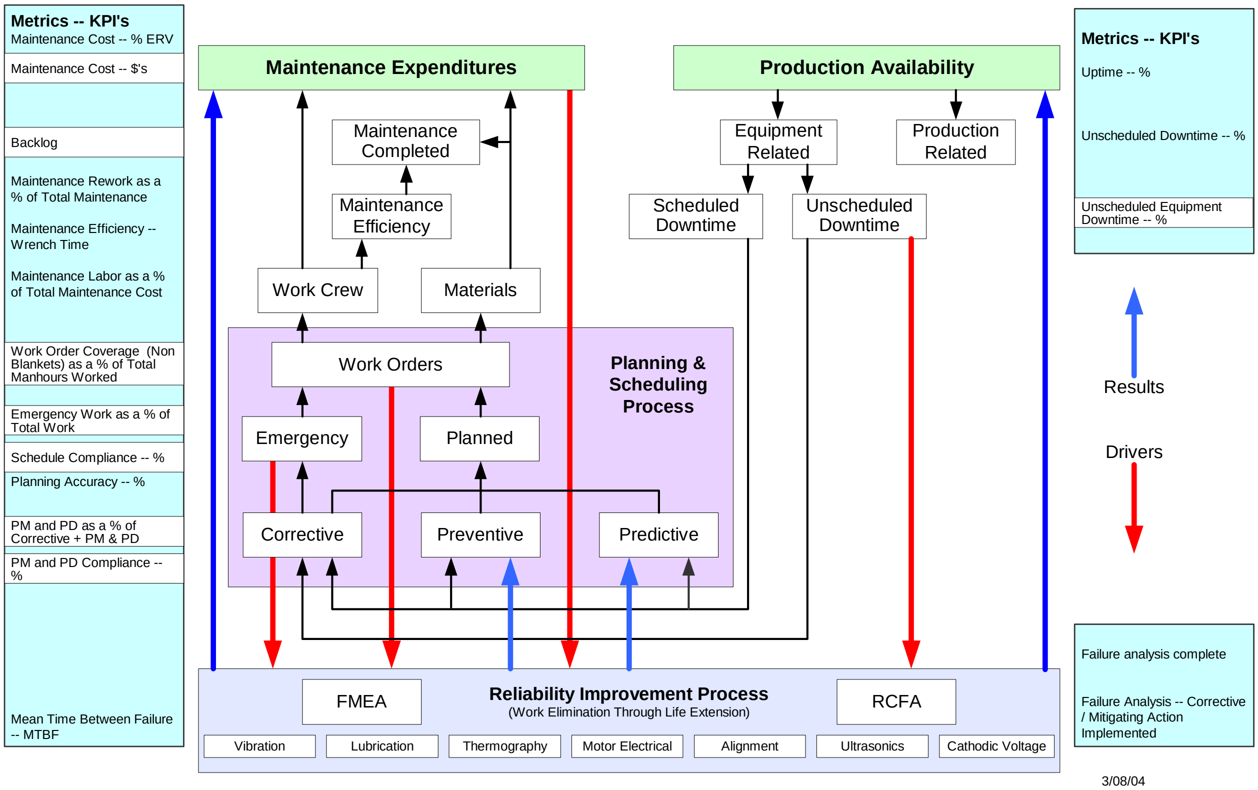


Figure 3.7 The Maintenance Process within Asset Optimization Showing Performance Metrics

The Maintenance Process must be Value Driven

The maintenance process itself has traditionally been viewed and managed as a cost-center where adherence to budget is of highest priority and everyone knows — and avoids — the rewards for managing below budget! The asset optimization process demands a far more effective profit-center orientation and mentality that encourages balancing risk and reward to improve effectiveness and gain maximum value and return. Where small improvement projects are typically started late in a cost-center budget cycle on a cushion of deferred expenditures, the profit-center focus of the asset optimization process encourages an early beginning to maximize return.

Reduced costs are not a command, but the result of comprehensive, prioritized improvements achieved through a rigorous, disciplined process.

Within maintenance, asset optimization requires an objective, value-oriented, complementary mix of condition-based, time-based, proactive and even run-to-failure maintenance strategies. The mix and proportion are directed to gaining maximum value for the plant specific process, systems and equipment. Condition-Based Maintenance (CBM) is typically the most profitable type of maintenance short of reliability improvement that eliminates requirements for maintenance altogether. Time based Preventive Maintenance (PM) is utilized in situations where experience or safety considerations require time-based actions, or when the measurements required for condition assessment are either inaccurate, unreliable, or too expensive. Proactive Maintenance is applied at design and during operation / repairs to minimize the probability (risk) of problems. Reactive Run-To-Failure (RTF) maintenance must be based on facts conclusively demonstrating that this method is most effective when all factors are considered. RTF must not be a default when there is no strategy in place. In all cases profit centered prioritization is applied to arrive at an optimum mix and balance.

The *Maintenance Technology* article cited earlier and summarized in Figure 3.4 states that 8 percent of maintenance expenditures are caused by errors in performing maintenance.

> *Better maintenance practices could reduce maintenance costs by 20 to 40 percent and increase OEE by 5 to 20 percent.* [56]

The following will elaborate a bit on each imperative for optimizing the maintenance process:

Necessities for a Solid, Effective Work Management Process

There is abundant, proven software available that will enable anyone to implement a solid and effective maintenance work management, Planning and Scheduling process. Numerous articles, papers and full conferences have been published describing an optimum implementation.

Demand Organizational Discipline

In far too many organizations most, if not all, work requests initiated are written and submitted as a “do immediately” necessity. In many cases those submitting requests believe that without this designation the work will never be accomplished. It is easy to see how this mentality feeds on itself to make conditions worse.

Installing a gatekeeper empowered to separate the work requests that actually justify break-in emergency work from those that can be safely deferred into the planning and scheduling process is an essential first step in ending a reactive culture. This person must be very familiar with production operations so the task may fall logically to a scheduler.

When PM and CBM programs are in place, excessive reactive work indicates the programs are ineffective. Positive action must be taken to determine the cause of the reactive work, why it isn’t eliminated by the programs and develop corrective action.

Periodic reviews of the maintenance backlog are useful in order to visualize the status, priority and aging of work requests. Non-overhaul work that doesn’t move through the management system to closure in one to two months may be unnecessary. An insufficient backlog detracts from the effectiveness of the planning and scheduling process. More details about work backlog and backlog management can be found in Chapter XIII.

Change from Emergency, Break-in, Reactive to Optimum Planned Maintenance

One objective of asset optimization is to minimize reactive, break-in maintenance. Industry leading facilities operate with reactive, break-in maintenance less than 15% of the total hours expended. Best-of–the-best will be around 10%. The most sophisticated will schedule about 10% to 15% of the weekly hours available for work on tasks that can be deferred knowing that some break-in work will be required.

Work accomplished in a break-in, reactive mode is chaotic and highly inefficient. Referring to Figure 3.7, wrench time, explained in more detail in Chapter IX, will be about 50 percent to 60 percent in an industry leading facility compared 20 percent or less at a site relying primarily on reactive maintenance to keep operating. ***Thus, a facility mired in reactive maintenance will need about three workers to perform the work of one at an industry-leading site.*** Since a maintenance crew is paid for working hours and not efficiency, Figure 3.7, a reactive facility will pay far more for the same work accomplished as an industry-leading facility. The reactive facility is at an even greater disadvantage because the industry leading facilities have more reliable systems and equipment (greater MTBF) and thus also less work to accomplish! And this simple example doesn’t include additional costs such as degraded quality of workmanship due to haste and pressure, need for and cost of expedited parts and production downtime that are typical characteristics of reactive maintenance.

If a facility has an excessive amount of reactive, break-in maintenance work the crucial question is how to move toward industry best performance. The question is not academic — no manufacturing business can survive long with maintenance costs two to three times the more effective competition!

Evolve into an Optimized Preventive and Condition Based Maintenance Program

PM and CBM, the latter often called Predictive Maintenance (PdM), are successful, proven practices that must be an integral part of any asset optimization program, Chapter V. PM injects maintenance tasks designed to avoid failure, for example visual inspections and scheduled lubrication. CBM relies on non-intrusive condition measurements taken during operation that accurately represent condition and are capable of identifying problems in their earliest stages. When discovered early, minor defects are typically easily controlled or corrected at minimal cost. CBM measurements can identify the specific flaw, component(s) affected and approximate time until corrective action will be required. Industry-leading facilities utilize condition measurements very effectively to avoid outright failure or an unscheduled interruption in production.

Over the years, industry has recognized that migrating from reactive or breakdown maintenance to condition-based maintenance has the dual advantages of increased effectiveness and decreased cost, Figure 3.8.

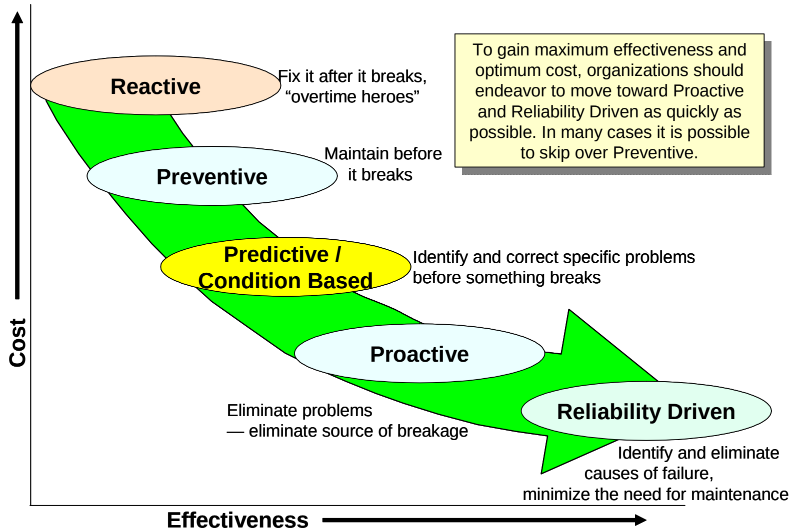


Figure 3.8 Cost Advantages of Maintenance Types

The EPRI chart cited earlier and shown in Chapter V, Figure 5.4, is used in many industries to demonstrate the relative improvement as maintenance evolves from breakdown, through Preventive to Predictive or Condition Based. Figure 5.4 extends the illustration to project the anticipated savings accruing from implementation of a profit-centered asset optimization program.

Safely Extend Overhaul Intervals

Power-generating companies are extending the interval between major turbine generator overhauls from four or six years to eight or more years. Turbo compressor overhauls in the oil and chemical industry have been extended from approximately four years to eight or more years. Extending the interval between, and reducing the length of, major equipment overhauls gains as much as 2 percent in operating availability and 30 percent reduction in maintenance costs. Safe accomplishment, with equal or better availability between overhauls, requires improved reliability and maintainability combined with regular condition assessment.

RELIABILITY — THE BASIS OF PHYSICAL ASSET OPTIMIZATION

Definition:

Reliability — The probability that a system, device, component or product will perform its required functions in a satisfactory manner for a given period of time when used under specified operating conditions in a specified environment.

The achievement of predictable results with as little variation as specific circumstances permit.

David L. Stringer, Brig. Gen. USAF at RCM / EAM 2006

Expressed in this fashion reliability has three key results oriented objectives:

- Satisfactory performance
- Predictable
- Minimum variation

Reliability has a maximum intrinsic value that is established at design.[22] As has been detailed in earlier sections, a large percentage of lifetime cost and potential availability are determined during specification, engineering design manufacturing and installation. Several have stated that as much as 80 percent of lifetime costs are established at commissioning. Unproven, outdated, or fragile technologies typically result in unreliable equipment and processes.[22] A key element of the drive for optimum reliability is the recognition that design, procurement and installation deficiencies must be corrected to ensure that in-service production availability meets mission requirements (for more detail see Chapter VIII and XX.

High intrinsic reliability is relatively easy to achieve with static equipment such as pressure vessels, piping, instrumentation and power distribution systems. It is much more difficult to achieve with complex mechanical equipment and valves that can be subjected to conditions such as lubrication contamination, turbulence, erosion, unbalance and misalignment.[68]

A Ford Motor Company plant announced:

"Zero Accidents, Zero Defects, Zero Breakdowns."

This is an illustration of the importance of production asset performance within a key industry. It may be the first time a trend setting, world class operating organization elevated the reliability of production assets to the level of safety and quality.

Value of Reliability

Figure 3.9 illustrates two failure curves, essentially p/f curves upside down. The first, leftmost represents an intrinsic reliability with approximately 50% probability of failure during the mission. If the curve represents unspared equipment, there is a 50% probability of interrupted operation / production — likely too high to be tolerated. Assuming the onset of failure can be identified, damage and the outage may be limited — but it will still occur. By increasing intrinsic reliability with a design or other fundamental improvement, the risk of failure can be substantially reduced. Optimum reliability has a clear value.

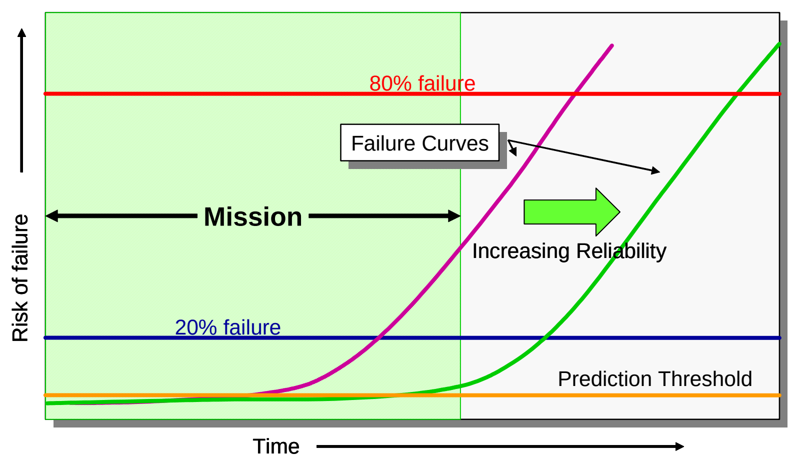


Figure 3.9 Value of Improving Intrinsic Reliability

Optimizing Reliability

A reliability evaluation involves statistically estimating lifetime reliability.[29] When design and other intrinsic defects are present, gaining sufficient reliability to meet production goals through maintenance alone may be prohibitive in terms of costs.[22] Intervention required for optimum production effectiveness will range from relatively simple inspections on equipment with high intrinsic reliability to comprehensive Preventive, Condition-Based and Proactive Maintenance on complex, critical machinery.[68] Occasionally, components and perhaps even entire equipment must be replaced in order to gain the necessary level of operating effectiveness.

A reliability improvement program has three primary attributes:

1. Eliminate failures and the cause of failures.
2. Extend asset operating lifetime.
3. Reduce the cost of asset care by reducing the requirements for work.

If a program is not directed at all three, it isn't a reliability improvement program.

As implied by the preceding, a reliability program is a proactive program. It must be managed proactively, constantly seeking opportunities to increase value through optimum reliability improvements. Once a defect is identified, RCA and FMEA are tools commonly used to develop corrective action. Design changes may well be required as well.

The reliability program is constructed around a strategy consisting of the following as a minimum:

- ❑ Overall objectives with specific business goals
- ❑ Specific objectives of the reliability program
- ❑ Prioritization of systems and equipment by risk
- ❑ Plan to improve production and cost effectiveness

Within the strategy there must be provisions for reliability analysis, RCA and FMEA as noted above, a process for reliability improvement including follow up to assure improvements are successful, and a strong reliability input to capital projects, see TPM, Chapter V.

Design for efficient operation and maintenance (maintainability) is important,[22] see also Chapter XX. Many companies have experienced equipment-operating difficulties that have resulted in failures. Likewise, routine maintenance tasks can be complicated by factors, such as interference that require design changes. The cost balance of reliability is illustrated in Figure 3.10.[1, 22] For every process, system, and asset there is a point of optimum effectiveness that balances the cost of improved reliability with the cost of unreliable manufacturing.

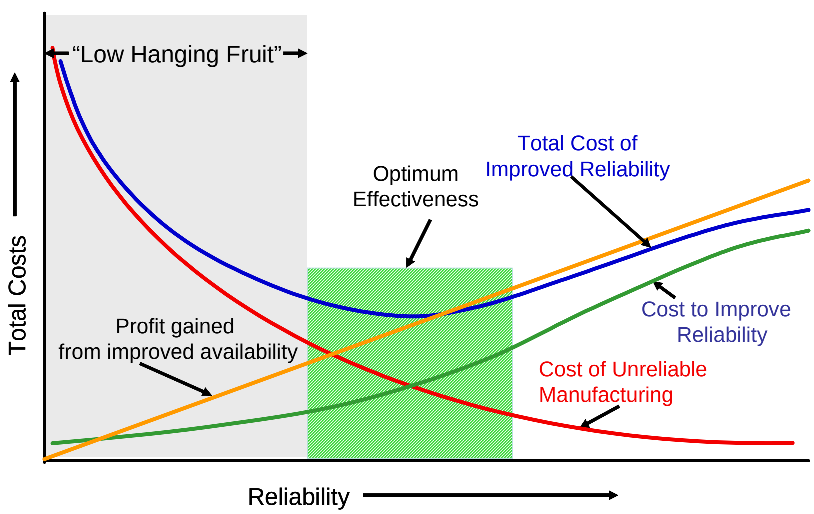


Figure 3.10 Optimum Reliability

An example is illustrative:

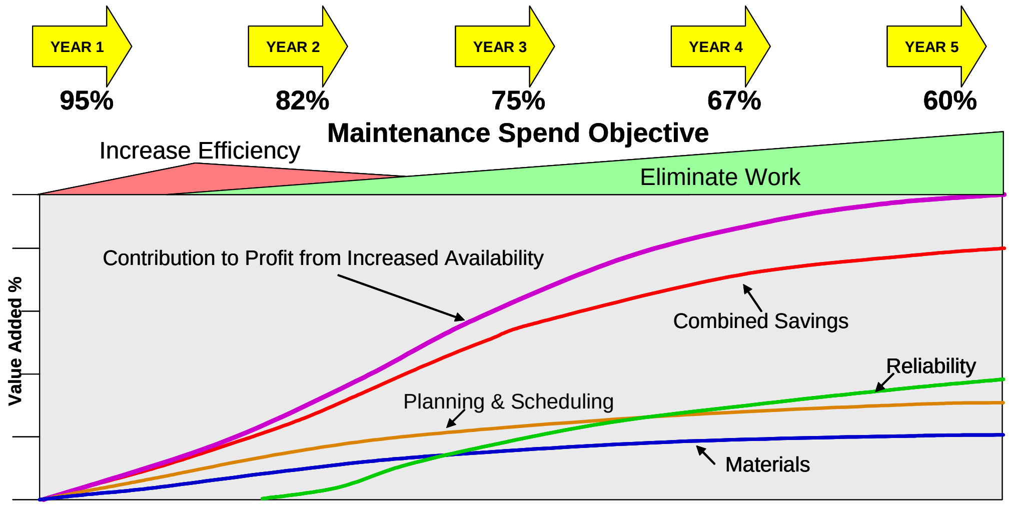
> *Variable speed DC motors used in a main production process were unreliable and costly to maintain. Replacing the DC motors with variable frequency AC motors essentially eliminated the problems. The AC motors proved orders of magnitude more reliable, far less costly to maintain and paid back the investment for replacement by increased production and reduced costs in less than a year.*

This case illustrates the advantages of looking beyond maintenance to lifetime reliability and cost. In this example, would a conventional maintenance improvement program have led to the conclusion, reached through asset optimization, to replace fundamentally unreliable equipment? Or would it have concocted more extensive and costly monitoring and maintenance actions to mitigate design deficiencies?

Every organization should strive for the lowest cost reliability that meets mission requirements.[19] A level of reliability that guarantees availability when required is a key issue, see Timed Availability, Chapter VI. Required availability in a defined increment of time may range from 100 percent to less than 60 percent for spared equipment. Failure to operate within a defined production window often causes major loss. A food processing plant that fails during harvest season, resulting in spoilage losses, is one example. Failure of a power generator during a heat wave that forces the purchase of expensive replacement power on the spot market, or results in the default mentioned earlier, is a another example.

Improved Reliability is the Only Way to Reduce the Need for Maintenance Spending

A well-implemented Work Management, Planning and Scheduling, process can potentially gain approximately 15 percent to 20 percent reduction in maintenance costs through improved labor efficiency (wrench time). Optimizing stores management might gain a further reduction of about 10 percent. The key question for those mandated to reduce spending by more than 25 percent is where can the remainder be gained? As illustrated in Figure 3.11, the remaining cost improvement must come from improved reliability — eliminating defects and the need for maintenance. This is a fundamental value principle of asset optimization and the only way to permanently reduce maintenance costs.



Reliability: Increase MTBF = Less Work Required, Less Reactive, Less PM / PdM

EARLY YEAR'S BENEFITS COME FROM IMPROVED EFFICIENCY AND WILL SLOW IN CONTRIBUTION. LATER YEAR'S BENEFITS ORIGINATE FROM ELIMINATING THE NEED FOR WORK — AND ARE SUSTAINABLE LONG TERM.

Figure 3.11 Contribution of Three Elements of Maintenance Optimization

> *Experience demonstrates that the best way to reduce cost begins by increasing system, equipment and component reliability. This leads to a reduction in requirements for work and hence the necessity for spending.*

Within a reliability improvement program:

- Every repair is considered an opportunity for improvement
- Equipment and components with substandard life are continually upgraded.
- Upgrade procedures are continually reviewed and improved.
- Surveillance is improved to minimize surprises.
- Communications and follow up are embedded in the process to assure evaluations of potential problems, requirements for immediate and long-term corrective action are received, understood and acted upon.

Improving reliability compliments both Planning and Scheduling and Stores Optimization. When improvement initiatives are started together in all three areas, reliability improvements begin bearing real fruit just about the time maximum gains have been achieved in the planning and scheduling and stores areas. In addition, and as shown in Figure 3.10 reliability improvements lead directly to improvements in availability, production output and profit.

Reliability is sustained by adherence to designated standards and specifications. Reliability is enhanced by modification and improvement projects.[129] There is a general feeling in industry that reliability is a valuable commodity.[7]

Any approach to reducing spending other than reliability optimization is temporary at best and gains only a portion of the potential value of defect elimination. Improved design, materials, operations, lubrication, and maintainability are examples of changes that increase reliability and reduce the need for maintenance. The asset optimization program includes a reliability management system that notes conditions found when equipment is being monitored, inspected or repaired, and tracks the cause for each equipment failure. Reliability management also includes reliability and risk analysis and continuous improvement.

The key lesson is that by eliminating defects, improving reliability both labor and parts costs are removed — reliability improvement addresses 100% of the maintenance costs!

FAILURE ANALYSIS (RCA)

Reliability analysis, including lifetime prediction (prognosis), and failure analysis and elimination provide the information necessary to extend life and avoid unplanned outages. Together, these lead to, and will be the cornerstone of continuous improvement. Continuous improvement progressively eliminates cause, extends life, and ensures full effectiveness and return from physical assets. Failure analyses, initiated by a variety of triggers (safety, environmental, one-time and cumulative cost) typically provide a great deal of avoidance information. However, pre-failure risk analysis, anticipation and early recognition are far more effective methods to improve life compared to waiting for failures. Waiting for failures to initiate corrective action is not a sound practice.[68, 76, 129]

There is a growing recognition that many mission-jeopardizing defects that are responsible for reduced effectiveness and resource consumption may be separated in time and space by months or even years from the point where symptoms are initially recognized. This requires extensive documentation and a more holistic process of analysis and improvement. Three examples from an engine manufacturer are illustrative:

> *A search for the cause of coolant leaks following delivery disclosed that the process of attaching a subassembly altered the engine's integrity.*[129]
>
> *Correctly torquing a pipe fitting led to leaks much later in the process when the fitting had to be turned to obtain the correct angular position for the mating hose. Ultimately, this problem necessitated a re-design to remove two potentially mutually exclusive requirements.*[129]
>
> *Defects often appeared late in the process of machining a complex casting. As a result, a great deal of value-added machine time was lost, as well as the casting itself. Based on costs involved, an expensive 100-percent radiography inspection of all of the raw castings was justified.*[129]
>
> *A fourth example involved a series of bearing failures that were ultimately traced to a change in suppliers that had occurred more than four years earlier.*

The latter example identifies some of the considerations that must be evaluated before making changes. If the MTBF of a typical component is 4 years or longer, how long will it take to discover reduced lifetime caused by a change in suppliers, design or materials? By the time a problem is discovered all involved with the decision may have moved on.

Ownership of reliability is a major key to success. Ideally, the individual(s) who are accountable for plant capacity should "own" reliability.

An important point to remember is that reliability is a means to an end — not an end in itself.

TECHNOLOGY INTEGRATION

Technology is a prime enabler and necessity for asset optimization. Asset optimization requires that control, information, management and monitoring technologies are all assembled into an integrated, interoperable structure that is accurate and accessible; see Chapter XIV for more details. Technologies provide a basis and focus for strategy development. For example, technology must enable rapid identification of systems and equipment that have demonstrated the largest detriments to revenue, availability and spending (both historical and potential losses) objectives together with cause of the variations. Having all available within an accessible, web enabled structure provides better, more effective communications between all who need to know specific performance information

ASSET OPTIMIZATION REQUIREMENTS FOR FACILITIES AND STRUCTURES

Asset optimization is normally associated with production equipment. All too often buildings, structure, heat exchangers, piping, piping supports and valves and other capital assets that are a vital part of the mission / production process are neglected. There is always the temptation to save by deferring sustaining maintenance. This only shortens lifetime and, when the end is reached, repair or replacement is likely to cost several times that of effective lifetime care. In these examples, what are the real costs of deferred preservation?

Deferred preservation, such as painting, has a cost that can be expressed in NPV.

> *One industry leading company has a procedure for estimating the cost of deferred structural painting at several stages of corrosion. Calculating NPV involves prioritizing requirements to obtain a clear understanding of the order of accomplishment and costs involved. This avoids, or at least identifies, the real cost of "savings" gained by consuming assets — the well known "pay a little now or a lot later" mentioned earlier.*

Buildings and equipment do not last forever and their continued use can often be too costly and adverse to the price of the product and customer loyalty. As an example, in the late 1970s and early 1980s North American automobile manufacturers finally had to come to grips with production costs. During the introspective analysis, executives finally realized that they were still manufacturing cars and components in production facilities that were built to suit practices used in the early twentieth century. The executives saw that the Japanese (and later, Korean) competition had constructed modern, very efficient facilities designed to gain the utmost from the latest manufacturing processes. These facilities, combined with advanced practices, provided the ability to produce high quality products at low cost.

The response was to close many of the old facilities, completely modernize others, and, in some cases, build modern state-of-the-art replacement plants. The design and building of new vehicle assembly plants also accommodated the inclusion of new technology, the most notable examples of which were the installation of robotic welders and painting and movable carts that enabled teams to assemble large portions of the vehicle in a given location. There are several lessons to be learned from this example including:

- An integrated approach in the design of new facilities can accommodate new technology and equipment management practices focused on providing a high quality, low cost end product.
- There are numerous hidden costs in adding building modification upon modification in hopes of avoiding the cost of extensive repairs, modifications or development of new facilities.
- **EVERYTHING** affects the quality, cost, and availability of the end product.

Senior executives must understand the importance of the role of lifetime asset optimization in their operation / business and how a proactive program will positively affect the bottom line. Here are a few examples:

Electrical: Electrical demand has grown dramatically over the years. New production equipment for capacity expansion (often computer controlled), variable frequency drives, computer networks, and other high technology information equipment are multiplying exponentially and placing burdens on the distribution system that were never anticipated. Electrical systems can remain in place for decades, in many cases a half-century or more. With the advent of computers, computer-controlled equipment, and systems, gross electrical demand and the need for conditioned power may exceed the electrical system's current capacity. Without upgrading the system, equipment may not operate at peak efficiency and / or service life may be diminished.

Roofing: Roofing systems have evolved over the years, including numerous, accurate diagnostic technologies that quickly assess the condition of the roofing material. Roofing failures are expensive and often incur additional expense in the form of damage to roofing support systems or equipment in the building. Periodically inspecting the roof, cleaning roof drainage components, and patching damaged areas increases service life of the structure, ensures an uninterrupted flow of work within the structure, and reduces maintenance costs. Without proper care, significant roof failure may begin in less than 20 years.

One individual lamented that his company "never repairs roofs — we wait until they are about to collapse, then initiate a capital replacement project."