Abstract:
Over the past fifteen years condition based or predictive maintenance has achieved near universal acceptance as the most effective method for maintaining industrial equipment. So much acceptance that condition based maintenance is often over applied. So much acceptance that some companies are abandoning the program because mission interrupting problems are so far in the past that institutional memory has been lost.

This paper will detail strengths and weaknesses of condition based maintenance utilized by capital intensive process, petrochemical, power, paper and manufacturing industries. Recommendations for achieving a most effective balance and eliminating weaknesses will be detailed. The discussion will continue with how condition based maintenance fits into the larger frame of Equipment Lifecycle Management. Equipment Lifecycle Management that begins at design, includes procurement and installation and continues through operation and maintenance to gain greatest value and effectiveness. Total Production Effectiveness, a new measure of performance that connects availability and lifecycle cost to guide prioritization and permit comparison of alternative action will be introduced. In addition to Condition Based Maintenance, the role of Total Productive Maintenance (TPM), Reliability Centered Maintenance (RCM), Planned (PM) and Reactive Maintenance will be discussed as strong contributors to total value when assembled and prioritized for specific mission requirements.

Introduction:
Since the 1960's there has been general agreement that reactive maintenance -- “fix it when it breaks,” is costly, inefficient and in many cases unsafe. That led to preventive maintenance; inspect or replace at regular scheduled intervals less than the average time to failure.

Experience indicates that a great deal of preventive maintenance is unnecessary. Components, replaced on an arbitrary time schedule are often in excellent condition with substantial lifetime remaining. In addition, the very act of performing an inspection or replacing components may hazard equipment if errors are made on reassembly. Horror stories abound where performance and condition degraded, and major problems occurred, following unnecessary preventive maintenance.

Enter predictive or condition directed maintenance: Maintenance tasks are based on condition measurements and performed on the basis of defects -- before outright failure impacts safety and production. Condition monitoring has proven very capable of identifying and tracking anomalies. Well-managed predictive maintenance has been generally successful and many leading companies are shifting from preventive to predictive maintenance wherever possible. Commonly mentioned objectives are 60% to 70% predictive, 10% to 20% preventive and less than 10% reactive. Predictive maintenance does have some shortcomings. Ongoing expenses to measure condition with portable equipment are often relatively high. Since most measurements don’t change significantly over time, there is a great deal of wasted labor necessary to locate the small portion of measurements that are changing.
Today, maintenance professionals are bombarded with equipment and programs, most identified with three letter acronyms. All promise great improvements in exchange for a purchase ranging from barely affordable to outlandish.

With a total focus on cost reductions, many are finding it increasingly difficult to justify investment in maintenance productivity. This occurs primarily because only a few have successfully translated technical and operating results gained by practices such as predictive maintenance into value and benefits in the financial terms necessary to assure continued support. Without this crucial information linking equipment performance to financial return, many successful predictive maintenance programs are being curtailed, even terminated, as cost reduction measures.

Cost reduction has several added dimensions. One is the loss of experience as senior maintenance workers and supervisors take advantages of incentives for early retirement. Today, cost reduction is primarily an exercise with numbers. Only a few recognize how safe, reliable operation and the absence of problems are directly connected to the efforts, contribution, commitment and experience of individuals responsible for the results. As champions depart, their experience lost and programs dismantled, what will happen? Some say a time bomb is ticking on the momentum of past efforts and success.

There is a growing realization that the entire idea of maintenance must be rethought and optimally reconstructed to gain full participation and value within the twenty-first century process and manufacturing environment. Characteristics include more intense operation, greater consequences of failure, multi-function, team-based organizations and fewer, less experienced, people. Within this environment, maintenance must become a full partner in a larger process to assure safety, availability and maximum profitability.

The ability to meet mission requirements at full capacity, efficiency, safety and quality is not just an objective but the objective. Benefits and value must be expressed in terms that connect directly to organizational business and operating objectives.

Guidance for assembling an optimized mix of maintenance practices is crucial. The keys are in two areas -- financial justification and information. The two must be coordinated to provide relevant, credible and compelling results to senior executives. We’ll call the overall process to achieve this objective Equipment Lifetime Management.

**Maximum Value over Least Cost:**

Insisting on maximum value over least cost is the kind of long-term commitment that requires a top to bottom change in culture. It is simple to say and superficially easy to understand. Where it becomes hard is establishing the concept as the normal way of doing business. Return On Investment and Net Present Value are two conventional ways to calculate the relative value of projects or decisions in order to objectively determine maximum value. The harder issue is to frame operational issues and schedule-impacting maintenance decisions in value terms. For the typical maintenance organization trained to think of minimizing costs, the concept of maximum value may seem foreign. Reducing maintenance costs is quite different than the value concept of reducing maintenance costs as a percentage of operating hours or production output in units, MW, pounds, tons, etc. The latter incorporates opportunities for added sales and the value of increased production.

**Reducing the Need for Maintenance:**

The only way to permanently reduce maintenance costs is to reduce the need for maintenance. Reductions in the need for maintenance come from diligent efforts to improve materials, design, maintainability, and operations. Root cause failure analysis, prioritized by failure impact (safety, production, cost, etc.), provides essential guidance. An example: replacing or modifying equipment that is unreliable and/or operating inefficiently. Changing to corrosion resistant materials to reduce need for maintenance is another example. Eliminating pipestrain induced casing distortion and shaft
misalignment and installing sealed bearings to assure lifetime lubrication free from contamination are two more. There are dozens -- all must be prioritized by financial impact.

**Optimizing the Physical Maintenance Function:**
It is widely recognized by maintenance people that maximum value in maintenance has generally been obtained from a condition-based program. The larger concept of Equipment Lifetime Management includes a complementary mix of condition-directed, time-based and, even run-to-failure maintenance when justified. It is important to understand that the latter must be based on facts that demonstrate run-to-failure is most effective when all factors are considered and not simply a default condition. Optimized Equipment Lifetime Management uses maintenance effectiveness assessments, Reliability Centered Maintenance (RCM), including Failure Modes and Effects Analyses (FMEA), and root cause analyses as tools. A maintenance program based on maximum value is the objective.

**Reengineering Maintenance Administration:**
Reengineering is defined as the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance. This means to start over, to reinvent the administration of maintenance, to throw out the old and bring in the new. The need for regulatory compliance requires care and extra communications to ensure legal responsibilities are met.

Once engaged in the reengineering effort, strong candidate characteristics for elimination include compartmentalization, excessive handoffs, and redundant approvals. Attributes to be streamlined include coordination, communications, and supervisory functions. The qualities of ownership, responsibility, and accountability are encouraged and promoted.

Enabling maintenance people requires hardware, software and training. The maintenance information system must be modernized to provide information, not just disconnected data, to the maintenance technicians and support people where and when they need it. This means not only a sufficiency of computer resources, but also a reworking of the manner in which those computers process maintenance data and present it as information.

**Management Investment:**
Over the years there has been general acceptance within industry that moving from breakdown to predictive maintenance saves money. The 1986 EPRI (Electric Power Research Institute) study showing plant maintenance cost per total horsepower per year has become so widespread an indicator that it has achieved status as a standard. It is used in many industries to demonstrate the relative improvement as maintenance evolves from breakdown, through planned to predictive. For this paper a graph has been developed to show the study's original results and to project the anticipated savings accruing from implementation of additional optimization, figure 1.
Maintenance is changing from a concept focused on how well a process or an individual machine works to a more complex concern with the lifetime cost of ownership beginning with design and procurement. Purchasing based on low initial cost is false economy if inefficiency and excessive maintenance quickly eat up the difference. Some companies take this concept a step further and apply offsets in the purchasing process to account for the lifetime cost of ownership. Installation, operation, safety, quality, commercial availability and maintainability, including cost are also issues. Computerized Maintenance Management Systems are changing from programs constructed to control the worker to Integrated Maintenance Information Systems that support self-managing maintenance teams. The acceptance of this change by senior manager and maintenance person alike requires better communications than presently exists. It is important for both to learn to communicate in terms the other understands. The maintenance practitioner must learn to position reports in relevant business terms. Non-technical senior management must learn enough of the technical vocabulary to ask relevant questions and understand the answers.

Within the maintenance information systems area, changes are occurring in capabilities to present maintenance information on computer terminals instead of maintenance data requiring interpretation. For a number of years, competing systems in the condition assessment area have developed independently. The individual industrial user is confounded with choices of proprietary products that cannot readily communicate with each other or with a third party desktop application. There is a solution in the making. MIMOSA —the Machinery Information Management Open Systems Alliance, described later, is developing and promoting conventions that will permit purchasers to choose the best product in each field with expectation of full, open interoperability.

A major culture change is required. And no successful culture change will occur without drive, inspiration and thorough involvement by senior management. Change has to come from the top down. As you cannot push a string, you cannot change the culture without top-down leadership. While it can be said that business is constantly changing, the culture of an individual work place seldom accepts radical change. Game theory in business applications, shows that a reluctance to change is a path to losing. The successful are those who are willing to both change and manage the process of change.

The senior manager will best appreciate quality and costs. The concept of “trade-ons” where higher quality and lower costs both occur is part of the benefits and results from Equipment Lifetime Management.

**Financial Benefits:**

Many world class organizations are adding to profits by implementing optimized maintenance practices. DuPont, one of the leaders, tracks maintenance cost as a percentage of plant replacement costs. They have worked this effectiveness index from 3.3% down to 2.3% and are gaining $400 million in avoided costs per year. This is the result of a focus on maintenance excellence that emphasizes planning and scheduling, a mixture of predictive and preventive maintenance, and reliability improvement.

The clear trend toward placing value on optimized maintenance is as close as the television. Ford, Cadillac, and BMW are advertising automobiles that are essentially maintenance free. Why has the interval between tune-ups increased to 100,000 miles-well over an order of magnitude improvement in less than ten years? The simple answer is the investment in design and the use of more robust parts returns value to the purchaser and profits to the manufacturer. The lesson is clear -- improved
maintainability returns value. With vision, commitment, willingness to change, and modern technology, maintenance is being controlled and converted to a profit contributor.

A Ford Motor Company plant recently announced a new focus, “Zero Accidents, Zero Defects, Zero Breakdowns.” This is another illustration of the importance of maintenance within the auto industry, and may be the first time a trend setting, world class operating organization elevated maintenance to the level of safety and quality.

The industry that supplies electric power to our homes and factories is also finding value through improved maintenance. Predictive or condition based maintenance could reduce power generating utilities’ overall operations and maintenance costs (non-fuel) by 5-10% and reduce fuel consumption by 1-2%. This is according to the Monitoring and Diagnostics Center, an Eddystone, Pennsylvania operation of the Electric Power Research Institute (EPRI). A power generating utility recently reported a documented average savings of over $2 million per year during the last three years from maintenance, availability and heat rate improvements gained with predictive maintenance.

Life cycle extension, improved incremental profit from increased availability, and delayed necessity for capital investment to meet market demands for added capacity are additional major benefits gained by improved maintenance. Extended life and avoided obsolescence affect depreciation and increase earnings per share.

Ron James, publisher of “P/PM Technology,” a trade journal devoted to practical applications of predictive maintenance technology, states that the savings currently gained from predictive maintenance represent only 10% of the savings potential in long term programs where the need for and the cost of maintenance is reduced.

**Maintenance is a Business Issue:**
If most of the processes and practices are available today, why then isn’t full value being gained? The primary reason appears to be inadequate communications between successful maintenance professionals and senior management. Maintenance professionals tend to be narrowly focused on physical achievements and technology. Few, if any, are sufficiently fluent in the language of business to communicate results in a way that is credible and attractive to senior management. Many maintenance professionals express frustration that their past and future contributions to corporate success and profitability is in danger of being lost through measures implemented solely to achieve short term cost reductions.

Maintenance is a business issue. All know the slogan, “pay me now or pay me much more later.” There are permanent cost reductions, value and profits to be gained through visionary, enlightened change. Maintenance can be controlled, planned and optimized for maximum value—but it can’t be deferred too long or ignored. Maintenance requirements ignored or deferred eventually reappear greatly multiplied in both cost and effect.

Thus, arbitrary cost reductions, unaccompanied by effective measures to reduce the need for maintenance, are very temporary and quickly result in cost increases. The choice is clear. Lead with maintenance optimization or wait until it is imposed by the same competitive pressures that forced adoption of modern manufacturing practices such as Just in Time and Statistical Quality Control.

**The Answer: Equipment Lifetime Management:**
Embarking on Equipment Lifetime Management requires a culture change, commitment to reducing the need for and the cost of maintenance, action directed to streamlining maintenance organization and a mix of specific physical maintenance practices (predictive, preventive, proactive and repair) directed to maximum profitability.

The maintenance administration process is composed of a small number of well-defined inputs and clear boundaries. Reengineering the administrative process must include establishing ownership,
responsibility, and accountability combined with empowerment that rewards initiative and maximizes individual contribution. Non-value added elements such as compartmentalization, excessive handoffs, and redundant approvals must be eliminated. Coordination, communications and supervisory functions must be streamlined during reengineering. Team based multi-disciplinary organizations are used by many organizations to improve operational efficiency.

Physical maintenance, the work done on and for machinery and equipment, has a broad range of requirements and natural constraints on radical change. Maintenance, like any physical function has to be flexible to adapt to change, often under circumstances that demand the application of a wide range of competency, skill and techniques. Fire fighting is a vivid example of a physical process. Firefighters can never be certain what to expect and therefore must have broad training, flexible equipment, and the ability to adapt quickly to a wide variety of conditions.

Maintenance fits the fire fighting analogy. A minor defect (small fire) is usually controllable and easy to correct. On the other hand, an unexpected major plant equipment failure (large fire) may be costly with side effects impacting safety, quality and production and must be avoided.

Important actions necessary to derive maximum value and profit from maintenance are designing for reliability and maintainability, correcting root cause problems, upgrading materials, improving the quality and integrity of lubrication, and providing better tools and training. Few would argue that fire prevention is far more cost effective than fire fighting. Systematic elimination of minor maintenance deficiencies before they lead to major damage and interrupt production is therefore the key to an optimum maintenance process.

Condition directed or predictive maintenance is one example of a proven, successful maintenance practice that can identify maintenance problems for elimination while still minor. Condition directed maintenance relies on an ongoing assessment of measurements that accurately represent condition to determine the need for and the scope of maintenance. Flaws are identified and corrected in sufficient time to avoid outright failure or an unscheduled interruption in production.

Equipment Lifetime Management requires an objective, value oriented determination of the optimum blend of predictive (condition directed,) preventive (time based,) and reactive or run-to-failure maintenance. While predictive maintenance is often the most profitable, preventive maintenance is called for in situations where experience or safety considerations are paramount, or when the measurements required for condition assessment are either inaccurate, unreliable, or too expensive.

**Technology Enables Maximum Gains:** Modern technology for measurement, information management, communications, and display enable full implementation of Equipment Lifetime Management and are essential for its success. Immediate access to vital maintenance information must be provided. Current condition, maintenance history, repair procedures and parts availability are examples of information that must be readily accessible by working level personnel to achieve maximum efficiency. Full and effective use of information technology depends upon empowered workers with training, education and knowledge to ensure that skill and ability match the complexity and demands of the work.

Production operators must be included in Equipment Lifetime Management. Intuitive, easily operated displays of condition are necessary. Video games are a familiar example. Displays on successful games must clearly convey status, condition, opportunity, threat, and even suggested action. Experts can similarly evaluate the condition of industrial equipment. However, focusing expertise on solving complex industrial problems and alterations that reduce the need for maintenance is a more productive use of resources. Software programs capable of automatic analysis and displaying refined, easily understood information must be woven into the fabric of Equipment Lifetime Management.
Management’s Challenge:
It must be recognized that successful change is often a slow process in which profits and value are gained through steady progress rather than quick fixes that sacrifice the future. Ideally Equipment Lifetime Management is characterized by the absence of problems. This is a sign of success and not an opportunity to further reduce costs by withdrawing support from the programs producing the results. With a shift in perspective, top-down commitment, effective implementation, continuing support and processes and practices oriented to maximum value; best practice profitability achieved by a few today can be the norm for all tomorrow.

Selecting A Financial Measure Of Performance:
A financial measure of performance that demonstrates the value of equipment effectiveness must have three essential attributes.

- Credible to business and financial executives who may have little or no appreciation for the potential contribution of optimizing equipment management toward the creation of enterprise value.
- Accurately depict the value of increased equipment effectiveness and utilization taking into account market opportunities for increased production and/or quality and conditions, product margins and manufacturing performance.
- Impartial arbiter that indisputably demonstrates the necessity for, priority and enterprise profit impact of investment to eliminate defects.

Ideally, the financial measure or measures must apply top to bottom within an enterprise. The measure utilized by a senior executive focused on shareholder value must be consistent with and linked to measures utilized by line management, engineers, process operators, craft and support personnel. All must understand the strategy, priorities and their individual contribution as clear direction and demonstration of the necessity to meet quality standards and perform assigned tasks effectively.

Team athletics provide a good analogy. Everyone on the team must be focused on the final score. Individual statistics, no matter how overwhelming, are of no use if the team doesn’t win. In fact, lucrative individual incentives offered many of today’s highly paid professional athletes, if not directed toward team victory, often have a negative impact.

Economic Value Added:
EVA (Economic Value Added) was selected as the representative financial measure to demonstrate the value of equipment effectiveness. Three principal reasons:

- EVA is increasingly gaining acceptance as the best business/financial measure of value, changes in value and performance. EVA promotes ownership and the profit centered mentality mentioned earlier. It has been stated that EVA is a better indication of value than conventional measures, even cash flow, and strips away many of the standard accounting procedures that may distort and disguise real value and changes in value.
- An increasingly accepted financial measure, EVA will be credible to the business and financial executives that control investment for increasing equipment effectiveness.
- The information needed to calculate EVA permit calculating other measures. RONA (Return on Net Assets) and ROCE (Return on Capital Employed) are examples.

Separate EVA models are proposed for the smallest identifiable producers within an enterprise. For the purposes of this exposition, producer is defined as an entity for which the cost of materials and price of finished goods can be calculated. Each unit in a multi unit power station, chemical plant or oil refinery are examples. Others include one paper machine in a multi machine mill and each line in a manufacturing facility. In many cases the output from one unit is the input to another. Under these
conditions, the calculation of transfer prices are all important to assure an accurate, representative picture of value creation.

**The EVA Model:**
Economic Value Added (EVA) is essentially after tax operating profit less the cost of capital. A positive EVA indicates value added above the cost of capital.

Referring to figure 2, blocks in the upper two rows picture a profit model and simplified calculation of EVA. From the left, the income from sales of finished goods minus the cost of raw materials, conversion costs and taxes equal after tax operating profit.

After tax operating profit minus the cost of capital calculated from net assets multiplied by an interest rate results in EVA. The larger the value of EVA the more value being created. A negative EVA indicates declining value. In a recent presentation, it was stated that a major multinational corporation requires EVA greater than 20% in good years and no less than 0% in bad years.

Production yield and conversion costs are the links between conventional measures of equipment effectiveness and financial results. It goes without saying that regardless of production effectiveness an enterprise won’t long survive if the cost of finished goods exceeds price.

Within the proposed EVA model, conversion costs are defined as all “inside the fence” costs required to produce a given product. Conversion costs, identified in the bottom row of figure 2, include utility costs -- fuel, electric power and water. Apportioned costs of steam and air produced centrally or within a process and distributed throughout a plant are other examples in this category. There may be more. An integrated steel manufacturer mentioned carbon monoxide produced in one process and used in another. In a power generating facility, fuel will probably be classified separately replacing the cost of raw materials in the second row of the EVA model. Apportioned administrative costs are another element of conversion costs. The costs of compliance with safety and environmental requirements must be included. Waste disposal is another conversion cost.

Returning to the usage of electric power -- it must recognized that between 50% and 85% of the lifetime ownership cost of a motor driven pump is electricity consumed. Operating efficiency has a double impact. In addition to increased power consumption (operating cost) when operating off the best efficiency point (BEP), the added stresses result in diminished lifetime and higher maintenance costs. As stated earlier, Equipment Lifetime Management directs attention to the importance of operating at best efficiency conditions.

Operating and maintenance (O&M) include the usual costs -- salary and wages, fringe benefits, repair parts and consumables. However, O&M also produces value as illustrated by the upward, light blue arrows in figure 2. Good operating and maintenance practices have a positive impact on production output determined by availability, production rate and quality. By reducing fluid, air and heat leaks and directing attention to the benefits of operating equipment at best efficiency, good O&M practices reduce utility costs. Likewise, good O&M practices reduce the risk of safety and environmental violations. (One company reported that 50% of environmental violations were caused by equipment failures.) Same for waste disposal. By extending life, reducing requirements for replacement and spare parts, good O&M practices also reduce capital -- an extremely important consideration in today’s financial environment.

World class enterprises recognize that conversion effectiveness measured as a reduction in conversion costs can only occur by a reduction in defects. Maintenance costs are reduced only by *permanently reducing the need for maintenance* -- not by reducing maintenance personnel or outsourcing. And this requires awareness (training) and investment. Pump flange alignment, precision balancing and coupling alignment, all have a cost and all have a traceable value within the EVA model. As an illustration let’s take a case where an improvement such as precision alignment
increases pump MTBF (Mean Time Between Failure) by an assumed percentage. The discipline imposed by the EVA model, combined with activity based accounting, forces knowledge of both MTBF and cost of repair. From there it is a relatively straightforward process to determine what effect an investment for improvement has on value expressed as EVA.

As stated in the previous paragraph, world class organizations recognize that trained personnel are imperative toward maximizing conversion effectiveness. This means personnel trained to question why in order to wring the last drop of efficiency from a given process. Attention to detail such as steam and air leaks, heat loss due to faulty insulation, inadequate lubrication, pumps allowed to operate well outside of best efficiency or with leaking or open recirculation valves. Attention to detail requires knowledge first followed by initiative and diligence. In the specific case of the EVA model, personnel must be able to connect attention to minute details to health of the enterprise and their own job security and satisfaction.

In a real enterprise the dispersion of EVA to individual equipment and even component level is complicated by the existence of multiple products, some of which may be intermediate products of another process, internal product transfer prices and the allocation of shared resources. This demands an accurate allocation of costs between producers and users -- activity based accounting.

The proposed EVA model pictured in figure 2 in two dimensions is really a three dimensional composite of all the identifiable profit producing processes within a producer enterprise. Although
the author is not aware of any one enterprise that has adopted this approach of individual accountability, the information technology to do so is certainly available.

In addition to demonstrating the value impact of practice and technology within a producer enterprise, the proposed EVA model must possess two other attributes -- the ability to predict EVA for a given investment at any level within the enterprise and then report on effectiveness (results) as the investment is implemented. As stated earlier ROI (Return On Investment), has proven notoriously inaccurate as both a predictor and reporter. A good part of the reason is that assumptions leading to ROI may be difficult to evaluate after the fact. Additionally, conditions may change.

The EVA model permits tracking any given investment and determining whether the investment had the anticipated impact. And if not, why not, including changes in forecast conditions such as market and price variations.

Referring again to the EVA schematic, figure 2, production effectiveness is often measured in terms of OEE (Operating Equipment Effectiveness), from TPM (Total Productive Maintenance). As shown in figure 2, OEE is a normalized quantity representing net production yield made up of the three terms mentioned earlier: Availability, Production Rate and Quality. The numerator of each term leads to production yield as shown by the background arrow.

Many companies utilize OEE as a prime measure of equipment effectiveness. Approximately 85% or better is considered world class performance.

In the author’s opinion, OEE has two significant weakness. In terms of OEE a process can be highly effective -- and very unprofitable -- if conversion costs are excessive. Additionally, OEE alone does not lead to opportunity or priority. By ignoring market and business conditions it is easy to focus OEE on the wrong activity. For example, focusing resources on increasing quality may not yield improved profit if availability is not addressed as well. Conversely, increasing production rate may not yield much improvement in profit if availability and / or quality decrease at the higher rates. The ability to insert “what if” into an overall producer model to determine an optimum balance is the crucial issue. When this is accomplished it may well turn out that deliberately sacrificing equipment lifetime produces the greatest profit. To take that thought to a conclusion, the emphasis then needs to be on maintainability.

**Timed Production Effectiveness:**

To incorporate the crucial importance of conversion cost toward enterprise profitability the author has proposed an expanded effectiveness measure based on OEE -- *Timed Production Effectiveness (TPE)*, also illustrated in figure 2.

Timed Production Effectiveness = Timed availability × Production Output × Conversion Effectiveness

*Timed Production Effectiveness* includes conversion cost and applies as a measure of the effectiveness of individual components as well as an entire facility.

The first term, *Timed Availability*, is defined as the percentage of time a facility, system or component is capable of producing a required result during the time window(s) in which production is scheduled / required. *Timed Availability* imposes three conditions to the calculation of availability:

1. For a process or facility in which production is sold out (shown on the EVA diagram as market conditions) the availability objective is 8,760 hours (8,784 hours in a leap year!). This to create an incentive for minimizing scheduled outages.
2. For a process or facility in which production is not sold out and for spared or redundant facilities, system(s) or component(s), the target or objective is the actual time in which operation is required.

3. In the event a component or system failure slows or interrupts production, the interruption does not end for the purposes of calculating Timed Availability until production is fully restored. **Timed Availability** thus reflects the full impact of a momentary malfunction that stops or upsets production for an extended period.

**Timed Availability** is the most realistic measure of availability for all facilities and components and especially those that must be capable of operating at 100% during a production time increment which may be less than total calendar time.

The second term, **Production Output**, is defined as production delivered in specification divided by production objective in units, MW, tons, etc. **Production Output** is thus actual output or throughput normalized to a target or objective value. The concept of a production time increment is also applied so that the term reflects output when required to meet scheduled demand. Since actual output can be greater than scheduled output, **Production Output** may be greater than 1. If off specification production is sold at a lesser price, a constant is applied to account for diminished income. Quality may also be tracked as a separate quantity as in OEE.

Some facilities measure and track the combined Timed Availability and Production Output as **Asset Effectiveness**. To emphasize an earlier statement, Asset Effectiveness is only part of the story. For the full picture, conversion cost and effectiveness must be addressed.

**Conversion Effectiveness**, the third term in TPE, is a conversion cost objective divided by actual conversion cost. Note the inversion of objective divided by actual to reflect increasing effectiveness when actual cost is less than objective. **Conversion Effectiveness** is used to measure the conversion efficiency of a specific component, unit or facility. As stated earlier, all applicable conversion costs; utilities (electric power, water, etc.), operating and maintenance (O&M), administrative and waste disposal must be included.

Several people who have been introduced to **Timed Production Effectiveness** have commented that their enterprise prefers real rather than normalized values. Easily accomplished. Many recognize that the denominator of **Conversion Effectiveness** divided by the numerator of **Production Output** results in Conversion Cost per unit Output -- a valuable performance measure in its own right. There are other vital measures that can be derived from TPE provided the information structure is properly constructed.

During several discussions of TPE, participants have mentioned the difficulty of obtaining accurate cost information. There are two answers: First, it is imperative to know exactly how much it costs to deliver a given product. Lacking this knowledge it is very easy to deliver a product at less than the manufacturing cost -- especially in today’s highly competitive climate where fractions of a cent may be the difference between profit and loss. Again, activity based accounting is a must! Next, it is always the author’s reply that regardless of whether accurate cost information is available today, competitive survival mandates it tomorrow. Those who cross the line between guesstimated and actual costs will have an enormous competitive advantage, as well as crucial information with which to prioritize activities.

Any discussion of the necessity of linking asset effectiveness to enterprise profitability must not neglect the leverage comparison between profit increases gained through increasing conversion effectiveness and production increases. Most process and manufacturing companies operate at a net profit after tax of less than 10%. This produces greater than 10:1 leverage in favor of improving conversion effectiveness. In other words $1 million value gained through increased conversion
effectiveness has the same impact on bottom line profit as $10 million additional production. When availability is high and production is sold out, improved conversion effectiveness may be the only way to increase profitability! As one example of converting value to production, a consultant brought in to survey the control air system at a large amusement park concluded that air leaks consumed the capacity of one full air compressor. In terms of net profit, air leaks required the equivalent of about 10,000 to 15,000 added paid attendance at the park! In a similar calculation accomplished at a sold out chemical plant the profit equivalent to increasing pump average MTBF by one year required an availability of 103%! Figure out how to do that and you’ll really make some money!

There is also the double edged contribution of increasing operating and maintenance effectiveness. In addition to the obvious advantages of reducing cost, and the not so obvious leverage mentioned in the previous paragraph, there are previously discussed major contributions to value illustrated by the large upward arrows in the EVA diagram. When production is sold out, increasing output through increased availability and/or quality (yield) contributes significantly to profit. Some companies have been able to avoid capital investment for added production by recovering “phantom” capacity within existing facilities. In addition, increasing production output with O&M costs held constant results in a per unit reduction. Thus, the double edged contribution.

Whatever the measurement criteria and benchmarks for conversion effectiveness they must connect directly to unit objectives and profit and be familiar and understood by senior executives. Nothing else will gain support from those who control the funds!

**Information:**
If financial justification is the heart that assures survival and drives success, information is the blood and arterial system that delivers nourishment to every element of a manufacturing or production operation. Information includes current and projected performance and condition, projected lifetime (prognosis), equipment specifications, operating and repair history, operating and maintenance recommendations and task instructions, safety precautions and constantly updating lifecycle costs. All are necessary and must be readily accessible. What was a given piece of equipment designed to do? What is it supposed to do? What is it doing now? Any problems in the past? How were they resolved? Combine all this with detailed operating and maintenance instructions and instant communications. Highly experienced people can accomplish more with greater efficiency. In the financial world this is called leverage.

And how is maximum power and efficiency obtained from the information engine? The answer is source independent, self-integrating, standardized, open information systems. The same philosophy that has driven the success of the personal computer far beyond what anyone could have imagined only ten short years ago. The same concept that provides total access to an incomprehensible array of information on the Internet.

Many are becoming aware that corporate Information System (IS) departments are becoming a powerful force in the selection of asset management technology. The real question is who owns and defines technology requirements? Is it those who know the process, will use the technology and are responsible for results or those developing the corporate information structure? The answer is that both must meet somewhere in the middle. And this can only occur if suppliers adhere to rapidly coalescing standards for communicating and displaying information.

What will this mean for equipment information? Technology can provide free information exchange of mechanical condition, performance, operating and maintenance records between condition assessment, maintenance management and process control systems. Operators and maintenance mechanics can see a machine’s condition, how it is operating compared to how it ought to be operating and any changes that have occurred. There will be full access to history, task instructions,
including parts lists, and safety precautions. If a problem occurs, an analyst can recover measurements as well as the exact sequence of events leading up to and during the problem.

Open systems provide two more significant benefits. Maximum headroom for continuing growth with increased experience and technology is one. While no one can anticipate tomorrow's information technology there is one thing certain -- it will be much different and better than today's! The reduced system specific training needed for proficiency when everyone adheres to a common operating standard is the second added benefit. Reports indicate this single factor will reduce installation and support costs by more than 25%. Both are present in today's PC office software and are strong contributors to acceptance and success.

**MIMOSA:**

All available evidence supports the superiority of open systems. Process control is rapidly moving from closed proprietary systems to open access and exchange. Why? A growing customer awareness that no single supplier can maintain “best for application” in every area required for modern automated control systems.

MIMOSA, The Machinery Information Management Open Systems Alliance, is a rallying point for open Equipment Lifetime Management systems. The MIMOSA Mission is stated as follows:

*Formulate business and technical solutions that will improve the acquisition, analysis, communication, display and use of information. Information that defines status, predicts lifetime and provides operating and maintenance recommendations for process, production and manufacturing equipment. Develop mutual benefit conventions and drive progress toward open exchange of vital information needed to gain greatest value for the largest group of potential beneficiaries.*

**MIMOSA Objectives:**

- Formulate and publish consensus conventions that promote the cost-effective unification of equipment condition, control, maintenance and performance information.
- Construct a consensus information model that will preserve, encourage and gain maximum value from vital maintenance technology.
- Develop compelling financial justification for optimized equipment asset management practices.

MIMOSA advocates open exchange of equipment condition related information between condition assessment, process control and maintenance information systems through published, consensus conventions. This to gain greatest value by combining vital condition information from multiple sources for collective evaluation, reaching accurate determinations of current condition and projected lifetime and communicating results in a useful, understandable form. MIMOSA is committed to preserving the advantages, effectiveness and rich detail contained in specialized applications such as vibration, lubricating oil and electric motor monitoring and analysis systems within an integrated enterprise information structure.

MIMOSA defines an open system as one in which components are able to communicate and exchange data automatically without any proprietary, system or supplier specific special interface protocols.

MIMOSA efforts are structured around three key principles:

- Provide a clear path for migration into a fully open, interoperable information structure
- Build from and extend current practice, conventions and products in incremental steps to minimize cost and risk.
Maximize participation with consensus solutions. Build support through continuing demonstrated success.

**Prime Benefits of MIMOSA:**
MIMOSA open system conventions provide:

- The most effective, least expensive means to measure and manage optimized availability, reliability and lifecycle costs of process, production and manufacturing equipment by electronic exchange of vital information between:
  - dissimilar condition measurement and advisory systems; e.g., vibration, lubricating and hydraulic oil condition, operating performance, electrical condition, thermography and others
  - condition assessment, control, maintenance management, and enterprise information systems
- Freedom to assemble comprehensive, self-integrating condition assessment systems from multi-source “best-for-application” components without expensive, inflexible and confining specialized system integration.
- Enterprise-wide awareness of results, benefits, credibility and business value of optimized maintenance (asset management) processes and practices through full participation in the information structure.
- Assurance of continuing, least cost upward growth and expansion to gain maximum advantages from improvements condition assessment, equipment, maintenance management, control and consumer information systems.

Other benefits include:

- Ability to concentrate resources and investment on highest value, core competency, application optimization and advancement rather than low value platform and custom interface requirements.
- Stimulation of new life, acceptance, expansion and success into the equipment asset and condition assessment fields by full participation in 21st century information processes.

**The MIMOSA Information Model:**
An information model is the crucial starting point. It defines boundaries for specialized systems so that each can perform designated tasks in an optimal fashion. In addition, defining information content at logical boundaries provides all involved with input and output requirements for each function.

The MIMOSA information model represents consensus among a broad variety of users including Dofasco Steel, M&M Mars, Sunoco, PG&E, PPG Industries, The Hartford Steam Boiler Inspection and Insurance Company and Virtual Convergence.

The MIMOSA information model, illustrated in Figure 3, contains five major sources/consumers of equipment condition information: *Condition Measurements* on the far left, *Enterprise Equipment Object Manager* at the top of the diagram, *Decision Support* in the middle, *Maintenance Management* on the right and *Distributed Control* at the lower center.
Enterprise Equipment Object Manager

The Enterprise Equipment Object Manager is the vital link between all integrated systems. As currently conceived it has six prime functions, some of which may reside in connected systems:

- Provide a unique site identifier.
- Capture the functional hierarchy of a specific facility -- area, unit, process, system, location, equipment and components.
- Define assets throughout a corporation with a unique identification to allow tracking specific equipment that might be reinstalled in a different location, or even site, following repairs.
- Map the current utilization of assets to their location in the process.
- Assignment of measurement locations within an enterprise to assure continuity of historical trend information as equipment and monitoring systems are altered or replaced.

Condition Measurements

Condition Measurements include on and off-line vibration, operating and process measurements such as temperature, pressure and flow, lubricating oil condition, motor characteristics: operating (current signatures) and static, and Thermographic images. The MIMOSA Common Relational Information Schema (CRIS) provides a published, open means to exchange these variables between compliant systems. Typical Condition Measurement data are illustrated in Figure 4.
Decision Support

The **Decision Support** block accomplishes the conversion process from data to information. Although many outside the predictive field appear to believe that **Decision Support** is little more than trending overall measurements, earliest warning of an abnormal change requires sophisticated analysis of complex dynamic characteristics.

The consensus of MIMOSA participants is that current state-of-the-art requires human judgment at several steps in the process between condition measurements and issuance of a work order. Typical information that must be available from **Decision Support** is illustrated in Figure 5.

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**Figure 4 Typical MIMOSA Equipment Data**

Data:
- ID’s: Plant / Location / Equipment
- Events
- Numerical values (measurements)
- Measurement trends
- Vibration Characteristics:
  - Vectors
  - Time Waveforms
  - Orbits
  - Spectra (frequency, order, CPB)

Thanks to: Ken Bever, John Hawkins, Alan Johnston, Art Jones, Peter Morgan

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**Maintenance Management**

The Maintenance Management System is the repository for a great deal of information that is useful for users in both the *Condition Measurement* and *Decision Support* functions. This information is shown in Figure 6.

**Figure 5 Typical Equipment Information within the MIMOSA Model**

**Figure 6 Typical CMMS Information within the MIMOSA Model**
Recording periodic predictive measurements is likely to become a scheduled activity of the Maintenance Management System. Completion and time required will be reported back for the purpose of cost accounting in the same fashion as work order completion. The two arrows between Maintenance Management and Condition Measurement functions illustrate these actions.

**Control Systems**

Many Distributed Control System (DCS) suppliers view vibration as another measured value that can be added to the DCS. There appears to be little awareness of the necessity and benefits of the rich detail resident within dynamic vibration signals for the purpose of earliest anticipation of problems and accurate lifetime prediction.

In the MIMOSA information model both data and information are made available to the control system. CRIS compliance has the benefit of being able to address every condition assessment system through a single, published protocol. The requirement for program specific interfaces for every component within the integrated whole is eliminated. Control system suppliers can elect to display measurements or state of health -- data or information. This offers maximum flexibility to meet a broad range of control system user requirements.

**Summary of MIMOSA Activities:**

Over two hundred people representing more than fifty companies in the US, Canada, Europe, Russia, Japan and Australia have contributed to MIMOSA progress toward open information exchange. Companies include twelve of the sixteen premier suppliers of condition monitoring products and systems, representing approximately 50% of total worldwide product and service sales. Led by Ken Bever, MIMOSA participants have developed the Common Relational Information Schema (CRIS) and a proposed model for information exchange between condition assessment, control and maintenance management systems.

A core group of CRIS tables, defined for vibration monitoring (VIB-FILE), were demonstrated successfully with a multi-supplier data exchange to a generic MIMOSA CRIS Interpreter developed by Pacific Gas & Electric Company. The demonstration took place during the *P/PM Technology, Predictive Maintenance Technology National Conference* in early December 1996. All the major suppliers of off-line, walkaround monitoring systems and three leading suppliers of on-line, real time data acquisition and analysis systems participated in the demonstration.

The core table concept within CRIS enables information users to freely exchange basic information between systems and sites with provisions for growth as requirements become more complex. It is being extended to oil/water/air sample (SAMPLE-FILE), thermography (THERM-FILE), control and trend data (TREND-FILE), machine diagnostic (DIAG-FILE), reliability data (REL-FILE), asset management (ASSET-FILE) and maintenance management (WORK-FILE) data. The first product capable of CRIS data exchange will be released by MIMOSA participating suppliers in 1998.

An SQL programmatic database interface level has also been defined for program-to-program interoperability using industry-standard ODBC database connectivity products. This specification allows for a periodic snapshot of data from a database to be made available (SQL Snapshot) or dynamic access to the database through the SQL Dynaset method.

An Integrator level specification has been defined for automatic synchronization of various vendors databases through notifications at the ODBC level between compliant systems. The Work-Integrator specification, currently under development, will allow Computerized Maintenance Management (CMMS) and condition assessment systems which support this functionality to send work requests to each other and receive updates on these requests.

An object specification is being formulated based on Microsoft COM (Common Object Model) and DCOM (Distributed Common Object Model).
CRIS and other MIMOSA information are available on the Internet at: www.mimosa.org

MIMOSA History:
The first MIMOSA meeting convened in September, 1994. The objective was to determine if there was support for developing open interoperability conventions, primarily for vibration information. Fifteen people from nine companies participated. The fifteenth meeting was hosted by CSI in Knoxville Tennessee in early August 1998, the sixteenth is scheduled for Indianapolis in November 1998. MIMOSA was incorporated as a non-profit in December 1996.

During the MIMOSA process it became apparent that exchanging condition assessment information had benefits. However, the real value was in facilitating information exchange between condition assessment, process control, maintenance and enterprise management systems. It also became apparent that a first step information exchange had to occur in software.

Conclusion:
The entire concept of maintenance is at a crossroads. Continue as headed, concentrate on keeping equipment operating and likely revert to maintain on failure. The alternative -- drive beyond maintenance to seek maximum value, provide financial justification and become an indispensable factor in effectively achieving the organization’s mission. Which will it be? Evolve gracefully and probably never reach full potential or drive a revolution to gain maximum value. The first requires no effort. The second requires a vision, strategy, initial and continuing proof-of-concept and a lot of hard work convincing seniors that the non-obvious is the best. Equipment Lifetime Management is the path. The choice is up to you!