Chapter 1

The Argument for Use of Detailed Procedures and Checklists for Doing the "Right Kind" of Maintenance

Those in the maintenance profession are constantly exposed at conferences, in professional literature, advertising and sales pitches to a wide variety of products, services and approaches that promise to advance your maintenance and reliability programs to higher levels of achievement. Some of the many options offered to those in the profession are listed below.

- Asset Management
- Availability Engineering and Management
- Computerized Maintenance Management
- Condition Monitoring
- Kaizen
- Lean Manufacturing (& Maintenance)
- Planned and Predictive Maintenance
- PM Optimization
- Proactive Maintenance
- Reliability Centered Maintenance (RCM)
- RCM Variants and Derivatives
- Root Cause Analysis
- Six Sigma
- Supply Chain Management
- Total Productive Maintenance
- Value Stream Management

So what does a maintenance manager have to do to master the maintenance process with so many options available?

The simple answer to this is: Go back to the basics! By basics I mean you should determine:

- **What maintenance to do**
- **How to do maintenance**
- **How and what to change to make it happen**
- **How to measure results**
- **How to present the results <u>and your requests for assets</u> in terms that business managers will understand and act upon.**

To determine <u>what</u> maintenance to do, use a method that has been in use for almost 50 years, now – Failure Modes and Effects Analysis (FMEA) and associated mitigation strategies analysis. If you are fortunate enough to be involved in purchase of a new plant, vehicle or production line, a portion of the purchase price should be devoted to a competently done FMEA. Maintenance requirements recommended by an Architect-Engineer (A-E) firm, system integrator and/or hardware original equipment designer and manufacturer (OEM) should be based on the FMEA, not just the accumulated wisdom of the designers, integrators and fabricators. In terms of maintenance I have found their recommendations lacking in many ways. To counter this problem, progressive companies such as Cargill are assigning reliability engineers to new facility projects, major production line upgrades or expansions. Their charter is to assure the R & M requirements are considered and acted upon from the beginning of a project planning process.

This is no small commitment on the part of Cargill, which operates worldwide over 1100 facilities on any given day.[1]

Most of you, however, are faced with maintenance of existing facilities from which the A-E's, OEM's and installing contractors are now quite distant, if they remain in business at all. You're on your own, pretty much, in determining what maintenance to perform. You may benefit from use of the methodology we now call Reliability Centered Maintenance or RCM, the centerpiece of which is FMEA followed by identification of maintenance requirements or mitigation decisions in four basic categories[2]. RCM methodology choices or "approaches" are growing each year as vendors come up with RCM-like variants and derivatives.[3]

Interestingly, no one in the past 45+ years has come up with a better methodology for determining **what maintenance to do** than the RCM approach. RCM, in whatever flavor of "Classical," "Variant" or "Derivative" one choses to employ it, is a basic requirement that maintenance and reliability professionals must understand. Even if you don't engage in a formal RCM effort in support of your plant, you must think like someone who has mastered the methodology in order to be successful in today's highly competitive, global economy.

How to do maintenance presents a set of challenges that are quite different than determining **what** maintenance to do. In many parts of the world, maintenance professionals take great pride in conducting maintenance based on "skill-of-the-craft." The assumption here is that on-the-job training and word-of-mouth instruction are sufficient to qualify a person to maintain production lines, vehicles and facilities, however complex they may be. I try to challenge that sense of pride, which overlooks common human traits – forgetfulness, the vagueness of oral communications and the highly variable ability of even the smartest humans to understand each other, even when speaking the same language with the same dialect and regional accent. Many of you have witnessed the classic demonstration of how garbled an oral message can get when passed along between three or four persons, within minutes. Think about your own communications with your significant other. In addition, results of on-the-job training can be highly variable depending on what's being taught, who is teaching and who is receiving the instruction. See Chapter 4 for a discussion on Total Productive Maintenance elements that address **how** to do maintenance. Chapter 8 addresses human error in the fields of maintenance and reliability and provides several ideas on how to mitigate or eliminate it.

To overcome this problem, consider use of detailed procedures and checklists.
My personal exposure to the need for precise written instructions detailing maintenance tasks came in the aftermath of a disaster, loss of the nuclear powered attack submarine USS Thresher (SSN 593) in 1963.

[1] Presentations by Cargill and Cargill affiliated "Allied Services" at Society for Maintenance and Reliability Professionals Certifying Organization meeting for sustaining member companies Sterling, VA, 22 July 2004.

[2] The four categories are Time Directed Tasks, Condition Directed Tasks, Failure Finding Tasks and Run to Failure Decisions

[3] For a description of different approaches to RCM see the **Physical Asset Management Handbook** by John S. Mitchel ISBN: 9780985361938, July 2012 pp94-97 available from Reliabilityweb.com MRO-Zone Bookstore, Ft Myers FL or Amazon

USS Thresher (SSN 593), pictured below, now lies on the bottom of the Gulf of Maine.[4]

Loss of USS Thresher occurred while I was a student at submarine school prior to being assigned to the world's first nuclear submarine, USS Nautilus (SSN 571). The loss of 129 lives was, to say the least, a very sobering event for the Navy. Those familiar with the details of the Thresher tragedy may recall that the investigation board concluded that the ship was lost due to flooding caused, most likely, by failure of a seawater system component that may have been reinstalled improperly during shipyard overhaul. Compounding the casualty were some design flaws that prevented the ballast tanks from being emptied expeditiously enough so as to achieve and sustain positive buoyancy sufficient to carry the ship to the surface in the face of flooding. Internal cooling system designs also featured a lot of piping subjected to submergence pressure, increasing the risk in case of failure. The Navy's response to loss of Thresher was to redesign the flawed systems, back-fitting the changes to all subs in the fleet and requiring these features in all new designs.

A "Submarine Safety" (SubSafe) program was also instituted as a direct result of the Thresher disaster. From a maintenance standpoint the centerpiece continues to be the requirement that detailed written procedures and comprehensive checkoff lists be developed and followed to the letter by all personnel engaged in maintenance of specified components of all systems affecting submarine safety. Thereafter, for over 50 years, now, no additional U.S. submarines have even come close to being lost due to a maintenance problem involving the systems included in the SubSafe program.[5] Workers in manufacturing industries in North America and Europe feel the pressure of global competition that threatens their livelihoods and prosperity. The iron and steel industry is one of the most recent examples (1990's) of this trend, just as textiles, shoemakers and others have before them. Yet, there are a few companies that are able to survive and thrive because of enlightened management. For many companies the measures were taken too late to forestall bankruptcy, loss of jobs and in some cases the entire business.

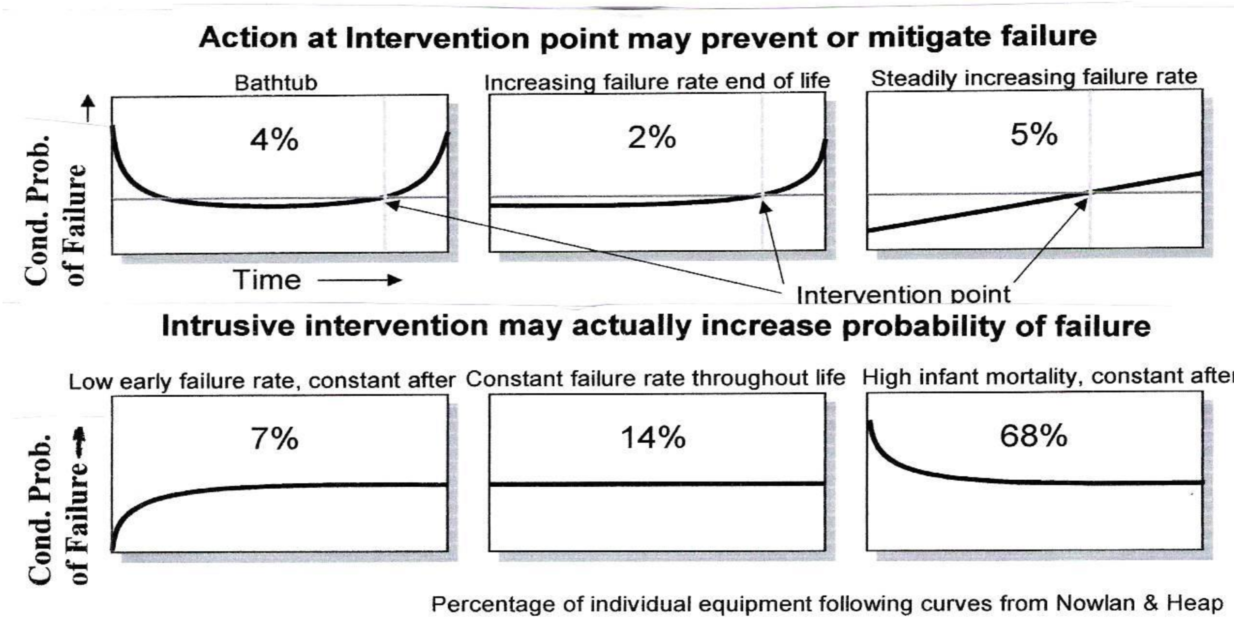
For others, committed to the long term view, the measures associated with reliability improvement, it meant preserving a future for most if not all stakeholders.

[4] Photo appears in Nautilus: The Story of Man Under the Sea by Roy Davis, USNI Press

[5] (USS Scorpion (SSN 589) was lost later in the 1960's, due it is now believed, to a faulty torpedo. Root cause is believed to be a design flaw in the torpedo propulsion system battery, causing it to explode in the torpedo room while it was being serviced and dooming the ship and its crew, including the Commanding Officer, who had been my roommate and mentor during my qualification in submarines on Nautilus in late 1963 and early 1964.)

During this decade of the 1960's that the Federal Aviation Agency, aircraft builders and operators came to the revelation (and proved it with statistics) that there was **very little relationship between time directed maintenance and (increased) reliability.** In fact it can be shown and this text will try to illustrate the point that **time based maintenance can be detrimental to reliability most of the time** and that **corrective maintenance, done on the basis of skill-of-the-craft and intuition, is the wrong (most costly, least effective, least profitable) approach** for mission, production or safety-critical plant components in any venue.

Those familiar with the origins of Reliability Centered Maintenance may recall the eye-opening "conditional probability of failure" profile curves. These are illustrated below.[6]



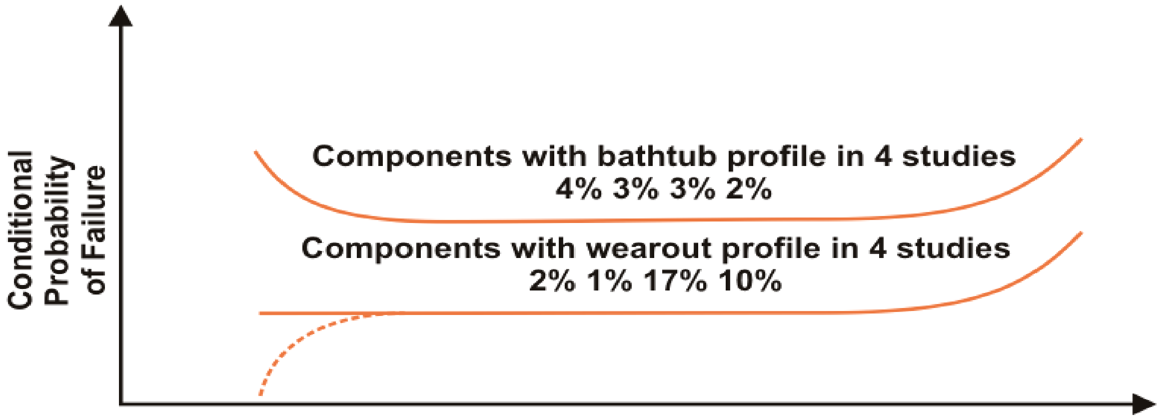
The most well known of these profiles was the "bathtub" curve (upper left in the figure above), widely considered at the time to characterize most equipment failures. However, statistical analysis showed that for civilian aircraft the "bathtub curve," (characterized by early stage high rate of "infant mortality," followed by a "flat" or random failure period and ending with rising "wearout" stage) applied to only a small percentage (4%) of components.

[6] This figure was adapted by the late Thomas H. Bond from the original Department of Defense report entitled Reliability Centered Maintenance by Nowlan & Heap of United Airlines, dated December 29,1978. It appeared originally (with different captions & axis labeling) in The Physical Asset Management Handbook 3rd & 4th Editions Edited by John Mitchell and published now by Reliabilityweb.com MRO-ZoneBookstore.

Later studies from the 1970's (also on commercial aircraft in Europe), from the 1980's (on U.S. Navy surface warships) and then from the late 1990's into the year 2001 (on U.S. Navy nuclear powered attack submarines) revealed virtually the same finding. The actual numbers for the studies are 4%, 3%, 3% and 2% for UAL, Broberg, MSP and SUBMEPP studies respectively. What makes the various conclusions compelling in this chapter using these studies is that they all used statistically significant data and the same method of comparative analysis as the original Nowlan & Heap report.[7]

Conclusions reached concerning the two profiles (bathtub curve that exhibits infant failure, random failure and then wearout and a curve that exhibits only random failure until "wearout" near end of life further **demolishes or at least greatly undermines the long held basis for preventive maintenance programs** that were made up largely of time directed tasks, **especially when the tasks are intrusive in nature**. These profiles and the associated percentages of components in the four studies further refute the idea that periodic "preventive maintenance" is the most effective strategy to prevent failures. All profiles exhibiting any form of "wear-out" characteristic (rapidly rising conditional failure probability) amount to **no more than 20%** of all components included in any of the studies, as illustrated and described in the figure below.

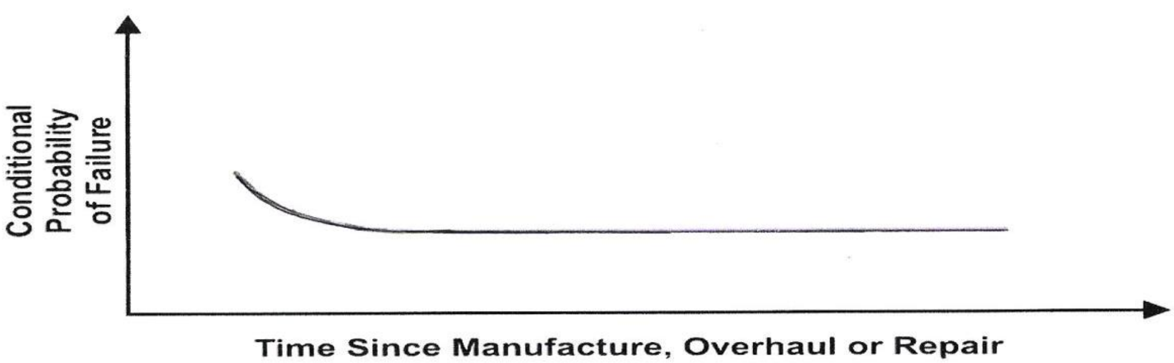
[7] The four studies from which failure profiles and statistics are taken are: "UAL Study" - DOD Report on Reliability-Centered Maintenance by Nowlan & Heap of United Airlines, dated December 29,1978, which used data from the 1960's and 1970's and earlier papers and studies referenced therein; the "Broberg Study" believed done under NASA sponsorship (reported in 1973) and cited in Failure Diagnosis & Performance Monitoring Vol. 11 edited by L.F. Pau, published by Marcel-Dekker, 1981; the "MSP Study" - long title "Age Reliability Analysis Prototype Study"- done by American Management Systems under contract to U.S. Naval Sea Systems Command Surface Warship Directorate reported in 1993 but using 1980's data from the Maintenance System (Development) Program; and the "SUBMEPP Study" reported in 2001, using data largely from 1990's, and summarized in a paper dated 2001, entitled "U.S. Navy Analysis of Submarine Maintenance Data and the Development of Age and Reliability Profiles" by Tim Allen, Reliability Analyst Leader at Submarine Maintenance Engineering, Planning and Procurement (SUBMEPP) a field activity of the Naval Sea Systems Command at Portsmouth NH.



This point is illustrated in the combination profiles illustrated in the graph. Note that the totals for the only profiles showing a wearout characteristic are 6%, 4%, 20% and 12%, respectively

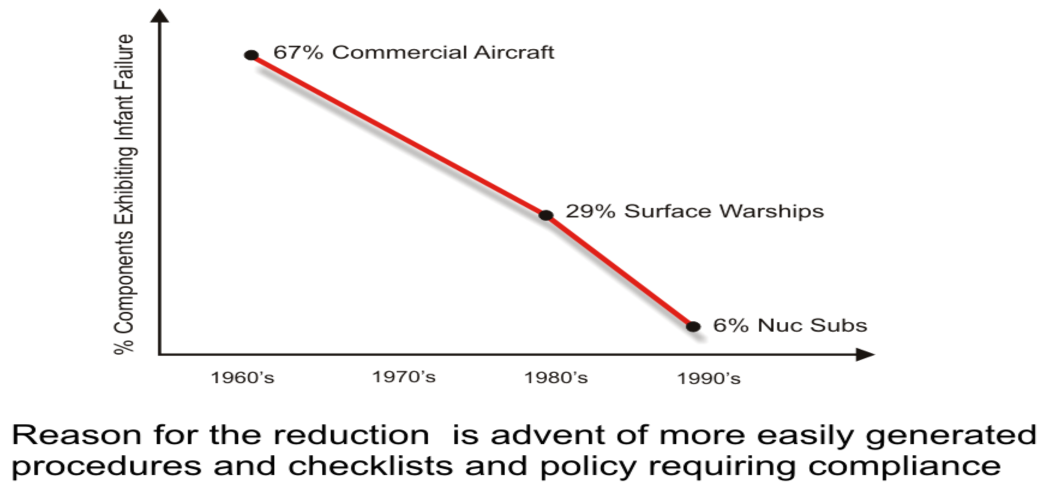
Infant failures and planned, time directed tasking – "It wasn't broke, but we fixed it anyway!"

The dominant failure profile for commercial aircraft in both U.S. and European studies was one characterized by the first two parts of the bathtub curve, "infant mortality" followed by random failures. The word "infant" in the context of time refers to the period right after a piece of equipment enters service either when new or after maintenance is performed on it. This finding of high levels of infant failures in commercial aircraft that were maintained by "licensed" mechanics and electricians was considered a rather surprising result, and it had some ominous ramifications. The most obvious was that the most likely cause of infant failure was some human error, either during design or manufacture of the replacement parts used and/or their installation or simply the opening, disassembly or reassembly process for any purpose. The simple addition of lubricant (for example - too much, too little or the wrong type) could cause premature failure.



Infant Mortality Failure Profile: The dominant characteristic, 68% and 66% in commercial aircraft studies in 1960s and 1970s, but only 29% in surface warships studied in 1980's and 1990's 6% in nuclear submarines by 2001.

This significant decline in infant mortality is illustrated in the graph below.



To understand the wide difference between these numbers (68% and 66% in the 1960's and 1970's, 29% and 6% in the 1980's and in 2001, a review of the evolution of maintenance for the machines involved in these studies during that period is in order.

In commercial aircraft maintenance, operational time (at intervals not to exceed 1000, 2000, 5,000 10,000 hours, etc.,) dictated when specific "preventive" maintenance checks and replacements were to be done. Licensed commercial aircraft mechanics and electricians were the only personnel authorized to do such maintenance. **But still, the infant failure profile was the dominant one of all six available.**

U.S. Navy preventive maintenance for surface ships and submarines was based on calendar time (monthly, quarterly, annually, etc.,). Many of the required inspections were intrusive, requiring varying amounts of disassembly. "Qualified" military technicians relied upon the skill-of-the craft, intuition and formal classroom and more informal on-the-job training more than written procedures.

The use of detailed, printed step-by-step procedures was in its infancy. If they existed at all, they were in technical manuals delivered when the equipment was new. Manuals were rarely kept up to date, thereafter, because of lack of funding or lack of appreciation for the importance of their content during equipment life cycle.

Navy crews were required to extract, reproduce, promulgate, and update maintenance procedures, but the local capability to do so was totally inadequate. None of the tools needed even existed on board naval vessels beyond manual typewriters and Mimeograph machines. The same situation existed in shore based facilities dedicated to fleet support. The labor and expertise in procedure writing required far exceeded the capacity and capabilities of the ships' crews and support activity staffs.

Recognizing this, the Navy began to develop and promulgate detailed maintenance procedures from shore based support activities that specialized in procedure development and distribution in the 1960's. Technical manual content and/or manufacturer's recommendations were used only as a starting point, and largely disconnected from procedures thereafter (because there was never enough money for most tech manual upkeep). Civilian contractors directed by the above mentioned dedicated naval support activities developed most procedures. The contractor personnel actually doing the work were predominantly former naval technicians with expertise in the systems and equipments.

The reasons for developing detailed procedures were compelling. Military personnel rotate frequently from station to station. Their duties change as they are promoted - as frequently as 6 times in the first 8 years in some specialties for the most talented personnel. Word of mouth and on-the-job training and intuition were simply too unreliable to assure safety and consistency in maintenance practices. There wasn't enough time in a career to promulgate everything through formal training courses. The only logical means of assuring continuous improvement in fleet readiness (maximum reliability and availability) was to implement a comprehensive "Planned Maintenance" program that was procedure based. At the same time the fleet had to change to assure use of and compliance with procedures, even for the parts of the fleet where the "best and the brightest" sailors worked (submarines).

At the same time, over several decades in shore support activities and civilian contractor firms, the Navy continuously updated the tools (such as computerized word processing) and technologies (such as electronic image integration into text) needed to generate and promulgate new and revised detailed maintenance requirements documents. In addition, the Navy made shore support activities accountable for promptly responding to fleet feedback and supporting organizations recommending changes to improve procedures and maintenance requirements. Effectiveness in following up on fleet feedback and new condition directed maintenance requirements became a basis for evaluation and promotion of responsible field activity commanding officers.[8] This facilitated the transition from time directed to condition directed tasking as RCM-based maintenance was implemented.

The practice of maintenance in general underwent a transformation from almost complete dependence on time-directed tasking (preventive or planned maintenance) to much more condition-directed tasking between the 1970's and end of the 1990's. Within the Navy, programs for operating cycle extension (between overhauls in shipyards) embraced RCM-based maintenance for fleet maintenance. During the 1980's this converted largely time directed maintenance programs to condition based strategies for about 220 surface warships and 122 nuclear submarines, including all of the 60+ attack submarines included in the SUBMEPP study reported in Allen's 2001 paper (footnote 7).

What is described above accounts in my opinion for the lower infant failure rates in naval vessels. Given the same type of evolution has occurred in commercial airline maintenance, I

[8] In the late 1970's the Director of Fleet Maintenance, a flag officer in the Naval Sea Systems Command, upon hearing of the poor track record of field activities in responding and acting upon feedback on maintenance procedures from the fleet and from other fleet support organizations, embarked on an 18 month crusade to improve the system. He made it clear to responsible field activity CO's upon whom he wrote fitness reports that they had to make this improvement in responsiveness or suffer consequences in terms of his recommendation for further promotion. The system improved dramatically during that period.

believe that an updated study of conditional probabilities for today's air fleet would show a significant reduction in infant failures, also.

It's okay to require time directed tasks, if the basis is sound and the "wear-out" characteristic is established for the component involved, but don't forget that few components **(<u>no more</u> than 20% in the four studies cited)** exhibit this characteristic.

Condition Directed Tasking – "If it ain't broke, don't fix it!"

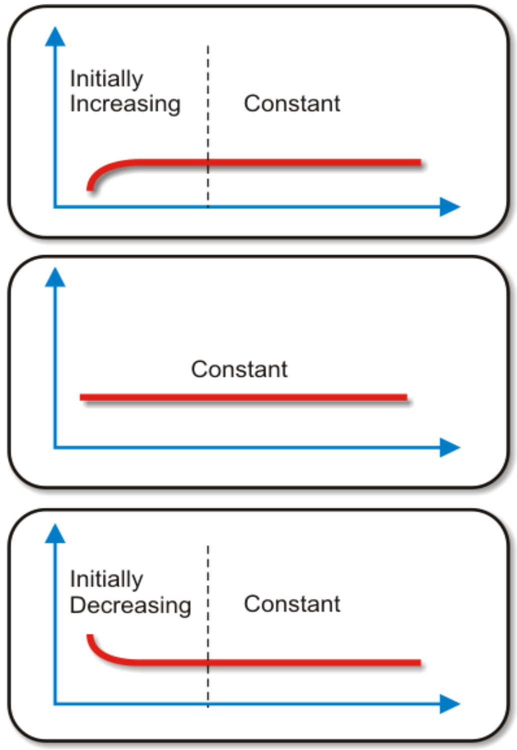
By the 1980's a wide variety of predictive maintenance or condition monitoring tools were beginning to appear. Vibration analysis, lubricant and wear particle analysis, infra red thermography, ultrasonic flaw detection, remote visual inspection using fiber optics and other technologies allowed early detection of degradation in many machines and systems. Widespread availability of ever more powerful desktop computers and, customized and off-the-shelf analysis software accelerated and facilitated this revolution in maintenance thinking.

Diagnosis of current condition and prognosis of likely future progression of problems became easier, safer, more sensitive and more accurate (than human senses and intuition) as mathematically and scientifically based methods such as trend, statistical or correlation analysis and pattern recognition came into use. Condition-based maintenance (that is, doing only condition monitoring until condition dictates the need for corrective action) was made possible by predictive technologies and analysis methods. In addition most predictive technologies are non-intrusive, minimizing the need for disassembly or removal of equipment from service in order to detect degrading conditions. As intrusive maintenance requirements diminish, failures caused by maintenance diminish. Condition monitoring requires careful attention to conditions under which the monitoring is performed so as to ensure comparison of data from one observation to another. This is an equally important reason to have procedures to support modern maintenance strategies.

Condition directed tasking makes a lot more sense than time directed tasking when considering the finding that no less than **71%** of components included in any of the four studies previously cited exhibited a "random failure characteristic" and **<u>no</u>** "wearout" for the majority of their conditional probability period of operation after manufacture, overhaul or repair. **<u>The actual numbers for the four studies are 89%, 92%, 77% and 71%, respectively, displaying random failure and no wearout for the majority of an operating cycle</u>**. If the failure profile percentages addressing gradually increasing (but random – with no wearout) rate is added to the numbers above then **none is lower than 80%**. What this means is that time directed tasks probably **won't work most of the time**. If the task is intrusive, there is a high degree of probability that the task will **increase** the likelihood of failure in the operating cycle that follows the maintenance action. The figure that follows illustrates this point.

- Totals (bottom line) reflect years of data collected on commercial aircraft, Naval Surface Warships and Nuclear Submarines
- Source: U.S. Navy Analysis of Submarine Maintenance Data and Development of Age and Reliability Profiles – Tim Allen 2001

UAL 1968	Broberg 1973	MSP 1993	SUBMEPP 2001
7%	11%	6%	9%
14%	15%	42%	56%
68%	66%	29%	6%
89%	92%	77%	71%



Procedure Based Organizations (PBO's) – "Fix it right the first time!"

The single most important reason for the significant difference in distribution of failure profiles and an order of magnitude difference in infant failures between commercial aircraft in the 1960's and nuclear subs in 2001, in my opinion, was the advent of computer based word and image processing programs along with more rapid communications methods. Although rudimentary in the early 1980's, by the mid 1990's they had almost completely eliminated the use of typewriters and "hand cut & paste print-masters" in support activities and their contractors. Electronic word processing and inclusion of digital images made possible the development and rapid update of detailed maintenance procedures. It is no fluke that only 6% of components in the SUBMEPP study exhibit the infant failure characteristic. Allen (footnote 7) attributes the low number of infant failures to thorough testing of submarine components before the ships return to operational service. This may be true to some extent, because testing is an integral part of the repair procedure in most cases. However, infant failures occurring while testing during shipyard overhaul or operational site refit pier-side and on sea-trials are not documented in the data gathering system used to record failures during operational periods. Work orders are not closed out until the operational testing is completed to the satisfaction of the operator (ship's crew).

Equally likely, in my opinion, is the fact that submarine maintenance and operations personnel are required to comply with detailed procedures (which include post maintenance tests and instructions for returning the system to a "ready to operate condition") in performance of repairs and to conduct in-service preventive maintenance of all types. **The result is that they "fix it right the first time."**

At the upper end of the procedure hierarchy are "Controlled Work Procedures." These were introduced for nuclear submarines in the 1970's and for surface warships in the 1980's.[9]

In submarine maintenance, detailed procedures are required to be used for repairs and in-service maintenance of all:

- Submarine systems
- Nuclear reactor, propulsion and electrical and auxiliary systems
- Sensor and Fire Control Systems
- Weapons systems
- Life support systems
- Emergency systems

Skill-of-the- craft based maintenance practices are permitted for:

- Hotel systems (Plumbing, cooking, water cooler, soft drink and ice cream dispensers, etc.)
- Entertainment systems
- Auxiliary lighting and systems (e.g., reading lights for berthing, etc.)
- Interior communications systems not designated as essential for ship operations

In the mid 1970's, it took over 18 months for a substantial change to a maintenance procedure to be disseminated fleet-wide. In the late 20th Century, a small change to a maintenance procedure, such as a revised safety precaution, could be transmitted by naval message to the whole fleet in less than 24 hours. But a more substantial revision could still take months to be fully disseminated. By the beginning of the 21st Century, a whole new maintenance procedure can be originated and transmitted to the whole world via the Internet in a matter of hours.

The basic conclusion one reaches concerning all of this is that infant failures in maintenance are caused by lack of procedures and/or failure to follow and learn from procedures. The more detailed the procedures and the more insistence on compliance with procedures an organization becomes, the more precise and less error prone its maintenance will become. The result will be an increase in reliability closer to limit that design and other factors.

So the answer to the challenge about how to do maintenance is - become a Procedure Based Organization – a PBO! –That's the "buzz-phrase" that you can take to the bank!

A Procedure Based Organization produces or receives and complies with detailed written instructions for conducting not only maintenance, but also operations and routine checks. This seems so basic that it is overlooked in most organizations and for all the wrong reasons! It's so much easier than it used to be, given availability of low cost word processing and scanning and

[9] A handbook for writing controlled work procedures was developed in the Naval Ships Systems Command and widely promulgated to submarine repair activities in the late 1970's. In the 1980's the high rate of infant failures and rework problems in surface warships came to the attention of the Surface Force Atlantic Fleet Commander, who, upon hearing what the submarine force had done, ordered a handbook, tailored to surface warships, be prepared and distributed. Subsequently, it was promulgated to all naval surface warfare vessels and supporting activities throughout the Navy.

image insertion equipment, that there is hardly any excuse for not doing it, given the benefits derived in terms of increased reliability. The fundamental approach is depicted in the diagram below.

Procedure Based Organizations

This diagram emphasizes two-way communications to sustain health of a procedure-based organization

Not only does an activity have to declare that it has a Procedure Based Organization, but it has to back it up with a working process for procedure and checklist origination, dissemination, feedback and follow-up. The idea of feedback and follow-up is reinforced in the diagram above by arrows that imply two-way paths for communications. It is not enough just to disseminate procedures and checklists. Users must have on-going evidence that their ideas for improvement are being received, considered and acted upon promptly. Changes that are concurred in must be seen to be incorporated in revised procedures and checklists coming out of a process that functions as well as is expected of the maintenance and operations processes it supports. Otherwise, enforcement of a policy requiring compliance will quickly become impossible, because of a perception that management support for the process is weak or non-existent.

In July of 2004 a one-day seminar was conducted in response to a query concerning what it took to become the world's best maintenance organization. The organization had been operational for only 18 months after rejuvenating a portion of a steel plant that had a hundred year history before shutting down and going out of business three years earlier. The new organization was doing quite well, having returned the equivalent of 80% of its new owner's investment in the short time it had been operating under new management with carefully selected staff. However, all there knew that world steel prices, then inflated due to the "China Bubble," could very quickly deflate to where they might not be competitive with other suppliers of the product they manufactured. They saw maintenance as an area where their equivalent profit margin (return on investment to their owner) could be improved. After attending the seminar, which stressed use of detailed procedures and checklists for both operations and maintenance, management decided to apply the principles to startup of one of their most complex manufacturing processes. They prepared a check-off list for start up of all systems needed to roll steel bars into coils of wire ready for shipment.

About two weeks after the seminar, the seminar leader followed up with the company president. He volunteered that they had applied the rolling line startup check-off list for the first time that week. They decided to run the check-off twice before the first bar of steel was introduced to the line. They found in the second check that they had missed two items the first time. After correcting these items during the second run-through of the checklist the startup went without any delay or incident, a first for that plant under the new staff. If ever there was a "Hallelujah Moment," for one preaching the benefits of detailed procedures and checklists, that was it.

This is not in any way to denigrate the methodology called Total Productive Maintenance (TPM). There are elements of TPM, such as the use of checklists for inspections, which if done properly and by the right personnel (operators in many cases rather than maintainers) will also enhance maintenance excellence and reliability derived from such an initiative. However, the checklists must be definitive enough to be effective in the hands of the least experienced person responsible for conducting them. When a particular inspection is called out, definitions of what one would be expected to see and what is acceptable and not acceptable must be spelled out in every case.

Under TPM methodology, while operators assume maintenance tasks, maintainers become free to enhance their skills through training and adoption of new tools such as predictive maintenance technologies and analysis methods. The end result is to move towards mastering maintenance by learning how to do it.

Links Between Stakeholders, Processes and Procedure Based Organizations

The key to success in use of procedures and checklists is "process," or more accurately its plural, processes. Members of organizations must absorb the idea of thoroughly understanding, supporting and managing their maintenance processes. The process for supporting procedures and checklists depicted in a most elementary way above is only an example of many that are intertwined, interconnected and inseparable. There are links between all aspects of a modern reliability and maintenance program and in the bigger picture in the survival of the organization. Several examples of actual processes in use today are provided in Chapter 5 of this text.

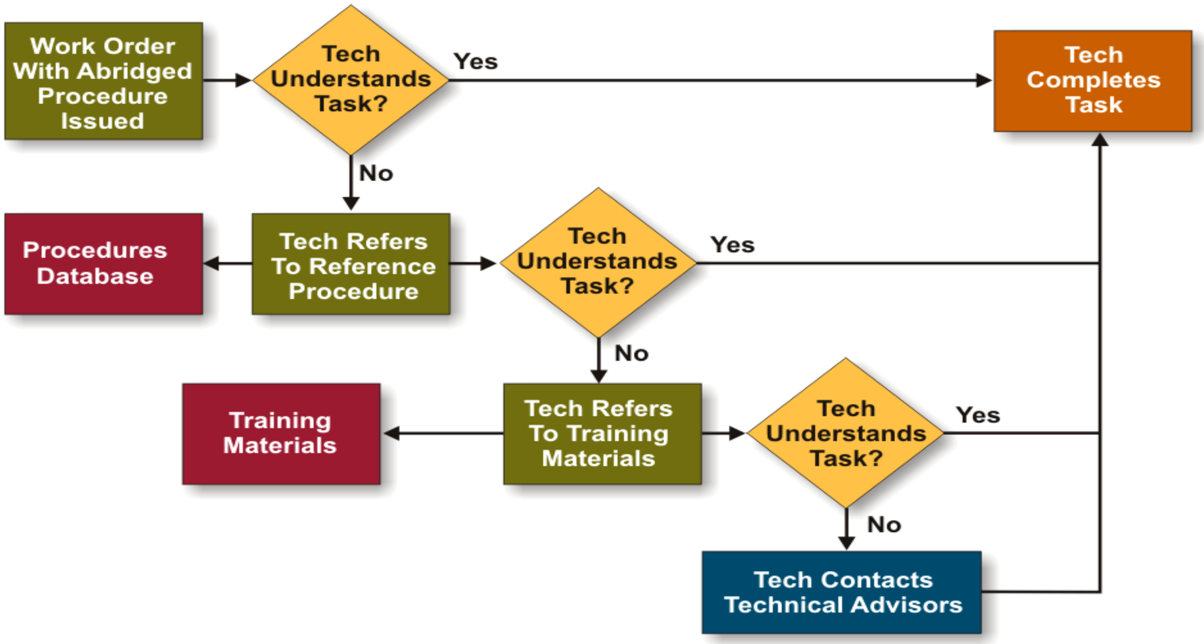
Link between Procedures and Employee Stakeholders – Employees of any organization have a stake in its survival, not only during their working years, but also after they retire, in many cases. When effective procedures and a continuous improvement process to include new "best practices" is put in place the employee stakeholders are to a large degree insuring the future viability of the organization upon which they may be financially dependent for the remainder of their lives. The best procedures address the right maintenance to perform, a result of a thorough application of RCM principles either formally or informally. Best practices are defined and reinforced for consistency and application. Training and certification requirements are specified.

Requirements for quality, safety and environmental compliance are covered so there is less chance of an undesirable incident.

Links between Design Improvements and Procedures – Procedures often provide the basis for improvements in equipment design. Improvements to improve maintainability, reliability and availability or to reduce labor hours or cost of replacement parts make it possible to improve productivity. This in turn can be the basis for lower production cost per unit of output leaving room either for reduction in cost to customers, increased profits or both. The idea is addressed in terms of "how" to do maintenance. In the case of maintainability improvements, when opportunities exist and are implemented to reduce the labor hours needed to perform a maintenance task, it frees personnel to do more to further reduce the need for maintenance and increase the time available for production. Care must be taken to incorporate the new 'quicker" and more reliable maintenance practice in procedures so there is no chance of slipping back into the "old" ways. That is why a compliance policy , referred to in the figure above must be enforced.

Links between Procedures, Planning and Scheduling - As the number of procedures grows, the process of planning and scheduling becomes easier and more efficient. In this case not only are preventive procedures needed, but also repair procedures. Every time a repair is needed it provides an opportunity for review and improvement of the applicable documents and supporting processes. Ideally the time needed to perform repairs can be reduced and documented, enhancing the possibility of scheduled outages being completed on or ahead of time and ensuring maximum possible time for production. Again, documentation of both the procedure for maintenance and the processes for carrying out maintenance and the supporting processes must be documented so as they provide a basis for change that has a good chance of becoming permanent.

In the broader context Procedure Based Work Management is depicted in the Process Diagram at the top of the next page. Note the link between training and the procedure. A technician must be able to understand the procedure or take action to gain understanding in order to avoid causing an "infant failure." There should be a sense of pride in the fact that the content of the procedures in use reflect "best practice." There should also be a sense of fulfillment that comes from the user's being able to recommend changes that will improve any procedure and that any change recommended will be acted upon promptly. Typical turn-around time from receipt of a recommended change to completed action (or rejection – with explanation and thanks for the recommendation) is 22 working days or 30 calendar days.



Procedure Based Work Management

Organizations That Are Beating the Odds and Moving to Better Reliability & Maintenance

Nuclear Powered Electricity Generating Plants – Commercial nuclear powered electricity generating plants have undergone many changes in the way they are operated and maintained, especially since the Three Mile Island reactor core meltdown incident, near Harrisburg Pennsylvania, in 1979. One of the major ways change is made and sustained is by institutionalizing the use of detailed procedures and checklists for executing all aspects of maintenance. The basis for this approach was already present in many of the utility organizations in that many of the employees there were ex-Navy nuclear power trained personnel who were used to having detailed written instructions provided for them to follow. This culture was also present in the Nuclear Regulatory Commission (NRC) that employed many personnel who had undergone rigorous training in the Navy Nuclear Propulsion Program developed and run for decades by Admiral Hyman Rickover.

Notwithstanding the lack of regulatory authority in 1979 (described in Chapter 8 of this text), the NRC was able to convince power plant personnel of the merits of enhancing what were the beginnings of Procedure Based Organizations. Today, with a stronger regulatory regime in place, every utility with nuclear powered generating plants has developed a culture that is thoroughly procedure and checklist oriented. In the case of the most critical, safety related procedures, changes are first checked by use on "mock-ups" that simulate actual plant configurations, so that any defects in the procedure or checklist can be detected before actual use on "real" equipment.

While the NRC "regulates" only the nuclear reactor systems of these generating plants and has authority only to require procedures and checklists be used there, the plant owners have found (to their surprise in some cases) that it is far cheaper and better in every way to require detailed procedures and checklists for maintaining the "balance-of-plant" systems as well.

The result in terms of plant performance is well established, now. Nuclear powered electricity generating stations are among the most reliable and profitable in the industry, capacity factors (ratio of actual output compare to rated output) already high for almost all plants continues to improve. For this and many other (mostly environmental and political) nuclear power plants are now among new plant construction options now being considered.

Anheuser-Busch has many different business interests, including theme parks and breweries. The latter business is extremely competitive and global in nature. As of 2002 Anheuser-Busch had 12.1% of the world market and 49.2% of the US market. Their nearest competitor, SAB-Miller, had 8.3% of the global market. In the years since, further consolidation has occurred and the percentages continue to change with acquisitions and mergers, license agreements and other business arrangements..

Anheuser-Busch has "standardized" its approach to maintenance and reliability in its 12 North American brewery plants. This was a radical move on their part in that previously, each plant manager and plant maintenance manager had relative autonomy from the "headquarters" organization and could "do their own thing." Many initiatives were involved such as:

- Converting all to a common asset management software (SAP) including use of its CMMS module
- Requiring maintenance personnel (some 1600 total involved) to take a large number of self paced and classroom training courses
- Learning how to "Manage to the Month" financially
- Undergoing routine audits, especially when budgets or other goals weren't met
- Focus on maintenance processes, procedures and checklists
- Focus on degree to which "culture change" was taking place
- Behavior issues (Push-back, etc)
- Productivity improvement through value added projects
- Equipment ownership and partnerships.

One of the basic goals, initially was to achieve cost savings and/or cost avoidance through maintenance initiatives equal to the amount of increase in wages that maintenance personnel expected to receive in the coming year.

There were many other advantages including:

- Personnel transfers between plants can be done without having to undergo any learning process to adapt to the culture of the new organization
- Processes, goals, systems for managing and execution are largely the same from plant to plant
- Staffing decisions are simplified and there is greater overall flexibility
- Since there's plenty to do there is less of a tendency to lay off idle personnel

How to Become a Procedure Based Organization

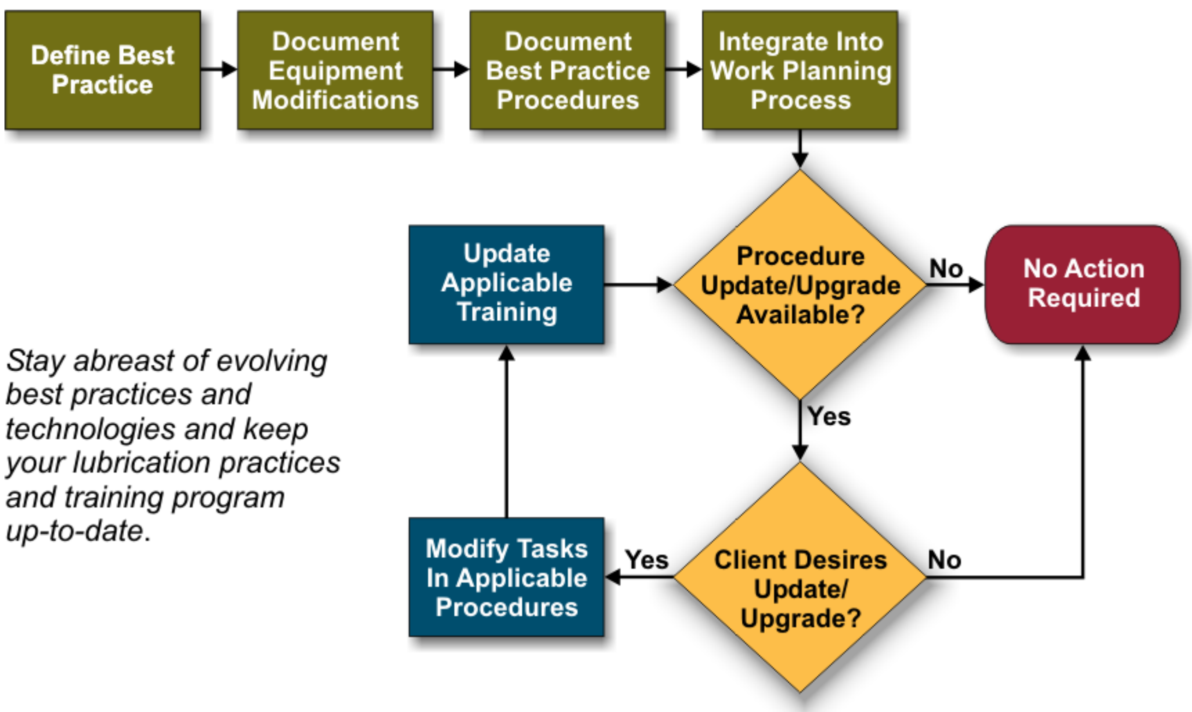
Become a procedure based organization by developing one really good procedure at a time. There are at least four (5) viable approaches to doing this. They are:

- **Employ subject matter experts to lend support where appropriate**

- **Hire recent retirees, train them on how to write procedures and check-off lists and task them to create the "legacy" set**
- **Assign soon-to-be retirees to do same as above**
- **Authorize overtime for current personnel to create procedures and check-lists (after training to do so)**

Expecting full time employees to originate procedures during the regular work day is unrealistic, at least initially (first 1-2 years). If the combination of initiatives you are introducing is effective, there may be time available in the long term to internalize routine procedure development.

However, the requirement to establish an effective feedback and follow up system for procedures and checklists is absolute. Without it, no organization can succeed in becoming procedure based organization. Ideally, a process diagram will be developed that provides great detail on all functions, inputs, outputs, feedback and follow up communications links as well as identifying all resources needed to carry out the process. An example process of this type is provided in Chapter 5 of this text. In the broader context the following process diagram outlines how new best practices are handled, in this case for a lubrication task.

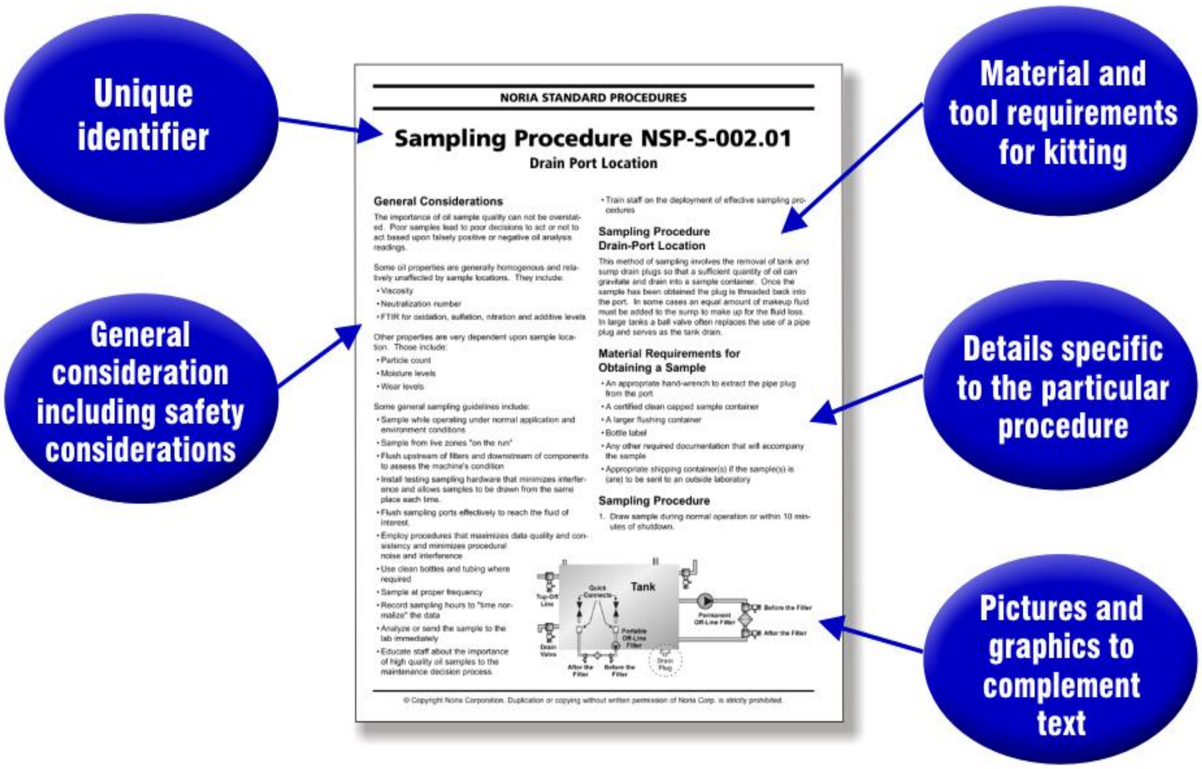


Managing Continuous Improvement in Best Practices to Incorporate in Procedures

Procedure Format and Content

Procedures should have standard terminology and conventions, depending on the "culture," language mix and skill level of the personnel who will be using them. An example set of guidelines is provided in Appendix A to this text that can be used for most English language applications

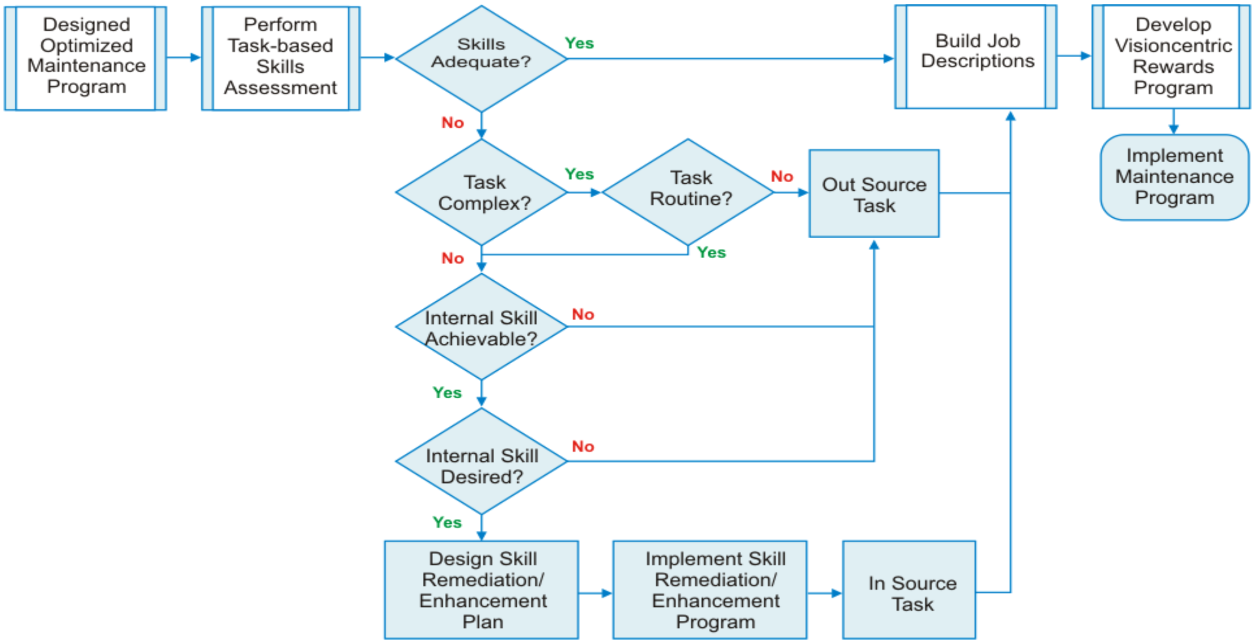
A decision should be made for all parts of an organization as to format and amount of detail needed for content of the procedures to be developed. Examples of formats used in North America are provided in Appendix B to this text. The anatomy of a good procedure is depicted in the graphic below.



Anatomy of a Good Procedure

Connecting Skill Requirements to the Procedures to Be Used

It is also necessary to connect skills requirements to maintenance procedures and this in turn may detail the training required for full time employees, hiring that may be needed or support needed from contractors. The process diagram that follows illustrates an approach to doing this.

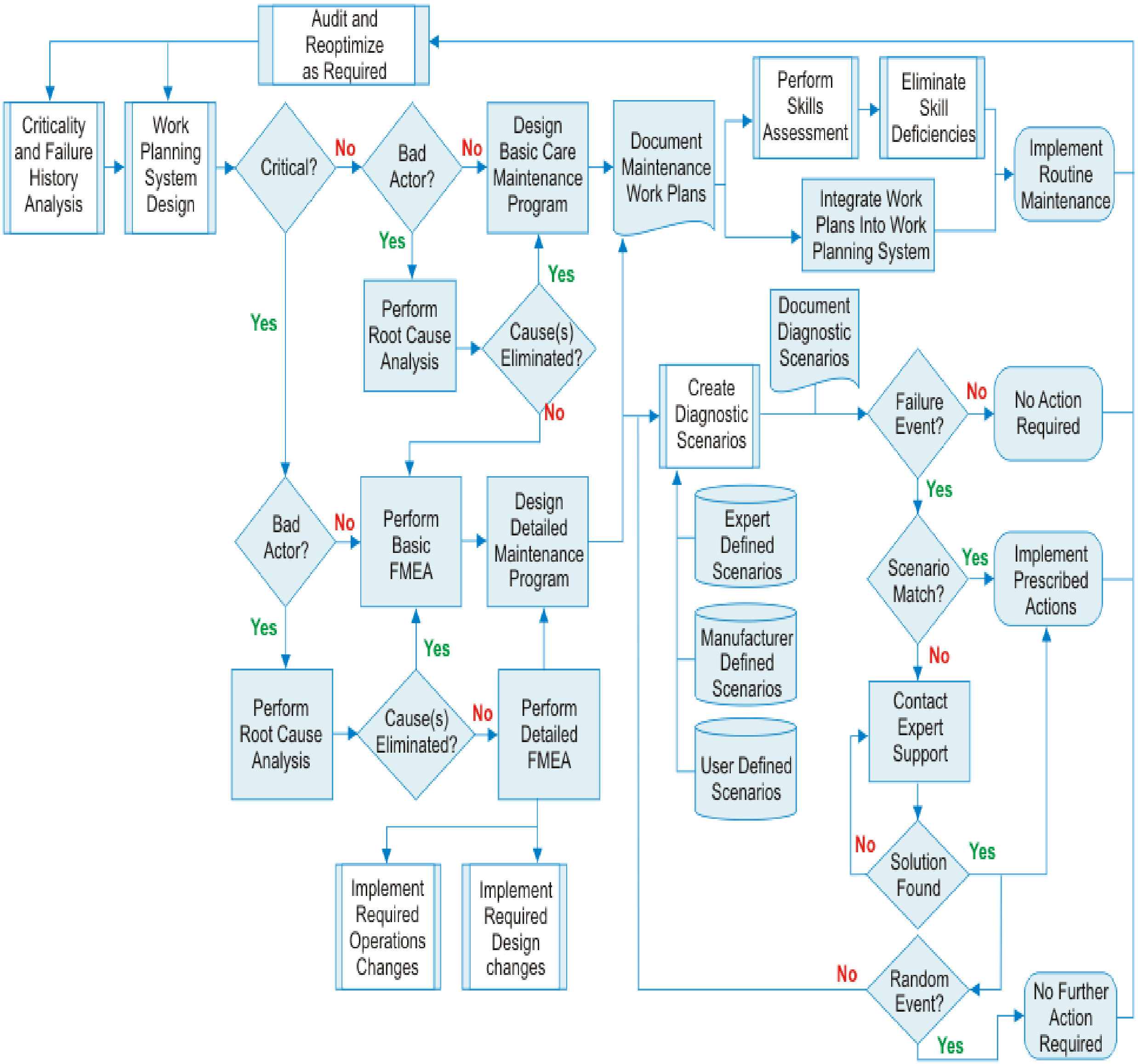


Connecting Skills Requirements to Maintenance Procedures

The overall process of developing Procedure Based Maintenance is depicted on the next page. Note that this ties many processes together, including:

- Criticality Assessment and Work History
- Work Planning
- Skills Assessment
- Root Cause Analysis
- Failure Modes and Effects Analysis (FMEA and by extension Reliability Centered Maintenance (RCM)
- Diagnostic Analysis
- Continuous Improvement
- Design changes to improve reliability

While the process depicted in the following graphic is generic in nature, it provides a goal toward which all organizations should direct attention. Chapter 5 of this text describes how to conduct a process analysis workshop and gives many reasons why this has proven to be an effective way to "streamline" and manage in order to compete in the global economy in which we find ourselves in this century.



Developing the Overall Procedure Based Maintenance Program

How to Measure Results

Reliability and maintenance metrics are many and varied. However, the ones that get the most attention are those involving throughput, quality, cost and availability. Outside of the maintenance organization no one really cares much about the number of work orders completed, backlog, man hours expended, measurements taken or any of the other maintenance related metrics that maintenance professionals may be involved with on a day-to-day basis, unless there is a need to use these as justification for more personnel.

Because of the many nuances involved, metrics are the subject of whole books. One of the best of this new century is Robert C. Hanson's Overall Equipment Effectiveness, A Powerful Production/Maintenance Tool for Increased Profits[10]

Understanding the metrics that the book mentioned above (and others) describe is the first major step in preparing communications that will mean something to those that control the flow of resources needed to achieve excellence in reliability and maintenance.

How to present the results and your requests for assets in terms that business managers will understand and act upon. Your may have noticed that there are very few people with experience in maintenance that have made a transition into overall business management. I hope you have also noticed that most business managers speak in terms that are seldom used in the ranks of the maintenance organization. The best way to communicate with business managers is in terms of a business case. One of the most effective ways of doing this is to talk and write in monetary terms. You must translate metrics such as those described in Hanson's book into how support from those controlling assets (dollars, manpower or other resources) will affect income and profits. Describe your function in terms of capacity to produce products and the profits derived from their sale.[11] Emphasize and justify asset requests in terms of investments those are concepts that have the possibility of getting attention of decision makers.

Once a maintenance manager understands what's understandable to business managers, board members and owners, he or she has a starting point in developing communications that get them to invest in sustaining and improving or adding assets.

Conclusions Regarding Procedure Based Maintenance Organizations

- **Procedure and process based maintenance organizations already exist in commercial, utility and government sectors**

- **Many programs "got religion" after a major crisis, actual or near disaster occurred and in some cases threatened continued existence**

- **Standardization of maintenance practices has proven to be more profitable than the "old" ways**
- **Procedures and checklists are used to:**
  - **Clearly define and reinforce best practice and expected behavior**
  - **Ensure consistency and continuity**
  - **Define training and certification**
  - **Ensure quality, safety and environmental compliance**
- **Value resides in the experience, ingenuity and engineering that the content represent**

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[10] Hanson's book, dated November 2001, is available from The Industrial Press of New York, NY. Be sure to acquire the one page of corrections to this first printing for ease of understanding. Later printings have incorporated the corrections

[11] The presenter is indebted to Dr. Mark R. Goldstein, Ph.D. of Manufacturing and Maintenance Infosource of Manassas, VA, who in two keynote speeches at Reliability Conferences sponsored by Industrial Communications Incorporated emphasized that the product of maintenance is capacity, not overhead cost.

- **Procedures and checklists represent solid standards for the organization**

- **It is difficult to distinguish benefits from process adherence, standardization, best practices, use of procedures and checklists exclusively**

- **The logic of statistics concerning failure profiles makes a compelling case for a way of assuring reliability, lower costs and higher profits**

- **Confluence of inexpensive, word processing and imaging and many non-intrusive PdM & CM technologies makes sustained reliability possible**

- **Today there is really no valid excuse for <u>not</u> moving towards procedure based maintenance**

- **Finally: The more detailed the understanding of the maintenance and reliability process and the more insistence on compliance with what are well known best practices, such as routine audits, and use of procedures and checklists, the more precise and less error prone maintenance will become.**