Procedure Based Maintenance

By:
Jack R. Nicholas, Jr., P.E., CMRP of MQS LLC

Abstract

This paper introduces a compelling argument for development of and adherence to procedure based maintenance when implementing and executing a modern program to ensure maximum capacity of a plant and reliability of its equipment. The argument is based on a new analysis of four (4) statistically significant failure profile distribution studies over the period of the last 40 years, the latest of which was completed in 2001. While all of the studies involve failure profiles in mobile platforms (two for commercial aircraft, and one each for surface warships and nuclear powered attack submarines) the conclusions that can be drawn from them apply equally to fixed facilities, commercial transportation systems and utility infrastructures of all types. It also applies to categories of equipment such as motors. The author will estimate the odds of ensuring a decline in reliability by assuming what we used to think were "truisms" about failure profiles in equipment. Several case studies are included to emphasize how these findings cross over to manufacturing, utility, and government equipment and systems.

Introduction

In the field of maintenance the traditional approach has been to rely upon the intuitive knowledge and skill of the crafts-persons who conduct it. There is a great deal of pride of workmanship and, in all too many organizations, a great deal of psychic income in addition to significant overtime pay for successful emergency repairs to return equipment to operation after unplanned shutdowns. There is a mystique that accompanies all of this that many skilled crafts-person would like management to believe firmly. That is that there are too many variables in maintenance, making compliance with written procedures impossible and impractical; that the "way we've always done it" is the best and only way to conduct maintenance. This idea spills over into preventive maintenance, also. Crafts-persons believe that their own intuitive knowledge is preferable to a written procedure and/or a thoroughly defined checklist. Aside from these problems, most organizations have allocated no resources to creation and on-going support of procedures and checklists. Accordingly these organization are beating on the wrong way of conducting maintenance in order to assure reliability. This results in at least a lost opportunity for increased profits from existing assets and at worst a fatal management omission. Management is gambling with profits and losing big time with the approach that emphasizes "pride" of workmanship over an approach that has been proven to work.

Lost in all of this is the concept of ensuring and sustaining reliability as both corrective and preventive maintenance is performed. Ideas about how things fail that we used to rely upon as a basis for preventive maintenance have been shown in the four failure profile studies over the past 40 years to apply to only a minor percentage of failures. In gambling terms, this means that odds are very long against a "win." From this it can be shown that time directed maintenance, in general, also should apply to only a minor portion of the failure modes which an organization must correct or mitigate. This is because we seldom know the profile for failure and assume that most components exhibit a "wearout" characteristic, but assign a frequency for maintenance anyway, as if they did. Further it can be shown that intrusive, time directed maintenance can be detrimental to reliability because humans are involved and they produce "infant failures." Non- intrusive maintenance and monitoring tasks should be sought, instead. Indeed, because of the distribution of the failure profiles described in this paper, the only logical approach for the mitigating failures in the majority of equipment is through the use of non-intrusive tasks supported by the use of procedures to assure consistent results.

As modern predictive maintenance tools and analysis methods have come into use, most of which are non-intrusive, the requirement for procedure-based maintenance becomes even more important. Analysis of data from modern tools such as vibration monitoring, lubricant and wear particle techniques, infra red observations, motor electrical condition monitoring and almost all other technologies depends for accuracy upon knowledge of the operating state of the equipment. Operating conditions and surrounding environmental parameters must be carefully established and recorded in order that thorough analysis can be performed. This can only be established by adherence to carefully written, detailed procedures and checklists.

Such procedures may be "imbedded" into equipment designed for data collection. However, procedures for connecting data must be carefully prepared and followed in order that there is complete agreement between
imbedded and non-imbedded details.

Thresher Disaster - April 10, 1963

One of the earliest revelations of the need for detailed procedures and checklists occurred when the U.S. Navy experienced the loss of USS Thresher (SSN 593) on April 10, 1963.
The loss of 129 lives was, to say the least, a very sobering event for the Navy.

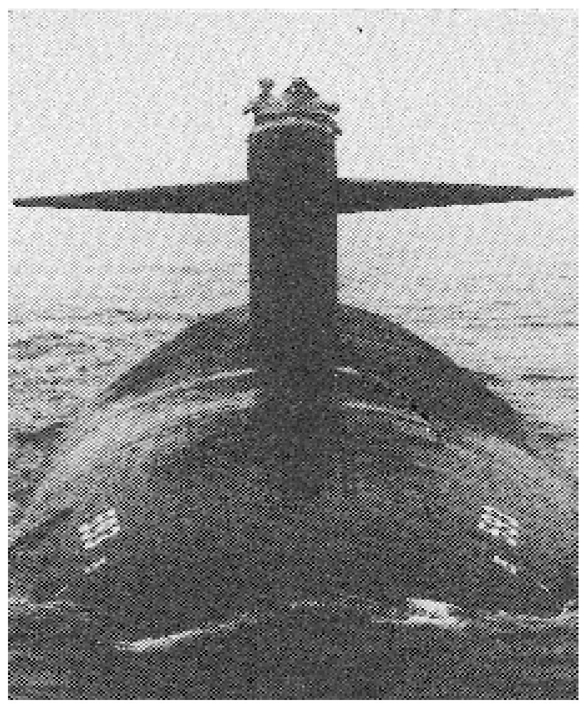


Figure 1 USS Thresher (SSN 593), now lies at the bottom of the Gulf of Maine

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 checklists be developed and followed to the letter by all personnel engaged in maintenance of specified components of all systems affecting submarine safety. Thereafter, no additional U.S. Navy submarines have even come close to being lost due to a maintenance problem involving the systems included in the SubSafe program.[1] This proves that the Navy lowered the odds that a failure of this nature would result in loss of a submarine. It raised the odds of reliable performance of the entire fleet.

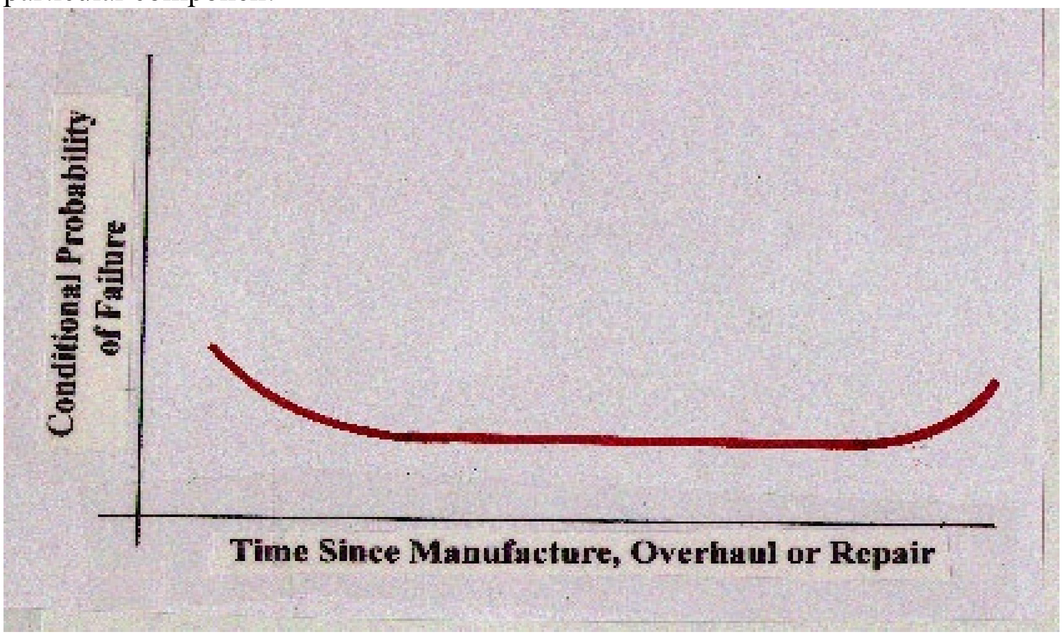
It was during this decade of the 1960's that the Federal Aviation Agency, aircraft builders and operators came to the revelation (and proved it with statistics) that there was very little relationship between time directed maintenance and (increased) reliability. In fact it can be shown to illustrate the point that time based maintenance can be detrimental to reliability most of the time and that any maintenance, done on the basis of skill-of-the-craft and intuition, is the wrong 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. The most well known of these profiles is the "bathtub" curve, widely considered, even today by some, to characterize most equipment failures. However, statistical analysis shows 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 rapidly rising "wearout" stage) applied to only a small percentage of components. Later studies using data from the 1970's (also on commercial aircraft), from the 1980's (on surface warships) and then from the late 1990's into the year 2001 (on nuclear powered attack submarines) revealed virtually the same finding.

[1] (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 Mr. Nicholas' roommate on Nautilus in late 1963 and early 1964.)

The actual numbers for the studies are 4%, 3%, 3% and 2% for UAL, Broberg, MSP and SUBMEPP studies respectively. [2]

What this means in terms of a gamble, that if one assumes that all components exhibit a "bathtub" shaped conditional probability of failure profile, that the odds are no better that 25 to 1 and perhaps as long as 50 to 1 that you have the correct maintenance task for a particular component



The Bathtub Curve – Applies to no more than 4% of components in four statistically significant studies over a period of about 40 years.

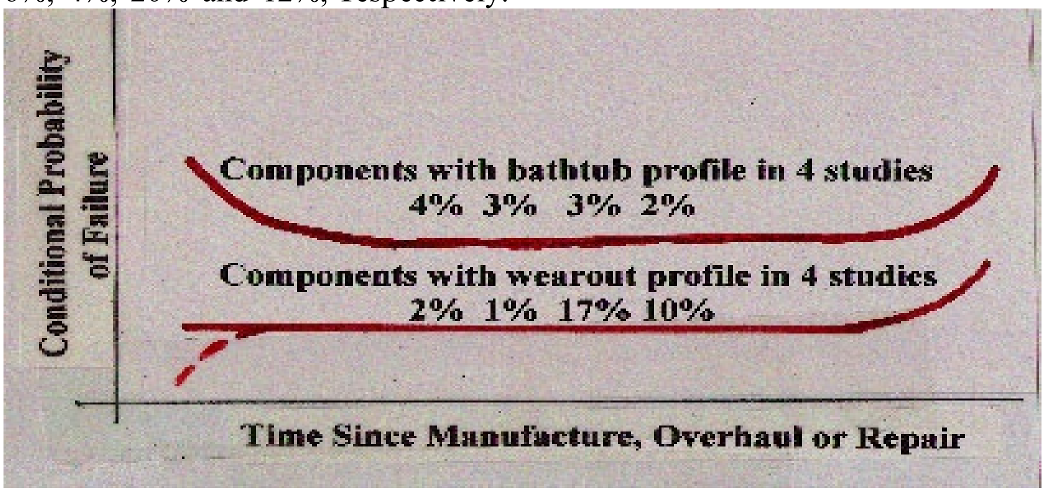
Conclusions reached concerning the two profiles that exhibit a "wearout" characteristic in all studies further demolishes or at least undermines the long held basis for preventive maintenance programs that were made up largely of time directed tasks, especially when the tasks are intrusive in nature. 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 <u>any</u> form of "wear-out" characteristic (rapidly rising conditional failure

[2] 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 sponsorship of the European Airline Maintenance Study Group (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.

probability) amount to no more than 20% of all components included in any of the studies. The odds of selecting a time directed task have improved to as good as 5 to 1 that and as bad as 25 to 1 that you can employ a time directed task to counter "wearout" if you assume that all components wear out within the period that you selected for execution.

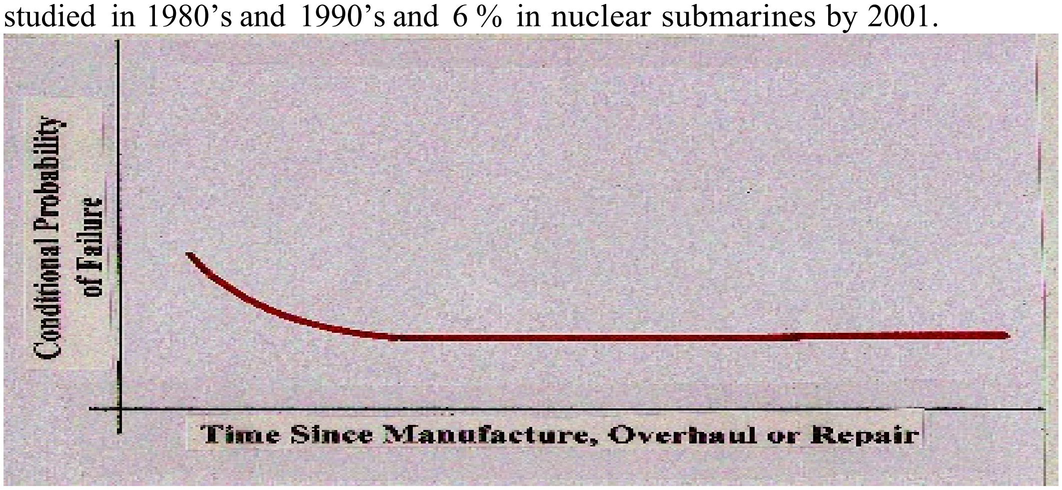
.

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



The dominant failure profile for commercial aircraft in both studies was one characterized by the first two parts of the bathtub curve, "infant mortality" followed by random failures. This characteristic applies to 68% and 66% of components in the two aircraft studies. No wear-out appears anywhere in the profile. In surface warship (MSP) study the infant mortality profile applied to 29% of components. In the nuclear submarine (SUBMEPP) study most recently completed the profile applies to only 6% of the many components included.

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



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

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 the 1990's, 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. 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. Licensed commercial aircraft mechanics and electricians and "qualified" military technicians relied upon the skill-of-the craft, intuition and 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. 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 labor and expertise in procedure writing required far exceeded the capacity and capabilities of the crews.

Recognizing this, the Navy began to develop and promulgate detailed maintenance procedures from shore based support activities 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. Civilian contractors directed by naval field activities that supported the fleet 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. 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 (raising the odds of) 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.[3] This facilitated the transition from time directed to condition directed tasking as RCM-based maintenance was implemented.

The maintenance profession, in general, underwent a transformation from almost complete dependence on time-directed tasking (preventive or planned maintenance) to much more condition-directed tasking. Within the Navy, programs for operating cycle extension (between overhauls in shipyards) embraced RCM-based 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 those in the SUBMEPP study reported in Allen's 2001 paper (footnote 3).

What is described above accounts for the lower infant failure rates in naval vessels. Given the same type of evolution has occurred in commercial airline maintenance, an updated study of conditional probabilities for today's air fleet would most likely show a significant reduction in infant failures, also.

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

By the 1980's a wide variety of predictive maintenance 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-directed tasking (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.

[3] In the late 1970's the Director of Fleet Maintenance, an admiral 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.

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 (no more than 20% in the four studies cited) exhibit this characteristic. Condition directed tasking makes a lot more sense than time directed tasking when considering the finding that noless than 80% of components included in any of the four studies previously cited exhibited a "random failure characteristic" and no "wearout" for the majority of their conditional probability period of operation after manufacture, overhaul or repair. The actual numbers for the four studies are 94%, 96%, 80% and 88%, respectively, displaying randomfailureand nowearout.

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 3) 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.[4]

[4] 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.

In submarine maintenance, detailed procedures are required to be used for repairs and in-service preventive 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 reached 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. This improves the odds that an organization can achieve a higher level of reliability closer to limits that design and other factors will permit.

So our answer to the challenge about how to do maintenance is - become a Procedure Based Organization – a PBO! –That's a "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 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

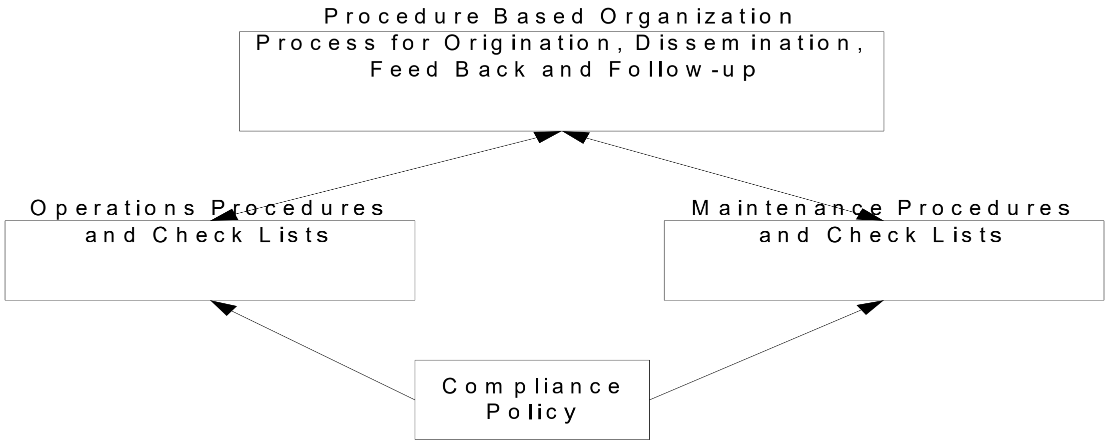


Diagram above emphasizes two-way communications to sustain health of a Procedure Based Organization

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 2004 co-author of the paper, Jack Nicholas, had the opportunity to conduct a one-day seminar 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 and 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 leader followed up with the company president to see how it had been received. The president 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 it. However, the checklists must be definitive enough to be effective in the hands of the <u>least</u> 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 <u>how</u> to do it.

From the depths of despair to record profits at Dofasco

In 1993 Dofasco, a fully integrated steel producer located in Hamilton, Ontario, Canada, was experiencing the effects of comparable but lower cost steel products from overseas eroding profits to the point where the directors seriously considered having the company go out of business.[5] Dofasco managers decided that the company might survive if manpower was severely cut and the remaining staff retrained, supported with productivity improvements and machinery upgraded for improved reliability. In the 18 months that followed about 35 percent of those employed were retired or accepted buyout offers. About 5 percent of the almost 14,000 employees were laid off. Subsequently, those who were still available were recalled in the next year as retirements, buyouts and deaths occurred.

The effect on staffing and organization of this very paternalistic company was dramatic. Over the years, successful crafts-persons were retained at Dofasco by placing them in "supervisory" positions where they could qualify for higher pay. With the downsizing and reorganization between 5 and 6 layers of supervision were eliminated. While one would believe this was a good thing, a very significant capability was also lost – that of preparing and supporting a very substantial set of procedures and check-lists. One of the major functions of the personnel occupying the "lost" positions was to prepare, review and approve procedures for corrective and preventive maintenance jobs. These had been

[5] In the ten (10) years following 1993 over 40 North American steel companies entered into bankruptcy and either stopped or radically reduced production to only the most profitable lines. Many were merged with other producers and disappeared as separate entities.

incorporated into Dofasco's Computerized Maintenance System (CMS) so that when a particular job was called out, the procedure for conducting it was printed out to become part of the package that accompanied the work order placed in the hands of personnel assigned to conduct it.

The procedures were quite detailed and provided a considerable legacy to those that remained in the downsized organization. They had many unique features and considerable detail in steps, safety requirements and tools and parts lists that were of great value to those doing the work. Recognizing their value, the managers decided that the capability to originate, update and provide continued support for procedures and check lists had to be re-established in remaining staff.

Very early in the long path to restore the company to target profitability, a series of training courses on writing procedures and checklists was conducted for key crafts-persons and first line supervisors.

Subsequently when the CMS was replaced with an updated Computerized Maintenance Management System (CMMS), the procedures and checklists were integrated, also.

The initiative to sustain a procedure based organization was only one of hundreds of actions and projects undertaken at Dofasco to bring the company to the point where in the year 2004 record profits were reported in several quarters. In addition, Dofasco invested some of its profits in and became a partner in a mini-mill in Kentucky and has established new tube mills in Mexico and at its home site in Hamilton, Ontario.

Use of procedures at U.S. nuclear powered electricity generating plants

After the Three Mile Island nuclear powered electricity generating plant incident in 1979, the U. S. Nuclear Regulatory Commission (NRC) began emphasizing the use of procedures and checklists (among many other measures) when carrying out both corrective and preventive maintenance on safety related systems of reactor plants. In addition, the nuclear industry's internal watchdog agency, the Institute for Nuclear Power Operations, provides guidance and audits to ensure that procedures, among many other initiatives, fully support the goal of preventing an incident like the one in 1979 or worse.[6]

The result for the nuclear powered electricity generation segment of the industry in the U.S. was that it was saved. It produces about 20% of the nation's electricity and has become a nearly irreplaceable segment of U.S. electric power. All statistics describing the performance of the 110 nuclear power plants of the industry are continuing to move in a positive direction. No incident like the one at Three Mile Island has occurred since. The NRC has started to grant extensions of operating licenses for up to 20 years beyond the nominal initial length of 40 years. Although nuclear powered electricity generating plants

[6] The Chernoble Nuclear Plant disaster in April 1986 in the USSR was caused directly by the use of a test procedure that had not been reviewed or approved by the authorities responsible for reactor safety. The explosion, fire and recovery efforts killed and injured hundreds of plant and responder personnel and resulted in the permanent evacuation of over 15,000 residents from towns nearby because of deadly levels of radioactive contaminants.

are not problem free, the overall performance has improved in all but a small number of plants to the point where new, inherently safer U.S. originated designs are being accepted, built and operated internationally. The new designs and are likely to be built in the United States within the next few years.

An interesting result concerning use of procedures at nuclear powered electricity generating plants is that owners have found that overall reliability and capacity factor (ratio of actual output of power in a given period of time compared to maximum authorized output, expressed as a percentage) are enhanced when detailed procedures and checklists are used for all systems, not just those that are safety related. This ensures that the maximum number of generated megawatts are available for sale, assuring maximum plant profitability.

How to become a Procedure Based Organization

Procedure based organizations accomplish the ultimate goal by implementing use of one really good procedure or checklist at a time. While those with compelling reasons, such as regulatory deadlines, may opt for contractor support, much can be accomplished by employing those already familiar with the plant in procedure and checklist development and implementation. Three suggestions follow:

- Hiring back the most effective recent retirees for several months at a time, training them to write detailed preventive and corrective maintenance procedures and checklists and assigning them the responsibility of creating a legacy in the form of a set of documents that form the basis for becoming a Procedure Based Organization – a PBO. The writers also should use the new documents to train personnel and encourage them to further improve them.
- Right after having them trained to do so, making the last job of those who are about to retire the origination of procedures and checklists for operations and maintenance of the production lines where they possess the greatest, knowledge, experience and training. They also should be the first to train others in use of the new procedures and checklists.
- Again, after training in procedure development, authorizing overtime to qualified volunteers on the current staff for the same purposes described above and continuing to do so as long as progress in being made towards becoming a "PBO."

Thereafter, procedure and checklist feedback, follow-up and continued support can be accommodated with internal resources converted from permanent staff that is no longer occupied fully with crisis-based, reactive maintenance. That will in fact happen as adherence to procedures and use of detailed checklists results in greater plant availability, reliability and less unplanned downtime.

Conclusions

Procedure based maintenance organizations already exist in commercial, utility and government sectors. Many programs were established after a major crisis, disaster, or near disaster forced the organizations into initiating many actions, of which the use of procedures and checklists was only one. Most were procedure based programs were established because it was more profitable than the old way of performing maintenance.

It is difficult to distinguish the benefits from procedures and checklists exclusively. However, the logic of the statistics derived from study of failure profiles makes a compelling case for procedure based maintenance. In addition, the confluence of inexpensive, modern word and digital image processing technology and the ready availability of many non-intrusive, predictive, condition monitoring technologies makes it possible for the conduct of maintenance with assurance of sustained reliability. Many other benefits flow from the use of detailed procedures and checklists, including the capability for improved output as well as improved and/or sustained product quality.

There is really no valid excuse, today, for not moving towards procedure based maintenance. The basic conclusion is worth repeating. 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 to as close to the limit that design and other factors will permit.