Application of Reliability-Centered Maintenance in Facility Management

By

Jorge Martinez

A Thesis
Submitted to the Faculty
of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the
Degree of Master of Science
in

Construction Project Management

January 2007

APPROVED:

____

Dr. Guillermo Salazar, Thesis Advisor

____

Dr. Leonard Albano, Board Review Member

____

Dr. Frederick Hart, Department Head

Abstract

Operational costs are of central importance for the economic health and sustainability of any organization. There are many contributors to these costs; some are industry specific, some are not. Factors such as organizational makeup and structure or general management and/or leadership practices all play a part, albeit, challenging to measure in terms of direct dollar correlation. Others, such as payroll, capital purchases, and asset management costs, to name a few have a more direct operational cost clearly linked to dollars and become the most practical place to look when trying to minimize operational costs.

One of the critical aforementioned contributors to operational costs is that of capital asset management; in particular the issue of maintenance and repair of a company's capital assets. More specifically, one can try to determine the best maintenance practice and schedule to use on varying systems in hopes of lowering maintenance costs and ultimately operational costs.

One approach is to formulate a maintenance cost equation given the specific data and constraints available to solve a probabilistic problem through simulation. This study proposes a methodology that could be used as a tool to determine what maintenance practices to use on varying systems, sub-systems, and components. The focal point of this methodology is to formulate viable simulation logic. The logic takes into account maintenance costs that must be identified and defined. Additionally, coupled with this is the need to create a Weibull Distribution, which helps predict the next failure based on historical data. By matching the maintenance cost with the Weibull Distribution of each system, sub-system or component the simulation logic or equation is created. With this model in hand, simulations are run using Monte Carlo Simulation. In the end, an optimal schedule is determined based on the input.

This thesis has three main deliverables. First, a maintenance methodology which assists in determining optimal component change out schedule based on historical data is created. Secondly, from the information gathered from Industrial Support Command Alameda*, ideal systems to target are identified. Thirdly, an implementation strategy is offered. Lastly, though not a primary deliverable, this study also offers some other maintenance related miscellaneous findings and/or recommendations.

***** *Nearly 50,000 line items from several large Coast Guard units were reviewed but in the end just one was chosen for the study, in this case Industrial Support Command Alameda as they had the best and most comprehensive database and from a maintenance perspective were a good representation of other Coast Guard Units.*

Acknowledgments

I would like to acknowledge several individuals that were instrumental to the completion of my project. First and foremost, I must thank my family for their always unwavering love and support not just for this thesis but for the times we've been apart because of the Coast Guard. It's hard enough being apart, and it's even harder missing holidays, anniversaries and birthdays; thank you Nancy, Sammy, and Ben.

I would also like to thank my advisor Dr. Guillermo Salazar. Though perhaps it's not enough, thank you for providing me with sage guidance and insights and for keeping me on the right path, especially during those challenging times (which was just about the entire time).

Next I extend my sincere appreciation to Dr. Leonard Albano for taking time out of his busy schedule to provide much valuable input and guidance to this thesis.

Lastly, I must thank CDR Jack Dempsey. Thank you for taking an interest in this thesis. Thank you for providing your insights and direction, and for funding my trip out to California to further develop and enhance this methodology.

Contents

List of Figures

1.0 Introduction

Organizational Overview:

The United States Coast Guard (USCG) is a federal agency of about 43,000 personnel. Along with its most important asset, people, come many resources to include ships, boats, aircrafts, and supporting infrastructure. The Coast Guard's shore-side infrastructure consists of over 22,000 buildings and structures (structures may include such things as aircraft hangars, boathouses, piers, bridges, roads, fences, towers and some other miscellaneous items). These buildings and structures are situated on1600 different sites and encompass 66,000 acres. The average building age is 43 years old and its total replacement value is approximately $8 billion.

The Coast Guard has six civil engineering units (CEU's) scattered throughout the country to address its civil engineering needs; these CEU's are located in Providence, Rhode Island; Miami, Florida; Cleveland, Ohio; Oakland, California; Juneau, Alaska and Honolulu, Hawaii. Above the CEU's are the corresponding area's (Atlantic or Pacific) Facility Design and Construction Centers and at the top is the Office of Civil Engineering at Headquarters in Washington, D.C. Beneath the CEU's are facility engineering (FE) units and public works (PW) facilities which are located at all major Coast Guard bases and support these bases and any outlying units. FE's and PW's are primarily responsible for addressing any maintenance needs that are identified in the major operational bases and their outlying units. However, much of the maintenance is passed down to the commands that occupy these spaces. In every major Coast Guard base, there is an Industrial Support Command with an engineering department to carry out these responsibilities. Specifically, they are responsible for carrying out maintenance and repair activities which are technically and fiscally within its capabilities. They are then required to forward to their servicing civil engineering units any discrepancy that is beyond their capability. These collective projects are then presented to a planned obligations priority board (or POP board). From there, the projects are prioritized and the available funds are appropriated accordingly. Figure 1 below shows from a macro level Coast Guard civil engineering perspective, the organizational layout of the service.

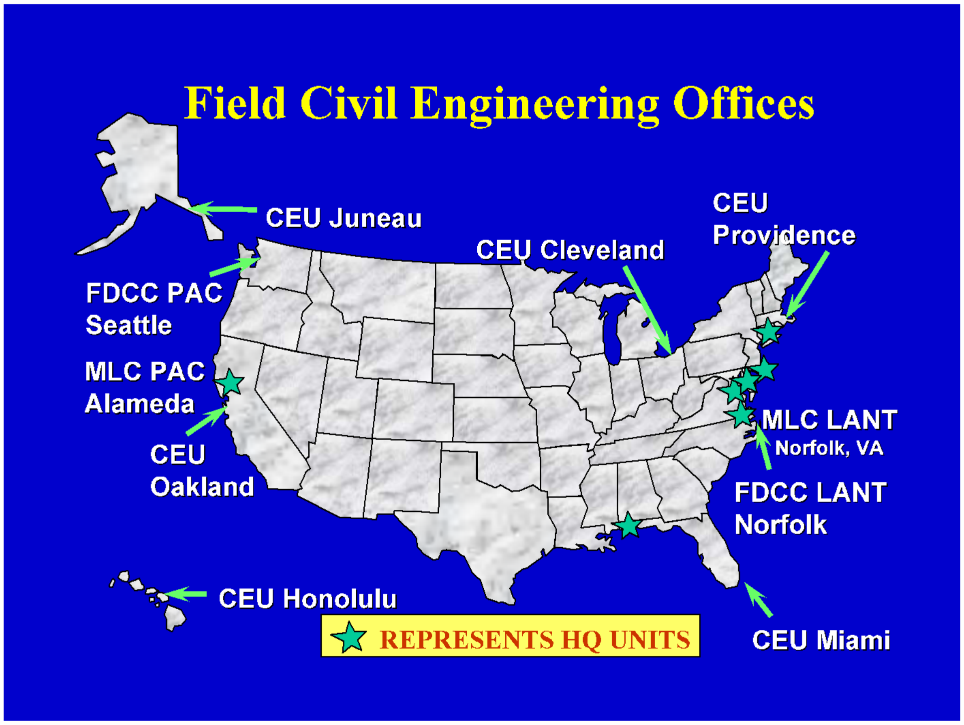


Figure 1: Coast Guard Civil Engineering Field Offices

From: New Roles New Solutions
Brown, 2005

From a budgetary standpoint, as of fiscal year 2005 there were over 10,000 maintenance backlog projects valued at $772 million (a backlog project is one which has been identified as needing to get done but due to the limited resources and competing interest it has not been able to be addressed). (Brown, 2005). The annual maintenance budget is approximately $500M and a trend over the past 15 years suggests that this backlog will continue to increase. More unnerving is the fact that the Coast Guard's Acquisitions, Construction, and Improvement (AC&I) maintenance budget, which includes major repairs and architect/engineering services, decreased from fiscal year 2005 ($211.4M) to fiscal year 2006 ($181.7M). Additionally, AFC 43 funds (AFC 43 is a Coast Guard funding code) which account for preventive maintenance, ground maintenance and minor repairs decreased from $190M to $160M in one fiscal year (Bevins, 2005). While the funding continues to decrease the capital assets continue to age. At the present funding levels, it will take 150 years to replace the shore plant rather than the 50 year planned life cycle. (FMLINK, 2003).

Additionally, in the Coast Guard's civil engineering realm there is little standardization in terms of buildings and structures and any associated system. Standardization in the Coast Guard is difficult because of many reasons. First, the Coast Guard is physically located all over the country and throughout many parts of the world. Each region has its own climate, building and structure type, and resource challenges among many other elements. Additionally, throughout the history of the acquisition of these sites, much was inherited and not planned as would have been ideal. Thus, Coast Guard buildings and structures are of different ages, different construction, different systems and components, and situated in vastly different areas.

Realizing the many challenges faced by the Coast Guard's Civil Engineering community, the Service has undertaken a tremendous revitalization initiative named Shore Facility Capital Asset Management or SFCAM. The initiative, which is in the infancy stages of implementation and refinement, will transform shore support from a decentralized traditional facility maintenance focus, based on locally defined requirements to a capital asset management focus. It is envisioned as a new tool to ensure that "the right facility is at the right place, at the right time, and at the right cost." (USCG SFCAM White Paper, 2003).

Through SFCAM many corrective actions and strategies were identified. One of the first corrective actions noted was that of "Leveraging technology to reduce the shore facility maintenance burden". Naturally, one of the strategies that followed specifically addressed the technology issue highlighting the need for further research. (Brown, 2005).

The objective of this thesis is to create a methodology that minimizes expected maintenance costs of mechanical, electrical, and plumbing systems by utilizing simulation to solve a probabilistic problem that takes into account failure history. Additionally, this thesis develops an implementation strategy to incorporate this methodology into the Coast Guard's Shore Facility Capital Asset Management initiative and addresses the need of leveraging information technology to streamline the maintenance process and facilitate accurate data gathering.

2.0 Background

2.1 Coast Guard and SFCAM:

The major underlying premise for the Coast Guard's Shore Facility Capital Asset Management, or SFCAM, system is to better align shore assets with the Coast Guard's mission at the lowest cost possible. The major objectives that were initially identified were:

- Link shore facility decisions to Coast Guard strategic goals
- Right size the shore plant
- Pursue divestiture of high maintenance facilities
- Better integrate shore maintenance and recapitalization efforts
- Leverage technology to reduce the shore facility maintenance burden, and
- Reinvigorate shore based preventative maintenance. (USCG FCA Procedural Guidance, 2003).

Many metrics were developed in support of these stated objectives; chief among them was the Condition Facility Assessment (FCA). The objective of the FCA is to provide criteria and methodologies to objectively rate the criticality of independent facility systems when compared with each other and against key attributes of any facility in general. Its stated purpose is to use the data and findings to assist the Coast Guard in "making decisions regarding capital planning, budget forecasting and investment strategies related to the maintenance, repair and replacement of major facility assets. It is the Coast Guard's intent to use the Facility Condition Assessment as a decision support tool to help improve the overall condition of its facilities and its work environments, and to justify projects to be executed in an annual work plan." (USCG FCA Procedural Guidance, 2003). FCA as a tool is nothing new. Varying industries have been using it for years.

The initial Coast Guard FCA was contracted out and has been completed in many places. The primary metric of FCA is the Facility Condition Index, or FCI. Mathematically, FCI is defined as:

FCI = cost of deficiencies/ cost of replacement value

The definition is further expanded to "The cost of deficiencies is the total dollar amount of existing maintenance and repair deficiencies. The figure does not include future work projections. Efforts in the Coast Guard will evaluate a refined version of the original definition." (USCG FCA Procedural Guidance, 2003). This is an initial estimation of what the Coast Guard believes FCI to be.

The figure below depicts a scatter-gram of the FCI for Coast Guard's Pacific Area buildings that are younger than 100 years old. The different buildings correlating FCI are scattered everywhere and adding no new information as to why some of the systems of the buildings of similar age are in such varying conditions.

Budgetary issues and the non-standardization issue help to explain why the structure's FCI's vary so greatly.

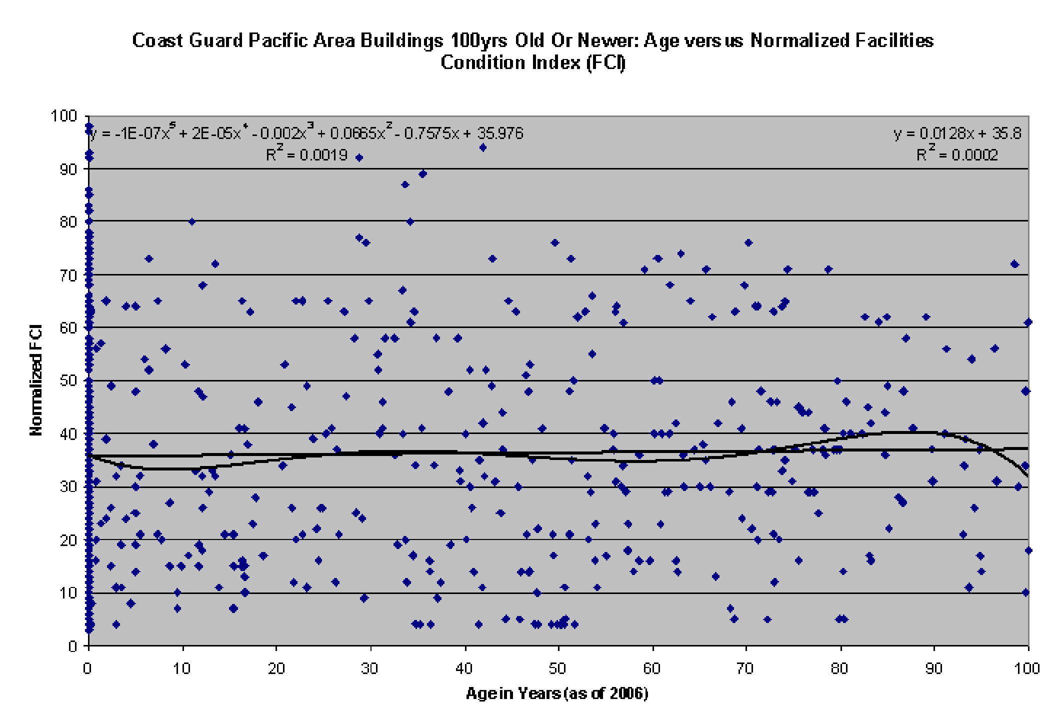


Figure 2: USCG Pacific Area Building Age v. FCI

From: US Coast Guard Facility Condition Assessment
April 2006

This FCI scatter-gram illustrates the point that the Coast Guard as of yet does not successfully manage its capital assets. Much research that can identify cost savings strategies are in great need; particularly given the reality of a decreasing maintenance budget and aging capital assets.

Back in 1998, the National Research Council conducted a study about the government's public asset management. The title of the publication was "Stewardship of Federal Facilities, A Proactive Strategy for Managing the Nation's Public Assets." The book touched on issues ranging from the factors contributing to the deteriorating conditions, to the budget process, to condition assessments, and ultimately to findings and recommendations. Overall, there were 16 findings and 12 recommendations. The most pertinent finding and recommendation that support the need for more research in terms of failure rates of systems and components, the kind of research that this study addresses, were as follows.

Finding 15 stated that only a limited amount of research had been done on the deterioration/failure rates of buildings and components or the non-quantitative implications of building maintenance. They went on to state that "This research is necessary to identify effective facilities management strategies for achieving cost savings, identifying cost avoidances, and providing safe, healthy, productive work environments. (Stewardship of Federal Facilities, 1998)

Building on this finding, recommendation 12 indicated that the government should conduct research in support of finding 15. They ended this final recommendation with the following paragraph.

> "To improve the management of facilities, to determine how maintenance and repair funds can be optimized, and to present budget requests effectively to senior agency managers and public officials, facilities program managers need access to more information about maintenance and repair cost-avoidance strategies and the deterioration of building component. This information would help them determine when individual components or systems should be repaired or replaced and how maintenance should be timed to optimize service life and minimize business disruptions. Information about cost avoidance is critical for conveying the importance and cost effectiveness of preventive maintenance to elected officials and the public." (Stewardship of Federal Facilities, 1998)

2.2 Current Cost Guard Practices (from an operational perspective):

Foreword

The objective of this study is to create a methodology that could be used as a tool to suggest best (or optimal) maintenance strategies (for systems or components) for the Coast Guard to use service-wide. However, due to the Coast Guard's organizational structure and size this study is based on a Coast Guard unit that accurately reflects a cross-section of the Coast Guard. This study concentrates on the west coast focusing on the Coast Guard Alameda base which is supported from a maintenance perspective by Industrial Support Command Alameda (ISC Alameda). Utilizing the data obtained from ISC Alameda, historical patterns of mechanical, electrical, and plumbing systems are analyzed and recommended opportunities for improvement are identified; that is systems to start measuring are ID'd so that the methodology could be tested before being implemented Coast Guard wide..

Background information on the Coast Guard Industrial Support Command Alameda is included as appendix 2.

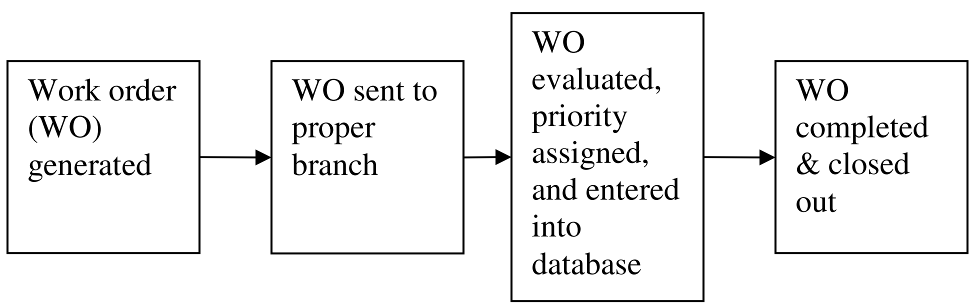
Before a methodology could be developed, it is necessary to establish a basic understanding of how maintenance (including that of systems and components) is carried out from an operational point of view. The Coast Guard currently practices a decentralized approach to the maintenance of capital assets but it is trying to move away from that approach via SFCAM.

From a purely maintenance perspective, there are many layers in the Coast Guard's capital asset maintenance community due to the size, location, and complexity of these assets. The Office of Engineering at Headquarters acts as the policy makers. The different CEU's act as the engineering operational commanders for their specific areas of responsibility. Among other duties, they set the budgets and distribute the limited funds, authorize and manage the large projects, and manage as best they can all of their underlying units while trying to enforce and get buy in for whatever vision, strategy, or agenda they have set.

Looking at the maintenance practice from an operational perspective, there are many levels above the operational unit that are integral parts of the maintenance puzzle. Thus much direction as to how to conduct business comes from above. The operational units understand the macro level process and how it works. They incorporate into their specific duties the best way to do business taking into account the rules and guidelines, particularly from an administrative and process perspective, that have been instituted from their commanders. However, by having so many hands in the pot, sometimes the big picture from an operational perspective gets lost. Headquarters and the CEU do not have the time or resources to devote to each specific unit to create an optimal maintenance process. On the same token, the operational units are merely trying to keep up with the mounting work that comes with a limited budget and aging infrastructure. As such, because of the overall pace of operations, it is very challenging to take a step back from a very basic perspective and try to determine an optimal way to accomplish a task or measure and evaluate the tools at hand. As such, many of the maintenance management tools in place have become little more than tools used to manage work orders.

Coast Guard wide, individual maintenance units like ISC Alameda use their own maintenance management tools, software and databases, often times locally created, to manage their maintenance practices. Several years ago Coast Guard Headquarters mandated that all units switch to the Maximo Enterprise Suite software, which is an asset and service management tool, to manage maintenance; however, no timeline was given and no additional training was provided. Not surprisingly, many operational units like ISC Alameda have decided to stay with their own management tools, software, and databases until this mandate is enforced.

At the Industrial Support Command Alameda, the process works as follows.



First a work order is either generated by the engineering division or the user of a space. The work order is evaluated and if approved, a priority number is assigned by a branch chief or his direct representative. The response priority matrix is as follows:

Priority	Description	Response time
1.	Emergency	Same day
2.	Urgent	5 days
3.	High Priority	15 days
4.	Routine	30 days
5.	Deferred	90 days

Work orders normally default to priority 4, or routine, unless otherwise prioritized by the appropriate personnel.

Once the work orders are approved for completion, they fall into a first in first out queue based on the priority level. The work is then completed accordingly by the appropriate shop (shop breakdown below). The proper documentation is then entered into the local maintenance management system.

index	Branch	Shop
1	Facilities	Electrician
2	Facilities	Plumbing
3	Facilities	Mechanical
4	Industrial	Electrician
5	Industrial	Dayboards
6	Industrial	Metal Shop
7	Industrial	Buoy Depot
8	Facilities	Alarm Shop
9	Industrial	Carpenter
10	Security	Keys/Locks
11	Security	Safe Work
12	Administration	Contracting
13	Administration	Planning/Estimating
14	Administration	Other
15	Facilities	Structural
16	Facilities	Engraving/Sign
17	Environmental	Waste/Recycle
18	Environmental	HazMat
19	Facilities	Boiler Shop

The local management system in place is a rather robust one supported by Microsoft Excel. The major headers for the various columns include index (as shown above) which refers to the branch and shop that is responsible for the work order, work order number, priority, location of work to be done, scope or description of work to be done, contact information or person requesting the work, work status, labor hour, and cost.

Below is a brief snapshot of the electrical shop's database. (Two year worth of electrical data is included as appendix 4).

tblWorkOrder

Prio	Buildi	Request	Bra	Cost
4		Perform Ec Cape Mendocino Dgps Battery Upgrade	4	
2	549	Install "shore Power" 3-phase (+neutral & Ground) Power In Hanger 1 For New Comm	4	
4	549	Remove Old And Install New Battery Chargers At Dgps Sites Pt. Loma, San Diego, Ar	4	
2	549	Install A Battery Back-up Power Supply For Group San Francisco's Hf Radio At Pt. Boi	4	
3	488	Request Ind Ems Tap Into Sandblaster Power Supply And Run Conduit Inside Of Sanc	4	$0.00
3	488	Provide Power Of 120 Volt Ac From Sandblasting Power Supply And Run Conduit Anc	4	
3	359	Two Phases Of Three Have Failed On Coast Guard-owned Portable Makita Generator	4	
1	549	Replace Power Cabling To Power Mound One; Rec.1,2 Power Mound Two; Rec. 1,2,3	4	
2	665	Troubleshoot And Resolve Loss Of 440v Power On Berth 1 Receptacles 1 And 2. Wo	4	
2	665	Repair/replace/troubleshoot And Make Operational All Power To Cgc Pier North Side.	4	
3	488	Provide One 120 Volt Ac Outlet With 20 Amps And 4 Receptacles From The Power Su	4	
3	549	Cgi Building # 5 Electricl Rehab Temp Gen- Set, Install New Gen Set Up-grade Electri	4	
4	549	Install A Battery Back-up Power Supply □□Address: Pt. Bonita	4	
4	549	Install New Conduit As Needed And Secure Along Concert Retaining Wall. Provide (d	4	
5	466	Remove Existing Gen-set Procure And Install New Emergency Generator Up Grade E	4	
3	549	Install Outlets As Discussed For Buoy Depot. Sand Blaster Tent.	4	
3	368	Need A Grounding Rod Placed For A Ready Service Pyrotechnics Locker And A Meta	4	
4	665	Estimate Cost To Repair/replace Power Cable To Power Mounds South End Of Cgi Pi	4	
3	665	Install Transformer Onbd Sherman.	4	
3	359	Bldg. 15 Has Inadequate Power To Supply Tools & Equipment. Request New, Larger,	4	
2	665	Replace Approx 150 Feet Internal Shore Tie Cable Onbd Cgc Sherman Per Casrep 05	4	
4	549	Replace/install New Conduit/drill Access Hole/disconnect Electrical/remove Hut From :	4	
2		A Hot Wire (120v) Was Exposed During A Recent Digging Project. Poc Cannot Seem	4	
5	448	Need Additional Electrical And Switchable Sipr/nipr Drops, 8 Total, 4 On The North, 4	4	
3	468	Electrical Plug-in Broken And Hanging Off The Wall. Potential Safety Hazard.	4	$0.05
3	549	Repair Hot Broken Electrical Wires And Install New Crissy Box & Conduit As Needed.	4	
3	453	Request Isc Industrial Procure And Install Conex Box In Conjunction With Bay 51-3 Re	4	
3	549	Install foundations for Six Video Cameras At Six Remote Locations And Network Equip	4	
4	549	Install Electrical Hot Water Heater Bldg. 5a Head. Make Operational. Lead Shop Indu	4	
3	342	Need To Install Electrical Service To An Additional Temporary Office Space Behind Bl	4	
4	549	1. Remove Landline & Poles As Environmental Mitigation Effort Between The Old Rad	4	
4	549	Conduct Ir Survey & Correct Discrepancies Or Submit Work Order As Appropriate On	4	
4	488	Install 2 lights that are already purchased that require 115 Volt AC along with conduit a	4	
4	553	Replace paramiter lighting on the Eagle Rd. side of medical and behind bldg 10	4	
3	531	Relocate light pole located at the main gate entrance. Move to new location in front of	4	
3	549	VTS building equipment room provide 6 electrical circuit from UPS service panel to eq	4	
3	549	Install 6 electrical circuits from the UPS service panel to eqpt racks. Identify existing ci	4	
4	549	The flat orange trailer has several lighting problems, such as a broken turn signal/brak	4	$0.00
3	492	Provide up-lighting to new palm trees to be installed on Campbell Blvd. Coordinate wi	4	$0.00
3	665	Test shore-tie electrical cables for grounds & open conductors. Remove and/or replac	4	$0.00
3	359	Deliver Ditch Witch mdl 3500 trencher to Ditch Witch for repairs to engine.	4	$0.00
4	599	POC is installing some new equipment in the radio vault near the Pt. Reyes lighthouse	4	########
3	549	Remove buried sub cable from VTS site 1 each Fab 7' ladder sections. Anacortis, WA	4	########
3	359	Troubleshoot and repair an electric vehicle. This is a secondary mode of transportatio	4	$0.00
4	549	Assemble exterior light post for Admiral's house.	4	$0.00
4	359	Relocate 3 receptacles by the welding booths.	4	$0.00
4	549	Relocate receptacles in Housing office.	4	$0.00
4	593	Install as requested lighting, tower, dehumidifier, fire alarm @ site. Funded 02/21/06 $	4	$0.00
3	492	Assist in determining status of H.V. wire tht could impact project scheduled.	4	$0.00
3	599	This work was estimated on Service Request Form 37565 The microwave radio vault r	4	$0.00

Page 1

Not all of the columns are routinely filled in and the scope is usually very vague, often times being little more than two words put together. Additionally, after corrective actions are done no one enters any more amplifying information making it difficult to determine exactly what work has been done. Here are some examples of the scope of work taken from ISC Alameda records.

- “Change ballast (work completed)
- “Repair lighting”
- “Electricity is out in break-room”
- “Elevator is out of service”

Trying to mine valuable information from such vague statements is not only difficult, but ultimately, impossible. Hence, not only are systems or components not being measured, but based on current state and standard operating procedures of the maintenance system in place, creating an optimal maintenance strategy would at best be very difficult if even possible. The historical data that is the critical linchpin to this methodology does not exist. Thus, in coming up with a methodology to be incorporated into practice at the operational level, it must be user friendly, easily understood, and be able to be implemented with minimal effort, and if possible provide early, measurable returns.

2.3 Maintenance Overview:

From the 1960s through the late 1980s, preventive maintenance was the most modern, advanced technique used by most industries on their facilities. The preventive maintenance (PM) process is predicated on two major assumptions/principles. They are:

1. A strong correlation exists between equipment age and failure rate, and
2. Individual component and equipment probability of failure can be determined statistically, and therefore, parts can be replaced or rebuilt prior to failure. (NASA RCM Guide, 2000).

Intuitively, one would accept these principles as valid; however, a study performed by F. Stanley Nowlan and Howard F. Heap showed that no strong correlation did in fact exist between age and failure rate for the majority of equipment, thus discrediting the first premise. (Nowlan, 1978). Additional studies have demonstrated that in excess of 80% of all failures are random. (Weber, 05).

The second premise was also discredited through a ball bearing experiment. It had been common practice in the past to replace ball bearing after some predetermined interval based on the assumption that the individual failure rate increases with time. In 1985 a ball bearing experiment was conducted to test this premise. It was standard practice to replace bearings after some number of operating hours based on the failure rate assumption. Thirty bearings were run to failure and as one could see from the graph below, a very large variation in revolutions before failure occurred.

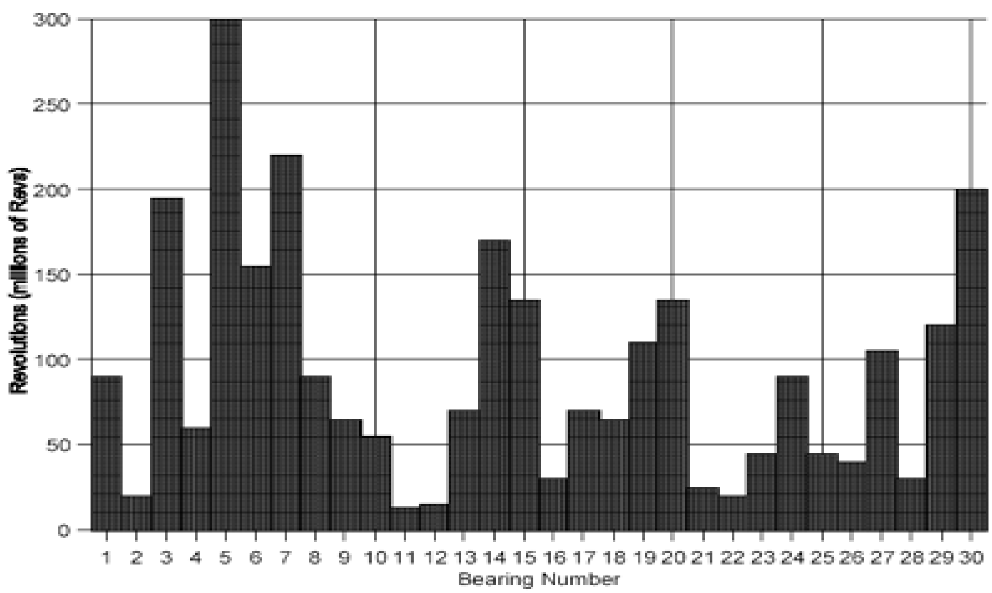


Figure 3: Ball Bearing experiment failure rates

From: Ball and Roller Theory, Design & Application
Eschmann, et al
John Wiley & Sons, 1985

This bearing experiment was not the only test to discredit the second premise. From all of the collective studies, NASA determined that a recognizable difference existed between the "perceived and the intrinsic design life for the majority of equipment and components." In fact, it was discovered that in many cases equipment life greatly exceeded the perceived of stated design life. (NASA RCM Guide, 2000).

However, this is not to suggest that PM should not be used at all. On the contrary, it should very well be used where appropriate; but it should not be defaulted to or used as the only process in place as has been done in the past. Instead, it should be part of a more comprehensive maintenance process, part of a reliability-centered maintenance process.

Reliability-Centered Maintenance (RCM) was one of several processes developed during the 1960 and refined through the 1970's in various industries but primarily the airline industry. The stated objective that created a study into these processes was to help people or organizations determine the best policies for managing the functions of physical assets and to also understand and manage the consequences of the failures. A basic look at the seven principal stages of the RCM process is illustrated below.

Figure 4: RCM Process breakdown

From: Enabling RCM Process with MXES
MRO.COM

“An RCM process systematically identifies all of the assets functions and functional failures, and identifies all of its reasonably likely failure modes (or failure causes).” (O’Hanlon, 2003). It then proceeds to identify the effects of these likely failure modes, and to identify in what way those effects matter. Once it has gathered this information, the RCM process then selects the most appropriate asset management policy. (Netherton, 1999). In essence, it is the process used to determine the most effective approach to maintenance by identifying actions that, when properly instituted will reduce the probability of failure and which are most cost effective. (NASA RCM Guide, 2000)

Reliability-centered maintenance analysis provides a basic framework for analyzing the functions and potential failure modes for a physical asset in order to develop a scheduled maintenance plan that will provide some acceptable level of operability. (The term “acceptable level” needs to be defined by each individual organization based on their individual needs of whatever system it is that they wish to measure.) In addition, reliability-centered maintenance should also take into account risk in some efficient, cost-effective manner. (Comparing Maintenance Strategies, 2005).

At the heart of the reliability-centered maintenance concept is that of life data analysis. Life data refers to measurements of the life of components or systems. The basis for developing a maintenance schedule can be centered on in-house testing, that is actually conducting specific tests on systems with stated objectives and deliverables; or more commonly (and less costly) they can come from historical data that has hopefully been well kept by an organization throughout the expired life of the system or component. By analyzing the aforementioned data or properly conducting in-house testing the reliability of any system or component can be accurately tracked, measured, and improved leading to lower maintenance costs (Comparing Maintenance Strategies, 2005). However, in either case it is important to realize that life data analysis from in-house tests or historical data are still always estimates. The true value of the probability of failure, the mean life, the parameters of the distribution, or any other parameter one wishes to consider is never truly known. The objective of life data analysis is to accurately estimate these true values.

A well crafted reliability-centered maintenance program should (or could depending on the size of the organization) incorporate condition based actions, time based actions, and run to failure. (NASA RCM Guide, 2000). Thus, reliability-centered maintenance is a process of processes; the important piece is tying the right system or component to the right approach. For instance, a maintenance strategy for a pump might look something like this. A reactive approach (or run to failure) might be suitable for all gasket material on the pump. Certainly, taking a pump apart for the sole purpose of checking the condition of the gasket would not be cost effective. PM would be appropriate for the impellor as it would wear down from hours of operations due to it rubbing in the housing. Thus, based on historical data (or more conservatively from the manufacturer’s recommendation), an accurate schedule for changing out impellors could be achieved. The pump motor would be a likely candidate for condition based monitoring as those failures are predominantly random. And if time and resources allow, a proactive approach with varying analysis can be taken on the pump as a whole by using the many different practices available (this is very unlikely, however, as a proactive approach is usually reserved for larger systems with frequent, expensive failure modes and undertaken by companies with large maintenance budgets). The methodology developed in this study concentrates on the first three approaches with more of a focus on preventive maintenance and condition based maintenance. (Proactive maintenance is not considered because it is labor intensive, expensive, and requires much expertise in the equipment and the process itself.) Reactive maintenance is usually obvious as those particular components rarely fail, have minor consequences and are routinely inexpensive. They could be categorized as consumables. Thus for the remaining majority of components, this methodology focuses on assigning the proper strategy (PM or condition-based) and schedule based on historical data. Figure 5 below shows the principle tenets of each approach.

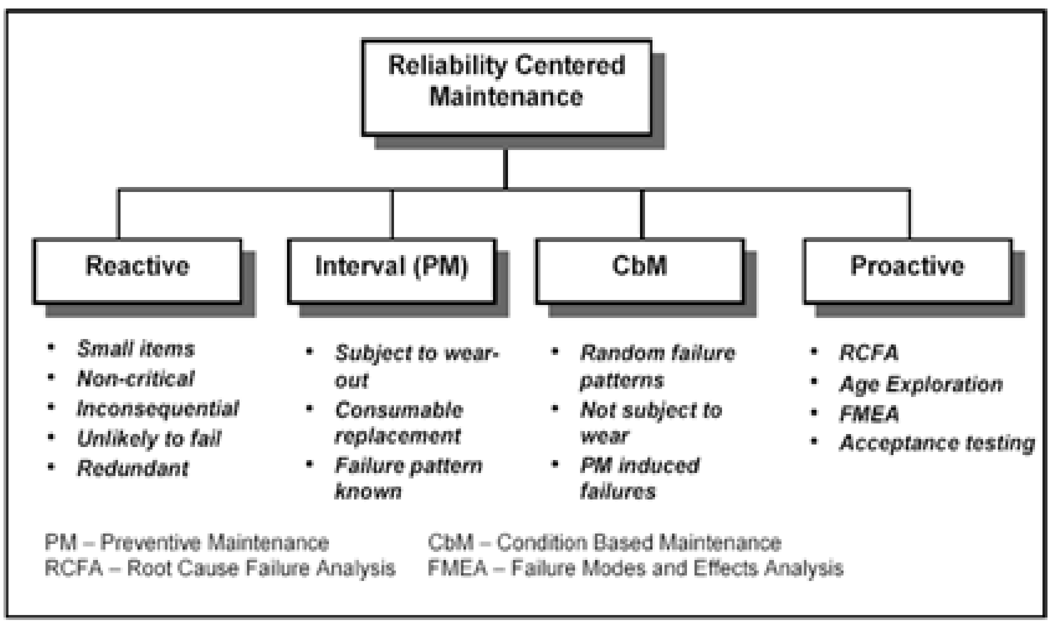


Figure 5: RCM Program components

From: NASA RCM Guide
February 2000

2.4 The Case for Reliability-Centered Maintenance:

When trying to change an organization's standard operating procedures or practice, there must always be a valid, measurable reason for change. When looking at it from a capital asset management perspective, it usually comes down to money, specifically, minimizing the costs of doing business. Usually, this argument needs to be very compelling in order to gain any traction.

From an overall operational perspective, general operating costs are rising at approximately 10% each year, thus providing many savings opportunities from a purely maintenance perspective. According to the President of the Reliability Center, Inc., in Hopewell, VA, every year U.S. industry spends well over $300 billion on plant maintenance and operations. Additionally, an estimated 80% of the $300 billion are spent correcting chronic failures of machines, systems, and even people that occur daily, sometimes even hourly, in plants across the country. These chronic failures are characterized as low cost and high frequency. The president, Mr. Charles Latino, goes on to say that eliminating these chronic failures can reduce maintenance costs somewhere between forty and sixty percent which could add up to about $115 billion in savings annually. This savings can all be accomplished without any major restructuring or employee layoffs. (Latino, 1996).

In his article, Mr. Latino sighted two successes. The first was a large mid-Atlantic producer of polymers. By vigorously investigating and eliminating chronic failures, in a ten year period this company went from employing 300 mechanics to employing less than 200 mechanics while doubling its capacity.

The second example sighted was that of a west coast refinery which recognized that a 2-year mean time between failures for pumps was unacceptable. It put in place a policy that would conduct a failure analysis on any pump that fell below the 2-year mean time between failure threshold. As a result of this initiative, the mean time between failure rates increased to six years resulting in a savings of about $2 million a year.

In 2004, ASME conducted a survey on condition based monitoring/maintenance and presented their results during their 7th biennial conference. The survey was taken by 156 different companies from over 15 different countries and as the survey title would suggest, it concentrated on condition based monitoring/maintenance.

As shown in figure 5, associated with reliability-centered maintenance (a subset of it) is condition based maintenance, sometimes referred to as condition based monitoring. According to the American Society of Mechanical Engineers, "CBM is the method adopted to monitor and diagnose the condition/s of the process, machinery, or component/s under investigation." Condition Based Monitoring therefore links directly with Condition Based Maintenance, a technique of diagnosing failure mechanisms and making a prognosis for the remaining useful life before failure. This enables corrective maintenance action to be undertaken on the identified failing component/s at a convenient time before anticipated time of failure." (Higgs, 2004).

According to ASME, the international response shows CBM to be a globally accepted maintenance practice. Some of the more telling findings were:

- 85% of respondents introduced CBM in order to adopt the practice of predictive maintenance into their company.
- 95% of respondents introduced CBM to reduce the number of unscheduled machine breakdowns.
- 83% of respondents said their businesses adopted CBM practices to save money.
- 77% of respondents said their CBM systems meets expectations
- 80% of respondents reported that operator and engineering awareness of maintenance issues has increased since their companies started using CBM.
- 76% of respondents stated that further maintenance initiatives have resulted following the implementation of a CBM system.
- 81% of respondents said that CBM has introduced predictive failure capabilities into their business, in turn improving maintenance scheduling. (Higgs, 2004).

Additionally, these companies listed the incentives of why they changed to a CBM or predictive maintenance practices. Here are some of the responses:

- We were carrying out a very labor intensive annual shut down and replacement program. CM reduced this dramatically.
- Interest by maintenance personnel to understand machine condition.
- As a strategy to enable reliability monitoring of the equipment.
- Previously used the services of a contractor before implementing in-house program.
- As a catalyst to change the organization's maintenance culture from reactive to proactive. (Higgs, 2004).

The incentives could be summarized as follows: to avoid annual maintenance shut downs, improve maintenance planning and scheduling, act as a maintenance training catalyst, monitor the reliability of equipment, and move from a reactive to a more proactive maintenance culture.

Studies suggest that maintenance is a relatively small portion of the overall life-cycle cost of a facility's operating cost usually accounting for about 5% of the total operating cost. However, these maintenance costs are still capable of achieving tremendous savings through the maintenance and operation phase of the life-cycle. According to NASA, savings of 30% to 50% in the annual maintenance budget are often obtained through the introduction and execution of a balanced reliability-centered maintenance program. To look at it from a Coast Guard perspective with an annual maintenance budget of about $500M, a savings of up to $250M could be realized just by instituting and properly executing a balanced and effective reliability-centered maintenance program. (NASA RCM Guide, 2000)

3.0 Methodology

3.1 Weibull Distribution:

Life data, as previously mentioned, refers to measurements of the life of components or systems and is the key to predicting future failures. The metrics used for differing systems vary and can be measured in hours of operation, a predetermined time cycle, miles, revolutions or any other metric that applies to the period of successful operation of a particular system or component. Since time is a common (and possibly the most common) measure of life, life data points are often called Time to Failure or more specifically Mean Time to Failure.

The Weibull Distribution is by far the most commonly used distribution in statistical modeling of life data. (Abernathy, 96) It was invented by Swedish Mathematician Waloddi Weibull in 1937. The Weibull is so popular because it is a versatile distribution function that can take on the characteristics of other types of distributions. Depicted below are common failure curves. No other single distribution function exists that can accurately take these shapes.

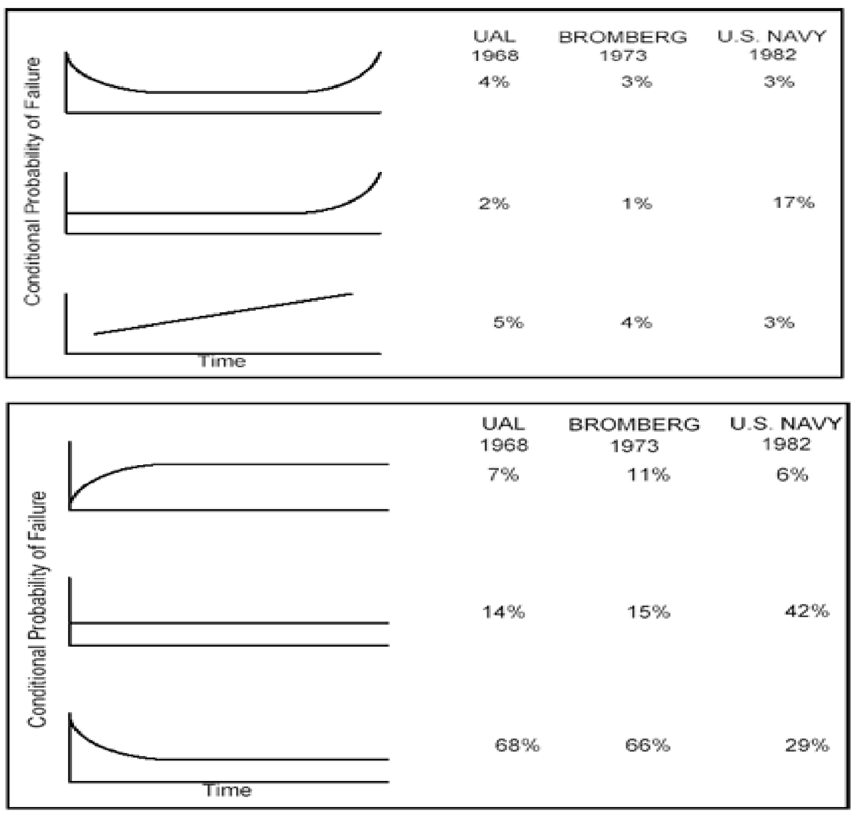


Figure 6: Conditional Probability Curves

From: NASA RCM Guide
February 2000

This ability to model a wide variety of distributions using a relatively simple distributional form has made the Weibull Distribution common place when dealing with life data and failure predictions. The Weibull Distribution uses three parameters in order to ascertain the best fitting PDF given the data provided. These parameters are the shape parameter, the scale parameter, and the location parameter. When referring to a two parameter Weibull Distribution, the location parameter is omitted. The location parameter is utilized when the data does not fall on a straight line, but falls on either a concave up or concave down curve. (Abernathy, 96)

The Weibull Distribution is a probability density function; that is it is non-negative everywhere and its integral from $-\infty$ to $+\infty$ is equal to 1. Mathematically the Weibull Distribution is defined as:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

where the shape parameter, β (beta), defines the shape of the distribution, the scale parameter, η(eta), defines where the bulk of the distribution lies and the location parameter, γ(gamma), defines the location of the distribution in time. (Abernathy, 96).

The first parameter is β, the shape parameter. Shape parameters allow a distribution to take on a variety of shapes, depending on the value of the shape parameter. These distributions are particularly useful in modeling applications since they are flexible enough to model a variety of data sets.

Beta, β, is the slope of the Weibull plot and thus determines which distribution best fits (or describes) the data presented. Additionally, the slope, β, shows which class of failure is present at any given time by looking at its value, when:

- $\beta < 1$, indicates infant mortality
- $\beta = 1$, indicates random failures independent of age
- $\beta > 1$, indicates wear out failures (Abernathy, 96.)

Infant mortality indicates that the components lifetime has a decreasing failure rate, meaning that the longer it runs, the less likely it is to fail. Conversely, wear out failures mean that the components lifetime has an increasing failure rate; that is the longer it runs the more likely it is to fail.

Many mechanical components or systems observe the three phases of β resulting in what is known as a bath-tub curve (illustrated below).

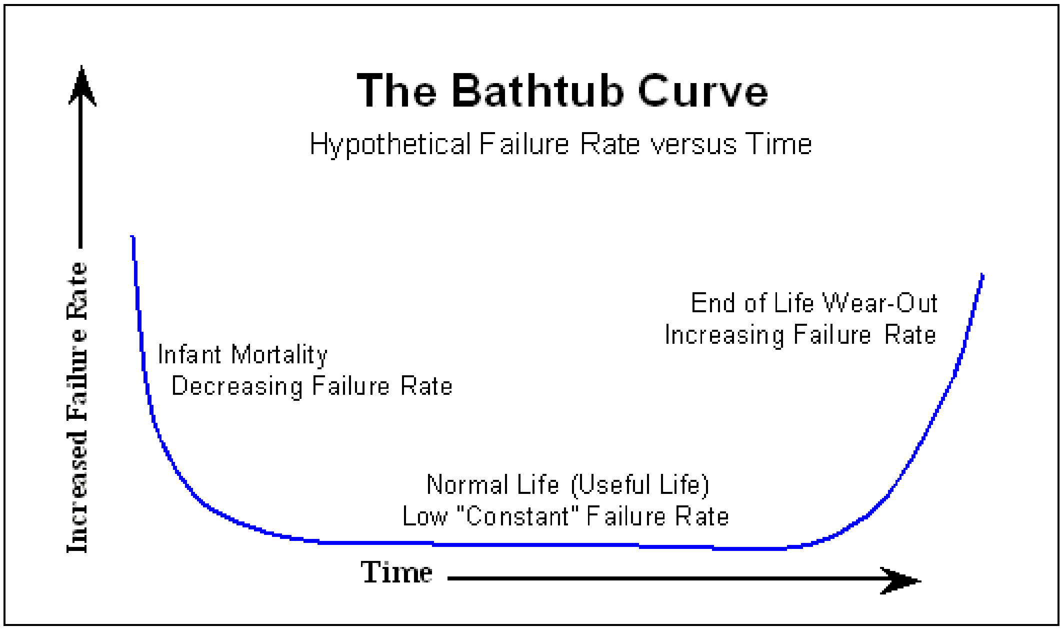


Figure 7: Bath tub curve for age related failures

From: Reliability, Maintainability and Risk
Butterworth Heinenmann, 1997

As one can deduce from the curve, infant mortality will happen, rapidly decreasing as time goes by. The important observation from this curve is to determine or predict when the wear out rate will commence and take appropriate action to mitigate or when possible, completely avoid the consequences.

Next, let's look at the η and γ, the scale and location parameters. First, for a normal distribution, the location and scale parameters correspond to the mean and standard deviation, respectively. Additionally, the standard form of any distribution is one that has a location parameter of zero and a scale parameter of one. The effects of manipulating these two parameters follow.

The effect of manipulating a scale parameter to greater than one is that of stretching the probability distribution function; thus the greater the magnitude, the greater the stretching. And of course, as one could intuitively decipher, the effect of manipulating a scale parameter to less than one is to compress the probability distribution function. The compressing approaches a spike as the scale parameter goes to zero.

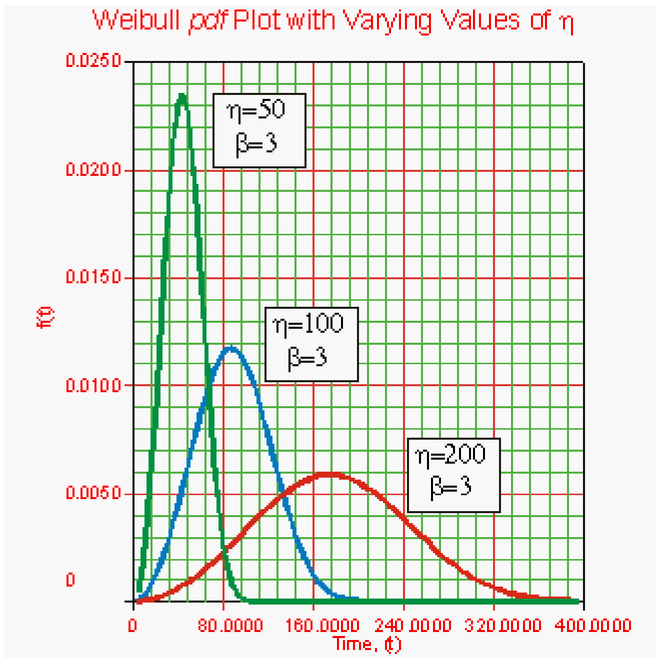


Figure 8: Scale Parameter Weibull Plot

From: Weibull.com

The effect of the location parameter is to translate the graph, relative to the standard normal distribution. A location parameter simply shifts the graph left or right on the horizontal axis.

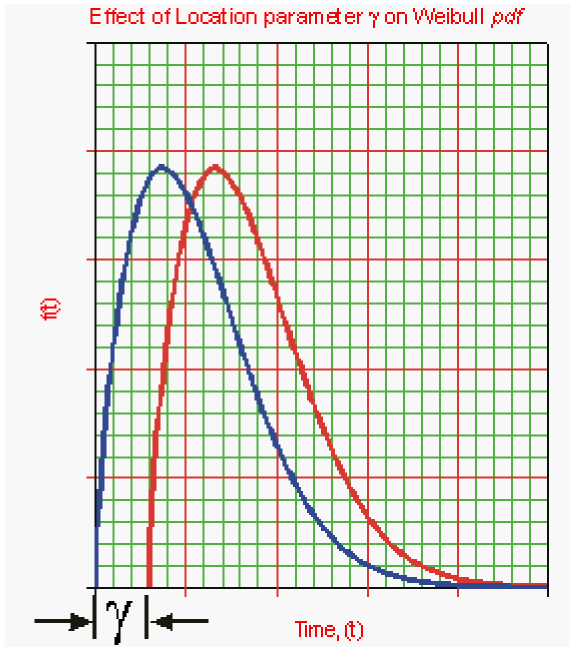


Figure 9: Location Parameter Weibull Plot

From: Weibull.com

The second part of the equation (the exponential portion) speaks to failure and reliability rates. Reliability is "The characteristic of an item expressed by the probability that it will perform a required function under stated conditions for a stated period of time." (Dummer, 1990.)

From a systems or components perspective, failure rate is defined as the frequency at which that component fails and is symbolized by the Greek letter λ, Lambda. The failure rate is function that is time dependent. Specifically,

$$\lambda = \frac{\text{number of failures per unit time}}{\text{number of components exposed to failure}}$$

The reliability rate as a function of time is defined as the exponential of a negative integral of $\lambda(t)$ where time is measured from o to t. Hence, mathematically, it is the exponential part of the equation and can also be written as:

$$R(t) = e(-\lambda t)$$

The important issue to note is that reliability is a very important part of the Weibull Distribution and is adequately addressed within the function.

3.1.1 Why use Weibull:

The Weibull Distribution has been used for failure analysis for over 50 years and continues to be common place in data analysis. Though originally invented in 1937 it was not well known until 1951 when Waloddi Weibull delivered his "hallmark American paper" on the subject. Shortly thereafter, the United States Air Force recognized or, at a minimum, perceived much value in this method and funded Mr. Weibull's research through 1975. Interestingly enough, at about the same time, reliability-centered maintenance was in its infancy stages with its genesis in the aviation community as well.

There are many reasons and advantages for using and the Weibull analysis. One of the first is that of being able to provide accurate failure analysis and predictions and forecasts based on very few samples. According to the New Weibull Handbook, failure analysis forecasts solutions are possible "at the earliest indications of a problem without having to 'crash a few more.'" By being able to devise a strategy based on early failures or early recognizable trends, much money can be saved in preventing future possible "chronic" failures before they actually progress to the chronic level.

The Weibull analysis can also save an entity or corporation from having to conduct any in-house run to failure testing of a new or existing component in hopes of determining the optimal maintenance strategy to incorporate for that given component.

Additionally, the Weibull analysis is user friendly. In particular, it provides a simple to read and easy to use graphical plot of whatever it is one is measuring. The New Weibull Handbook states, "The horizontal scale is a measure of life or aging.… The vertical scale is the cumulative percentage failed. The two defining parameters of the Weilbull line are the slope, beta, and the characteristic life, eta. The slope of the line, β, is particularly significant and may provide a clue to the physics of the failure…. The characteristic life, η, is the typical time to failure in Weibull analysis." Even "bad" Weibull plots are informative to the trained eye because the trained eye still can:

- Identify mixtures of failure modes
- Identify problems with the origin not located at zero
- Investigate alternate aging parameters
- Handle data where some part ages are unknown, and
- Construct a Weibull curve when no failures have occurred.

In terms of maintenance planning, the Weibull plot, when used effectively, is extremely useful, particularly in the case of reliability-centered maintenance. By looking at the slope (β), it could be determined whether further action (inspection, overhaul, replacement…) is needed depending on the company's predetermined thresholds. For instance, if β is less than or equal to one, then no further action is needed as the risk of failure has been determined to be acceptable. However, if β is greater than one, then depending on what component and what strategy is in place, different outcomes come into play. Specifically, if the cost of an unplanned failure is greater than the cost of a planned replacement, a strategy that identifies an optimal replacement schedule should be in place. However, if these costs are very close to each other (or are equal), then the strategy in place may be to let the component run to failure (so long as no safety issues are at play).

To again cite the New Weibull Handbook, "Using Weibull failure forecasting, quantitative trades are made between

- Scheduled and unscheduled maintenance
- Forced, retrofit, and convenience retrofit,
- Non-destructive inspections versus replacement,
- Corrective action versus "do nothing",
- Different times-between-overhauls,
- Optimal replacement intervals."

Also as per the New Weibull Handbook the scope of a complete Weibull analysis incorporates a thorough, comprehensive study that includes:

- Plotting the Data and interpreting the data
- Failure forecasting and prediction
- Evaluating corrective actions
- Engineering change substantiation
- Maintenance planning and cost effective replacement strategies
- Spare parts forecasting
- Warranty analysis and support cost prediction
- Calibration of complex design systems
- Recommendations to management in response to service problems

Failure types include:

- Development, production and service
- Mechanical, electronic, materials and human failure
- Quality control, design deficiencies, defective materials

And mathematical modeling for system analysis includes:

- Monte Carlo simulation
- Reliability growth-Reparability models
- Exponential, binomial and Poisson models
- Kaplan-Meier Survivor model

By recognizing the many options afforded in terms of a Weibull analysis, an entity could pick and choose how to proceed in terms of carrying out an analysis.

It is important for a company to honestly asses its needs in terms of maintenance. Thus, if it chooses to closely monitor and measure maintenance costs in hopes of minimizing or at least decreasing them, it must ensure that it is concentrating on the right issues, issues that only an individual company can determine for itself given their specific situation. This could be accomplished many ways but tapping into its subject matter experts is a natural starting point. As such, once the issues are identified and a logical measurement system is in place, data collection can commence.

3.2 Problem Description and Logic:

Reliability-centered maintenance coupled with a Weibull analysis provides a comprehensive framework for analyzing functions of systems and/or components and their associated failure modes. This is done so that an optimal maintenance plan and schedule can be incorporated based on the system and its predetermined level of risk failure as determined by the company.

As such, much thought must be given to the logic and issues at play within the maintenance strategy taking into account primary issues such as, but not limited to, the effects of a failure on operations, costs, and resource availability. The logic should also take into account ancillary issues such as safety or any other issues that any company can identify and wishes to quantify.

In this methodology, ancillary issues were left out. This was purposefully done for many reasons. First, leaving out these issues helped create a logic that was simple and user friendly with few but critical inputs, thus keeping the measuring part of the analysis simple. From an implementation standpoint, if people are overwhelmed or perhaps don't see the reward of the upfront work, then they are more likely to not pursue that option. By keeping the measurement portion (or critical equation inputs) as simple as possible, it makes the process more attractive and more manageable to those operational units that are over-tasked with their limited resources and funding. Secondly, the Coast Guard's non-standardization issue must be considered when coming up with the logic. Many of the Coast Guard's systems and their associated components were inherited; thus two similar situations (use an AC unit cooling a 10,000 SF space as an example) could be using two completely different systems, perhaps different sizes, different components, different age etc. This certainly makes it very challenging to identify Coast Guard wide common ancillary issues if they even exist. Also adding to the non-standardization confusion is the location of these systems as they will be exposed to varying circumstances (corrosive environment, weather, usage etc…) due to their location. The United States Coast Guard is located everywhere from Asia to the Middle East and from Puerto Rico to Alaska and Hawaii, and everywhere in between. Some places like office buildings could be located in the heart of cities, other more operational locations may be on rivers or on the ocean. Thus from this collective perspective, the varying conditions become a little more apparent. Lastly, though this methodology only focuses on the primary issues, the way it is constructed, safety issues aside, ancillary issues would play a very small role, if any, in the recommendations produced.

In proceeding with the logic, the next step is to identify the critical issues; they are time and money; however, each must be clearly defined. First, the time issue must be quantified.

In addressing the time issue the maintenance strategies in place must be identified. In the Coast Guard, two primary strategies are utilized. They could be summarized as scheduled preventive maintenance or as condition found maintenance.

Scheduled preventive maintenance is based on a predetermined maintenance schedule broken down by systems or equipment. After a certain period of time, system specific maintenance is conducted whether it is needed or not. This could include something as simple as changing out gasket material or as involved as overhauling an engine or completely replacing some piece of equipment (though this is less likely).

Condition found maintenance is predominantly corrective action or run to failure. This usually occurs when a work order is submitted to the servicing engineering or public works office after a "problem" has been encountered. Sometimes, these problems are encountered through an inspection, but most often it is because something has failed.

Based on the two primary strategies, a very basic logic diagram is shown below. In the diagram, the green squares are referred to as decision nodes and indicate that based on a decision there may be several possible outcomes. The red circles are referred to as a chance nodes and indicate that there is a chance of different outcomes that are not necessarily controllable (though their likelihood could be predicted).

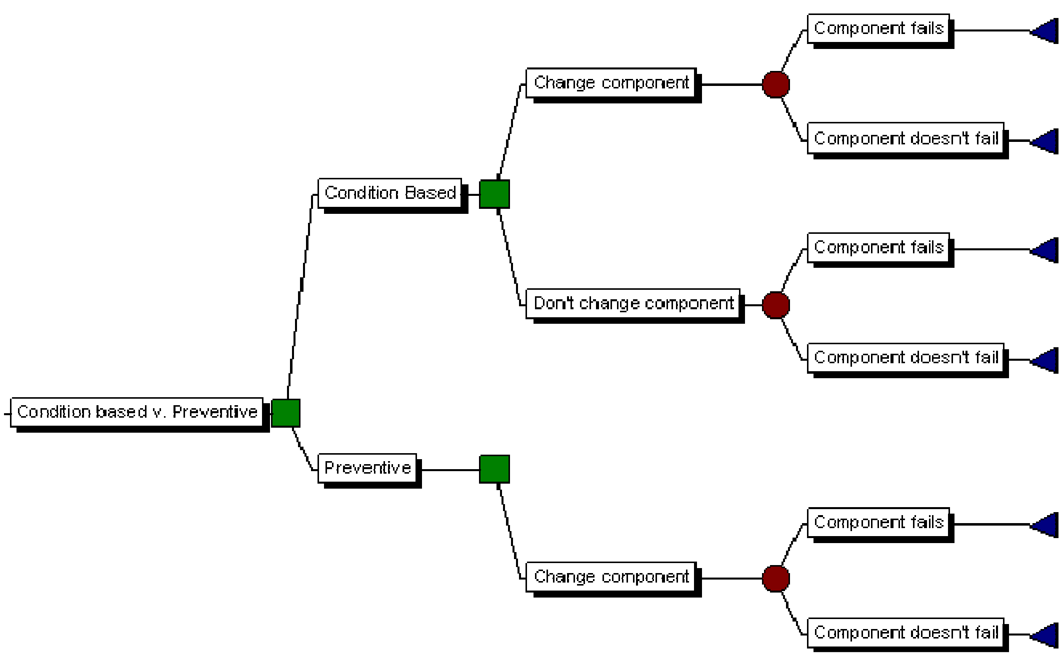


Figure 10: Condition based v. preventive maintenance

Following the diagram above, when looking at a condition based strategy, based on a certain condition of a component (whether by inspection or because it failed), the component will either be changed or not changed. After that has been accomplished, then that component has some probability of failing or not failing and associated with it failing or not failing is a specific cost. From a preventive perspective, a component is changed out based on some measurement of time, regardless of condition. The component would also be changed out if it failed. Once the component is changed, then there is a probability of failure and corresponding cost associated with it. However, an integral part not accounted for in the diagram above is that of time.

By focusing on historical data using the Weibull analysis, component failures can be easily and accurately predicted. By being able to predict a specific failure rate or probability of something failing “soon”, then a better strategy can be put in place or could validate the one already in place. Depending on the component and its probability and consequences of failure, the strategy could be to change out the component before it fails, let it fail, or conduct an inspection on the component or system.

The second prong of this approach is the cost issue. Defining the cost of a component change out depends greatly on when it is performed; particularly, was it a scheduled change out or was it corrective maintenance performed because the component failed? For creating the equation, primary issues to be considered are:

- The replacement cost of the component to be changed out
- The amount of time the system will be down due to individual component being changed out
- Cost associated with the system being down
- Time needed for the change out
- Amount of man hours and associated cost needed for the change out

The equation is:

$$TMC = RC + DTC*DT + LC*LT$$

Total Maintenance Cost (TMC) is as the name suggests, the total maintenance cost. More specifically, it is the total cost for a component change out and is the cost to minimize.

Replacement Cost (RC) is the replacement cost of the component which is a constant irregardless of whether the change-out was scheduled or corrective.

Cost per hour of down time (DTC) includes side issues associated with the component change out. For instance, if the component is part of an A/C system, perhaps a temporary system has to be brought on line. This cost could include the temporary system if it is rented, cost for man hours spent on setting up, operating, and taking down the system, etc. Any costs that are associated with the down time of the system due to the component being changed out should be included. However, any associated labor cost should not be included as it is accounted for under a separate heading.

Down Time (DT): The amount of time the system is anticipated to be down to include how long it would take to replace the component. DT will vary given the circumstance; that is whether it was corrective action (failed component) or scheduled maintenance. In a scheduled maintenance scenario, one could safely assume that the right people, tools and spare part are in place to properly carry out the scheduled change out. Conversely, in an unscheduled scenario, the right people, tools, or even the spare parts may not be on hand, thus prolonging the time of change out.

Labor Cost (LC): Hourly labor cost rate for changing out the component.

Labor Time (LT): The length of time (in hours) to change out the component.

Ultimately, tying time to failure and the total cost for component change out together, a change out schedule for any given component is determined. Through this methodology, first the Weibull distribution is determined to characterize the components probability of failure. Next, taking cost into account, if the cost of an unplanned replacement is greater than that of a planned replacement, then an optimal change out schedule exists and must be determined so as to reduce maintenance costs. If the planned schedule is too short, than the replacement costs go up unnecessarily, if it's too long than the unplanned replacements drive up the total costs. Thus the objective is to find the interval that minimizes the expected cost.

Utilizing the @Risk software with Monte Carlo Simulation (this will be further explained in the following sections), for any component all of the aforementioned costs are entered. Additionally, armed with the historical data, the program has the capability to use the Weibull Distribution to simulate when the next failure will occur. All the costs previously mentioned will be entered as constants and used appropriately when written as thresholds into the program. The program would work as follows: First, the Weibull distribution parameters are introduced. Next, the replacement cost, cost per hour of down time, time for a planned replacement, time for an unplanned replacement, replacement interval (function of time) are entered.

The only variable will be that of time (replacement interval). Depending on what the mean time to failure for any given component is will help determine what change out schedule (or replacement interval) to run. For instance, if a component on the average fails every 100 hours, the replacement intervals could be 80, 90, 100, 110, and 120. The simulation is then run for 2,000 hours to ensure many change outs and give an accurate expected cost.

The output of the simulation would give the minimum, maximum, and mean expected cost of each schedule, again based on the aforementioned inputs. Then depending on the output of each schedule, the search could be further refined to reach an optimal change out schedule for that component.

3.3 Mathematical Terms of Importance:

In the case of reliability engineering it is important to describe the random behavior of a system by one or more parameters. This can be achieved by using numbers mathematically known as moments of a distribution. Moments are used to describe properties of a distribution. Most common moments are expected value, variance and standard deviation. (Billington, 1992).

In determining TMC the expected maintenance cost or expected value is being exposed given the parameters. (Expected Value is often times referred to as the average or the mean). As the parameters vary, so would the expected value of TMC. In the case of a discrete function, mathematically, expected value would be:

$$\mathrm{E}(X) = \sum_i p_i x_i$$

In the case of a continuous probability density function, it would be:

$$\mathrm{E}(X) = \int_{-\infty}^{\infty} x f(x)\, \mathrm{d}x.$$

The dispersion, sometimes referred to as the spread, of a distribution is known as the variance. The variance, which helps determine the shape of a distribution, indicates where the possible values are located or spread around the expected value. However, more important then the variance is the standard deviation, which is the square root of the variance. The standard deviation helps represent how spread out from the mean any given set is.

Mean time to failure (MTTF) measures the average time a system or component will fail. This is accomplished by taking the total operating time of a component divided by the total number of failures. For instance, if an impellor, after replacement, breaks down in 100 hours, gets replaced, breaks down in another 115 gets replaced, and then breaks down in 85 hours than its mean time to failure is easily calculated.

$$\textbf{MTTF} = \frac{100 + 115 + 85}{3} = 100 \text{ hrs}$$

3.4 @Risk Software Background:

The @Risk software is an add-on software package for Microsoft Excel. It is produced by the Palisade Corporation. The software is primarily designed for risk analysis and allows users to define probability distributions and run Monte Carlo simulations for input and output variables within an Excel spreadsheet.

Some of the key @Risk features as advertised by Palisade and used in this methodology are:

- @RISK uses Monte Carlo simulation to show you many possible outcomes in your Microsoft Excel spreadsheet – and tells you how likely they are to occur. This means that you finally have, if not perfect information, the most complete picture possible. You can judge which risks to take and which ones to avoid. While no software package can predict the future, @RISK can help you choose the best strategy based on the available information. That's not a bad guarantee!
- The power of Monte Carlo simulation lies in the picture of possible outcomes it creates. Simply by running a simulation, @RISK takes your spreadsheet model from representing just one possible outcome to representing thousands. With @RISK, you can answer questions like, "What is the probability of profit exceeding $10,000,000?" or "What are the chances of losing money on this venture?"
- Replace uncertain values in your spreadsheet with @RISK probability distribution functions. You've probably heard of some of these, such as normal ("bell curve"), uniform, and triangular distributions. Choosing which @RISK distribution function to use is easy. @RISK comes with a distribution viewer that lets you preview various distributions before selecting them. You can even set up your distributions using percentiles as well as standard parameters. Furthermore, you can use your own historical data and @RISK's integrated data fitting tool to select the best function and the right parameters. (*Decision Tools, 2001*).

4.0 Simulation Modeling

4.1 Simulation Modeling Overview:

A basic definition or explanation of computer based simulation modeling is a computer program that attempts to simulate any given model of a particular system in hopes of gaining insight or knowledge about the operations of the system being modeled. The formal modeling of systems is predominantly achieved through a mathematical model, which attempts to define in mathematical terms the system in question, in turn finding analytical solutions to problems and ultimately enabling the prediction of the behavior of the system from a set of parameters and initial conditions.

This methodology utilizes Monte Carlo simulation. The Monte Carlo simulation method is commonly used when trying to simulate a model where many variables are involved and uncertainties are present. The Monte Carlo method works by generating acceptable or suitable random numbers that follow the parameters that have been input and then running many iterations, each time generating random numbers. From those iterations, an expected value or mean is determined.

Modeling allows for simulating real world applications without the real world costs. Thus, many experiments with an unlimited amount of variables could be run to see what each individual variable's impact may be on the system, what its associated costs are, any possible scheduling concerns, or any particular issue of interest. However, the burden of ensuring that a productive model is developed lies squarely on whoever is developing it.

In developing a reliability focused simulation model, the following logic must be utilized in order to ensure a worthwhile simulation model:

1. Define the system to simulate
2. Define the goals for the simulation
3. Try to identify components and/or subsystems where possible, redefine the system if necessary
4. Represent as best as possible a reliability model of the system taking critical issues into account
5. Introduce time dependency and define system reliability metrics
6. Create the simulation logic
7. Run the simulation

4.2 Problem Specific Modeling:

The model developed for this study concentrates on mechanical, electrical, and plumbing components. The reasons for developing a system that concentrates on these components are several. First, these systems are found everywhere within the Coast Guard irregardless of location or size of the unit. While the components will vary, there is an abundance of them. That leads to many opportunities for improvement and endless possibilities for sharing of best practices and allows many to benefit from the testing of some. Next, these systems are easily identifiable as are any corresponding subsystems and components. This allows for more easily determining the critical issues to consider. Lastly, data should be easily measurable and readily obtainable once any given system or component has been identified as one needing to be "reviewed".

To review, the critical issues are:

- The replacement cost of the component to be changed out
- The amount of time the system will be down due to individual component being changed out
- Cost associated with the system being down
- Time needed for the change out
- Amount of man hours needed for the change out

The cost equation is:

*TMC= RC + DTC*DT + LC*LT*

Where TMC= total maintenance cost, RC= replacement cost, DTC= Cost per hour of down time, DT= down time, LC= hourly labor cost, and LT= labor time.

First, this equation (coupled with the Weibull distribution that predicts the next failure) is applied to a specific system or component. Next, the time variable is introduced; specifically, based on a component's historical failure rate, the change out schedule is determined and the simulation iterations are run. Then different predetermined change out schedules based on the failure rates are run. Thus, the mean expected cost of each time variable will be compared focusing on the smallest mean expected cost. A refined search is then run to more accurately identify the optimal schedule.

4.3 Example Run:

For the example run, the following basic failure information is provided. Let's assume this failure history is of a pump impellor for an air-conditioning system for a Coast Guard housing complex. The housing complex has a limited maintenance budget with many competing interests. Thus the goal of the simulation is to minimize the expected maintenance costs of any system or component where possible.

Pump Impellor	Failure time*
1	90
2	96
3	100
4	30
5	49
6	45
7	10
8	82
9	27
10	77

*Failure time is measure in hours of operation

From the data above it can be determined that the Mean Time to Failure (MTTF) is 60.6 hours.

MTTF = (90+96+100+30+49+45+10+82+27+77)/10

Additionally, the variance is 90 (100 – 10 (highest value – lowest value)).

Assignment of the other values is as follows. Every hour the system is down, it costs $300. The replacement cost for the impellor will be $50. If the impellor is replaced as planned the system will be down for a total of 1 hour. If a failed impellor is being replaced (unplanned replacement), than the system will be down for 15 hours. From this information, utilizing @Risk, the methodology presented will determine the best strategy to minimize the expected cost. The system will be simulated for 1,000 hours operations to ensure many change outs.

With the hard data available, certain steps need to be taken in setting up this simulation:

1. Determine the Weibull Distribution parameters
2. Determine the interval schedule to be tested
3. Begin time at zero (a new impellor)
4. Determine the total time run to ensure the 1,000 hour simulation time has not been reached
5. Determine the number of downtime hours associated with the impellor replacement
6. Determine the associated cost of downtime
7. Begin the clock for the next impellor (time old impellor stopped plus time of change out)
8. Repeat the steps until 1,000 hours have been reached
9. Run the Monte Carlo Simulation to determine the mean expected cost

These steps are then repeated for each interval to be tested. In this case the initial intervals to be tested are 50, 60, 70, and 80 hour change out schedule. These are logical choices since the MTTF is 60.6.

After determining the mean expected cost for each interval, a more refined search is completed to try and pinpoint the best interval. The accuracy will only be in five hour increments (i.e. 65, 75, 85 hrs) to keep things simpler. However, it is very easy to pinpoint it down to the hour if that is the individual preference of the unit conducting the simulation.

4.3.1 Results:

Eample run

Cost per hour of down time:	300
Replacement cost:	50
Planned replacement (hrs):	1
Unplanned replacement (hrs):	15
Weibull beta:	1.5533
Weibull eta:	70.0485
Planned replacement schedule:	50

Time	Next failure	Planned Replacement	Under 1k hours	Down time	Replacement Cost	Down time Cost	Total Cost
0	62.9870522	50	y	1	50	300	
51	113.987052	101	y	1	50	300	
102	164.987052	152	y	1	50	300	
153	215.987052	203	y	1	50	300	
204	266.987052	254	y	1	50	300	
255	317.987052	305	y	1	50	300	
306	368.987052	356	y	1	50	300	
357	419.987052	407	y	1	50	300	
408	470.987052	458	y	1	50	300	
459	521.987052	509	y	1	50	300	
510	572.987052	560	y	1	50	300	
561	623.987052	611	y	1	50	300	
612	674.987052	662	y	1	50	300	
663	725.987052	713	y	1	50	300	
714	776.987052	764	y	1	50	300	
765	827.987052	815	y	1	50	300	
816	878.987052	866	y	1	50	300	
867	929.987052	917	y	1	50	300	
918	980.987052	968	y	1	50	300	
969	1031.98705	1019	y	1	50	300	
1020	1082.98705	1070	n	1	50	300	
				Totals:	1050	6300	7350

Expected Total Cost (500 iterations)

Change out <u>Schedule:</u>	Min	Mean	Max
50 hours	$7,266	$46,776	$78,666
60 hours	$23,100	$47,443	$77,000
70 hours	$21,700	$42,044	$63,700
80 hours	$25,900	$46,408	$63,700

Refined search

Cost per hour of down time:	300
Replacement cost:	50
Planned replacement (hrs):	1
Unplanned replacement (hrs):	15
Weibull beta:	1.5533
Weibull eta:	70.0485
Planned replacement schedule:	75

Time	Next failure	Planned Replacement	Under 1k hours	Down time	Replacement Cost	Down time Cost	Total Cost
0	62.98705	75	y	15	50	4500	
77.98705	140.9741	152.9871	y	15	50	4500	
155.9741	218.9612	230.9741	y	15	50	4500	
233.9612	296.9482	308.9612	y	15	50	4500	
311.9482	374.9353	386.9482	y	15	50	4500	
389.9353	452.9223	464.9353	y	15	50	4500	
467.9223	530.9094	542.9223	y	15	50	4500	
545.9094	608.8964	620.9094	y	15	50	4500	
623.8964	686.8835	698.8964	y	15	50	4500	
701.8835	764.8705	776.8835	y	15	50	4500	
779.8705	842.8576	854.8705	y	15	50	4500	
857.8576	920.8446	932.8576	y	15	50	4500	
935.8446	998.8317	1010.845	y	15	50	4500	
1013.832	1076.819	1088.832	n	15	50	4500	
				Totals:	700	63000	63700

Expected Total Cost (500 iterations)

Change out <u>Schedule:</u>	Min	Mean	Max
65 hours	$13,300	$39,575	$59,500
75 hours	$21,700	$44,363	$63,700

In the initial run, the change out schedules that were simulated were 50, 60, 70, and 80 hours. As is evident, the lowest mean was at 70 hours. In order to try to pinpoint where the best schedule laid, a second more refined search was conducted. Since it is not known whether the optimal schedule lay above or below, 70 hours, 65 and 75 hours were run. The second search led to the discovery that the optimal change out schedule for this particular component was every 65 hours. By following this schedule the expected maintenance cost would be minimized. The results could be even further refined to a specific hour if exacting specificity is required. Keeping to a five hour increment, however, is easier to remember and measure and thus more appealing for specific units to incorporate.

Again, if the planned schedule is too short, then the replacement costs go up unnecessarily, if it's too long then the unplanned replacements drive up the total costs. Thus this simulation found the interval that minimized the expected cost.

4.3.2 Computer Simulation Code:

The simulation code used in this methodology, shown below, illustrates how easy and user friendly this methodology and simulation can be. Minimal spreadsheet skills and @Risk training would be all that would be required to use this effectively.

Since @Risk is merely a Microsoft Excel ad-on, the simulation code is very basic. First, the figures for cost per hour of downtime, replacement cost, planned and unplanned replacements, Weibull parameters, and schedule are just input at their desired or previously determined value. Next, each column has the same repetitive code with minor adjustments depending on what row it lies. Broken down by column and for uniformity reasons defaulted to the first row, the code is as follows:

Time: It started at 0, then coded for each row as

=MIN(B13,C13)+E13

Next Failure: Coded for each row as

=A13+RiskWeibull(D7,D8)

Planned Replacement: Coded for each row as (simple addition)

=A13+D9

Under 1k hours: Coded for each row as

=IF(A13<1000," y"," n")

Down time: Coded for each row as

=IF(B13<C13,D6,D5)

Replacement cost: This is taken from the input in the top portion of the spreadsheet. If component costs change, only the corresponding input needs to be changed instead of each individual row.

Down Time cost: Coded for each row as

=E13*D3

5.0 Findings and Recommendations

5.1 Findings:

The linchpin for the success of this methodology is exactly what is missing in the Coast Guard, historical data for systems and components. This lack of data is attributed to poor record keeping. Part of the reason for the poor record keeping could be lack of training, perceived minimal return for the extra work, no specific requirement or guidance available or perhaps not even in existence, or from a more macro perspective, perhaps there was poor strategic maintenance planning. Whatever the reason, a richer, more robust database must be created. Here are some obvious omissions from ISC Alameda's database:

- Only tracking some replacement costs
- No signs of labor tracking at all, not even in terms of time, let alone costs
- Scope of work is at best very vague
- No amplifying information about work after completion
- Thus no opportunity for lessons learned/best practices/root causes

The best way of ensuring that the right information and/or data is being collected and measured is by writing a well thought out and executable standard operating procedures manual (SOP). Additionally, strictly following the guidance provided in the SOP must be enforced to ensure that 100% of all maintenance activity is not only being recorded, but being recorded properly.

In developing this SOP, two overarching mandates must be in place. First, absolutely no work is to be performed without a work order. Secondly, all work orders are to be entered into the maintenance management system/database.

More specifically, listed below is some crucial information that was either completely missing or lacking any useful substance on a consistent basis. This data should be tracked as accurately as possible and incorporated into any future SOP:

- *Type of work:* As much specificity as is available must be recorded in order to truly understand what is requested/required as per the work order. Ten years down the road someone should be able to read and understand, in a very specific sense, the work order request.
- *Work order comments:* Again, as much specificity as is available must be recorded. At a minimum, this section should include what the problem was, what the cause of the problem was if known, and any corrective actions. Additionally, any best practices that were encountered should also be included.

- *Labor:* Tracking labor can help determine which particular system or component is taking up the most labor hours. Obviously some systems require more time than others to fix or inspect so this alone is not an indication of a problem, but it is a place to start looking.
- *Parts:* Any parts associated with the work order need to be recorded. This parts history could be beneficial in identifying possible problem areas and could further be used to determine optimal quantity orders.
- *System downtime:* If a system goes down or is purposefully taken down, the amount of downtime should be tracked. This will help develop what the average downtime of the system should be and hopefully help reduce downtime overall. This could also assist in setting thresholds that when met, a failure analysis will be conducted.

5.2 Data Analysis:

Coast Guard data that would assist in identifying possible systems or components as primary candidates for further analysis and improvement does not exist. The records at ISC Alameda were so incomplete that carrying out such a limited failure indicator analysis was impossible. Breaking the down the available data from ISC Alameda by mechanical, electrical, plumbing, and more specifically boilers, from a purely monetary perspective the breakdown is as follows: (boilers were included individually because they were the only specific component with its own indicator.)

- Electrical - $107,354.90
- Plumbing - $53,582.81
- Mechanical - $40,330.45
- Boilers - $48,923.50 (102 out of 139 (73%))

However, even though there are numbers related to each specific trade (and boilers) they are not very useful. First they are very generic and tell very little. All it tells is how much money was spent by trade in the two years of available data. Secondly, the accuracy of these numbers is called into question. There is no way of knowing what was omitted, what exactly these numbers represent, where they came from, who entered them and why. Furthermore, even with the data that was recorded, none had any associated labor cost or time and the majority had absolutely no cost associated with it at all. Specifically:

- 51.5% of all of the electrical work orders had no associated cost at all. (603 out of 1171 work orders)
- 65% of all of the plumbing work orders had no associated cost at all. (352 out of 545)
- 66% of all of the mechanical work orders had no associated cost at all. (61 out of 92)
- 73% of all of the boiler work orders had no associated cost at all. (102 out of 139)

Once enough data is available, here are the most common failure indicators for ISC Alameda to consider:

- High maintenance cost
- Most emergency work (as per the priority matrix)
- High frequency failure
- High amount of downtime

5.3 Recommendations:

5.3.1 Data gathering Solution: Information Technology

With the need for accurate up to date data being so vital for this methodology and in support of a primary SFCAM objective, technology must be leveraged. Specifically, a system that utilizes bar codes and personal digital assistants (PDA's) to track all pertinent data and inventory should be implemented. In particular, wireless PC compatible PDAs equipped with barcode scanners to organize and control inventory should be considered.

First, every piece of inventory must be accurately accounted for and subsequently bar coded. Each shop must conduct its own thorough inventory and enter it into the Maximo database. Then, each location and parts bin should be labeled with an appropriate barcode.

After the initial inventory and bar-coding is complete, PDA's must be brought on line. First, the software for the PDA's must be compatible with Maximo so that the system can be accessed from anywhere by any maintenance personnel. Next, a wireless network that connects the PDA's to the Maximo system must be established by the servicing Coast Guard Electronic Support Unit (ESU). Lastly, each shop needs to purchase an appropriate number of PC wireless-compatible PDA's and makes them accessible to anyone who will be carrying out any type of maintenance work that day.

Such a system will streamline the work order processes by creating a plant wide wireless network with every PDA having a detailed list of current preventive maintenance and/or work orders. Each shop would then have real-time communication between each PDA and its Maximo management system thus enabling them to implement a truly accurate and paperless process for work orders and inventory control by instantly updating the database.

The process would work as follows. A maintenance staff member picks up a PDA and executes the first work order on the list. He/she needs a part for the work order. They go to the appropriate location for that part, scan the parts bin barcode with their PDA and inventory is immediately updated. Additionally, the work order is no longer active so the next member would take on the next work order. Once the work order is complete, or the work for the day is complete, all other required and/or amplifying information (as per the SOP) that was not entered through the PDA is entered into the system at any computer terminal.

The Army Corps of Engineers (COE) recently implemented a similar system to address a different problem. During the extensive cleanup effort after Hurricane Katrina, the COE realized that a faster, more accurate paperless system needed to be in place to remove large amounts of debris after natural disasters. The COE's research and development center developed a system, *Debris Removal Bar Code*

Tracking Database System, which utilized bar codes and PDA's. (The case study, included as appendix 1, explains this system in greater detail.) While startup costs were roughly $20,000, the system greatly improved the accuracy of all data in the process and significantly reduced the staffing requirements and program costs. In Jackson, MS where this system was successfully beta tested, it saved "an estimated 5,500 hours of labor, or at least $150,000 per month." (US Army COE, 2005).

5.3.2 Implementation strategy

Implementing the methodology presented in this study should produce cost saving measures in the short and long term maintenance operations of not only ISC Alameda but all Coast Guard field maintenance units. However, before this could be implemented the Coast Guard needs to do several things. First, the Coast Guard needs to provide training in Maximo for all field maintenance units. Each Maintenance and Logistics Command (Atlantic and Pacific) should create a Maximo tiger team and schedule training through their perspective areas. A timeline to complete the training should be set with the tiger team charter. Secondly, each MLC should create standard operating procedures that follow the guidelines set forth in the findings section of this document to properly implement this methodology. These standard operating procedures should be incorporated into the Maximo tiger team training. Lastly, once this training has been completed, Headquarters needs to enforce the use of Maximo by every maintenance unit. Once these requirements are met and as SFCAM continues to roll out, this methodology along with the IT data management solutions is highly recommended to be rolled out along with SFCAM. Particularly, this methodology supports the SFCAM initiatives of:

- Leveraging technology to reduce the shore facility maintenance burden, and
- Reinvigorating shore based preventative maintenance.

However, in implementing this methodology the following implementation strategy that takes into account both philosophical and practical issues should be adhered to. Due to the lack of data, at this point, the philosophical issues are more critical. (The record keeping portion for the overall success of this methodology was thoroughly covered in the findings section so it will only be briefly mentioned in this section.)

Philosophical issues:

Theoretical or paradigm shifts

In order for this methodology to be successfully incorporated some sense of "buy-in" must exist. A philosophical shift in the way that the various departments and shops conduct their daily business must be prevalent and must start from the leadership and trickle down. This shift must include an acceptance into wanting to leverage technology and an authentic desire in and accountability for measuring data.

Information and Teamwork

In order to ensure true buy in from the most important folks, the ones that carry out the daily routine, a very successful, direct line of ideas and communications must exist. This methodology will only work if those at the deck plate level have not only a sense of buy in, but one of ownership as well. As such, it is the responsibility of the leadership to clearly delineate and explain the importance for such a change. Of equal importance, the leadership must listen to the “deck plate” for not only best measurement practices but best maintenance practices in general.

Training/Standardization

The critical issue to any new way of doing business is the training piece. A detailed, specific training program must be developed. Both practical hands-on and class room training should be incorporated. Extra emphasis should be placed on the record-keeping and measurement aspect of the process and how to properly enter any and all data into the Maximo database as the degree of success of such a methodology has a very real, direct correlation with the quality and accuracy of the date.

Also emphasized should be the need for a well written scope and work order comments so as to facilitate the evaluation of that same data. It is critical that the standard operating procedures (SOP) to be developed require at a minimum what the problem was, cause of the problem if determined, corrective actions taken, and any recommendations to prevent future failures all be logged. Repetitive failures could then be compared to previous work done.

Additionally, it is essential that the process is standardized across all of the different shops. Following the SOP should help, but the supervisors must ensure that it in fact is being followed.

Lastly, Maximo must be the management system of choice as it is already supported and utilized through all the many layers up through Coast Guard Headquarters so connectivity all the way up to the leadership of the organization is present as is the technical and fiscal support of the system.

Measures of Effectiveness

Just as this methodology relies heavily on measuring, so does its success and validation. Clearly outlined system measures of effectiveness need to be outlined prior to implementation. Some areas of focus (but not limited to) should be as follows:

- Budget measurement (actual versus forecast and historical)
- Overall equipment effectiveness (amount of downtime)
- Maintenance costs (best defined by individual units)
- Parts inventory turnover
- Amount of completed projects
- Backlog levels
- Work order levels broken down by priority level
- Average man hours per work order

- Amount of maintenance rework
- Amount of emergency work

The amount of time and resources devoted to measuring the methodology must be given much thought. Some of the aforementioned issues are more easily measured then others. Ideally, these metrics should be simple to measure but must be effective at the same time.

Practical issues:

In order to successfully implement a simulation methodology the following logic should be followed.

1. Define the system to simulate
2. Define the goals for the simulation
3. Try to identify components and/or subsystems where possible, redefine the system if necessary
4. Represent as best as possible a reliability model of the system taking critical issues into account
5. Introduce time dependency and define system reliability metrics
6. Create the simulation logic
7. Run the simulation
8. Evaluate the results, develop strategy and implement accordingly

The first logical step is to define the system to measure (and eventually simulate). The best way to "optimize" this methodology is to apply it to the systems, sub-systems, and components that can best benefit from it. Because of the vagueness in the scope of the work orders and lack of any other amplifying information it was impossible to tell what specific systems appear to be possible problem areas again highlighting the importance of the first (the philosophical) part of the strategy. Thus, the starting point will be to get the technicians and any other deck plate level members to try and get a sense as to what may be viable candidates. However, being that boilers have their own index code and accounted for nearly $50,000 of maintenance work, it probably should be one system to be considered.

The next step is to define the goals of the simulation. A good starting point could be to minimize expected maintenance costs. However, this does not need to be the case. Other goals could center on increasing operational availability of certain systems and/or components (increasing the MTTF), or try to pinpoint root causes (or failure modes) of systems. In essence the operational and maintenance requirements (or any other shop specific requirements) could help dictate what the goals of the simulation should be.

Next is to break down the system in question to the lowest possible and practical component. This is critical in helping determine a possible root cause for the failure, or at least identifying where the failure is occurring.

Next is what could be the most difficult and critical part; determining what critical factors or issues are at play with the system and/or component in order to define the metrics and ultimately the model. Used in this methodology were replacement cost, labor cost, (which should be rather standard) and miscellaneous downtime costs. But there are other issues, local or otherwise, that need to be identified and could only be identified by those who use and/or work on the various systems. Once a satisfactory logic with critical issues has been determined, then introducing time dependency (or whatever the logic is dependent on) naturally follows.

Lastly, the simulation is run, the results are evaluated and changes are implemented accordingly. Then the changes are measured based on the measures of effectiveness that were previously developed.

5.3.2 Maintenance Related Observations/Recommendations:

1. The Coast Guard needs to move away from reactive maintenance and incorporate some sort of RCM strategy specifically when referring to MEP systems. From a macro perspective, the Coast Guard is headed in that direction, however, not enough work has been done in order to move in that direction with any great sense of urgency. However, operational units can take incremental steps in that direction, this methodology being an example and/or possibility of an incremental step.
2. Operational units should try to standardize their equipment as much as possible. Every system or major component replacement is an opportunity to standardize.
3. Data collection methodologies should be reviewed and reworked as necessary. Ultimately, Coast Guard wide standardization in data collection methodology would be ideal and pay huge dividends by utilizing existing competencies and minimize training among other things.
4. The use of Maximo Enterprises should be enforced. A timetable and usable SOP should be provided by Headquarters and training by the servicing CEU's.

5.3.3 Future Coast Guard Research:

As the Coast Guard moves into completely incorporating Maximo at every level of the Coast Guard maintenance world, a logical area of research is one that develops a process (and SOP) that integrates Maximo with reliability centered maintenance. In particular, the following should be considered.

1. Equipment classification for analysis- determine how the equipment to be analyzed will be classified from system, to sub-system, to component taking into account the existing strategies and tasks from an operational perspective.
2. Failure modes- define the failure modes and their impact on operations, cost, and safety.
3. Criticality ranking- based on the probability and severity of the failure consequence, rank the failure modes.
4. Maintenance strategy- based on the above analysis, determine the optimal strategy for each system or component.

6.0 Bibliography

Books and Publications:

Abernathy, Robert E. The New Weibull Handbook. 2nd ed. North Palm Beach, FL: Abernathy, 1998

Billington, Roy, and Ronald Allan. Reliability Evaluation of Engineering Systems: Concepts and Techniques. 2nd ed. New York: Plenum Press, 1992.

Clemen, Robert, and Terrence Reilly. Making Hard Decisions with Decision Tools. Pacific Grove, CA: Duxbury, 2001.

Dummer, G. W., and R. C. Winton. Elementary Guide to Reliability. 4th ed. Elmsford, NY: Pergamon Press, Inc, 1990.

Eschmann, D., et al, Ball and Roller Theory, Design & Application. London, UK: John Wiley & Sons, 1985

Harris, Tedric A., Rolling Bearing Analysis. New York, NY: John Wiley & Sons, 1984.

Levitt, Joel. A Complete Guide to Preventive and Predictive Maintenance. New York: Industrial Press, 2003.

National Aeronautics and Space Administration. NASA Reliability-centered maintenance Guide for Facilities and Collateral Equipment. February, 2000.

NAVAIR 00-25-403. Guidelines for the Naval Aviation Reliability-Centered Maintenance Process. February, 2001.

Nowlan, F.S. and Heap, H.F. Reliability-Centered Maintenance. San Francisco, CA: Dolby Access Press, 1978.

O'connor, Patrick. Practical Reliability Engineering. 2nd ed. New York, NY: John Wiley and Sons, 1985.

Reliability, Maintainability and Supportability Guidebook. Warrandale, PA: Society of Automotive Engineers, Inc, 1990.

Stewardship of Federal Facilities: A Proactive Strategy for Managing the Nation's Public Assets. Washington, D.C: National Academy Press, 1998.

Winston, Wayne. Simulation Modeling Using @Risk. New York: Duxbury, 1996.

Magazines, Journals, Papers and on-line resources:

Brown, E., 2005. New Roles New Solutions- U.S. Coast Guard's FY06 Programs and Initiatives. Coast Guard Headquarters PPT Presentation to American Society of Military Engineers.

"Comparing Maintenance Strategies Based on Cost and Availability." ReliaSoft-Reliability Edge. Volume 6, Issue 2. 2005. <http://www.reliabilitynews.com/v6i2/maintenance_strategies.htm>

"Enabling the Reliability-centered maintenance Process with MXES." MRO Software, Inc. <http://www.mro.com/corporate/pdf/061506_Finalv2RCM_mxeswp.pdf>

"Facilities Management Resources Best Practices, SFCAM". FMLink: GSA Facilities Maintenance Resource. 2003. <http://www.fmlink.com/ProfResources/BestPractices/article.cgi?gsa:0205d.htm>

Hiatt, Bruce. "Best Practices in Maintenance." Plant Engineering Magazine. Dec 1998. <http://www.tpmonline.com/articles_on_total_productive_maintenance/management/13steps.htm>

Higgs, Phillip, et al. "A Survey on Condition Monitoring Systems in Industry." Plant Maintenance Resource Center. July 2004. <http://www.plant-maintenance.com/articles/CBM-Survey-results.pdf>

Latino, Charles. "Hidden Treasures: Eliminating Chronic Failures Can Cut Maintenance Costs Up to 60%." Plant Engineering Magazine. Nov 1996. <http://www.tpmonline.com/articles_on_total_productive_maintenance/rootcause/hiddentreasure.htm>

"Military Facilities: Coast Guard Island." Global Security.org. Nov 2006. <http://www.globalsecurity.org/military/facility/coast-guard-island.htm>

Netherton, Dana. "Standard to Define RCM." Maintenance Technology on Line. Jun 1999. <http://www.mt-online.com/articles/06-99mm.cfm?pf=1>

O'Hanlon, Terrence. "Reliability by the Numbers." Maintenance Technology Magazine, March 2003.

Perakis, A. N., and Christopher Milkie. "Statistical Methods for Planning Diesel Engine Overhauls in the U.S. Coast Guard." Naval Engineers Journal, Spring 2004: 31-41

"Reliability-centered maintenance: 43 Tonne Crane Case Study." LSC Group. <http://www.lsc.co.uk/downloads/documents/cs-cs-03_RCM_43_tonne_crane.pdf>

"Solving Complex Probabilistic Problems Through Simulation." ReliaSoft-Reliability Edge. Volume 6, Issue 2. <http://www.reliabilitynews.com/v6i2/simulation.htm>

"2001 Maintenance Task Selection Survey Results." Plant Maintenance Resource Center. Sep 2001. <http://www.plant-maintenance.com/articles/pm-survey-01.shtml>

United States Army Corps of Engineers. Debris Removal Bar Code Tracking Database. U.S. Army Research and Development Center. December 2005. <http://www.erdc.usace.army.mil/pls/erdcpub/docs/erdc/images/ERDC_FS_Product_DebrisRemovalDB.pdf>

United States Coast Guard. Facility Condition Assessment Procedural Guidance. 2003. U.S. Coast Guard Shore Facilities Capital Asset Management Division.

United States Coast Guard. Services: Support Summary. U.S. Coast Guard Civil Engineering Unit Miami. <http://www.uscg.mil/mlclant.ceumiami/serv17.htm>

United States Coast Guard. Services: Shore Station Maintenance Program. U.S. Coast Guard Civil Engineering Unit Miami. <http://www.uscg.mil/mlclant.ceumiami/serv2.htm>

United States Coast Guard. White Paper: U.S. Coast Guard Shore Facility Capital Asset Management- Concepts, Strategies and Metrics. U.S. Coast Guard Office of Civil Engineering. April, 2003.

Varuio, J. K. "Availability and Cost Functions for Periodically Inspected Preventively Maintained Units." Reliability Engineering and Systems Safety, Issue 63 1999: 133-140.

Webber, Al. "So You Think You Have the Right Maintenance Program?" Maintenance Technology on Line. Nov 2005. <http://www.mt-online.com/articles/705viewpoint.cfm?pf=1>

E-mail, Software and CD-ROM:

Bevins, Robert (RBevins@comdt.uscg.mil) 2005, *Maintenance Budget* 15 December. Email to: Jorge Martinez (martinezclan1503@msn.com)

The Decision Tools and StatTools Suite including @Risk: Student Edition. Palisade Corporation, Ontario, California: Duxbury, 2001. <http://www.palisade.com/risk/default.asp>

Facility Condition Assessment Space Utility Assessment. CD-ROM, USCG ISC Alameda, Alameda California.

US Army Corps of Engineers®
Engineer Research and Development Center

Product

Debris Removal
Bar Code Tracking Database

Technology

ERDC's Construction Engineering Research Laboratory (CERL) designed and implemented a bar code tracking/database system to replace the hand-written load tickets used in the Corps of Engineers disaster debris removal program. The system consists of a simple and efficient combination of three basic electronic components: (1) a hand-held, ruggedized personal digital assistant (PDA), (2) a battery-operated bar code reader, and (3) a printer. The system operates as follows:

1. When the Corps employee initially measures/certifies the debris truck, a unique bar code is attached to the vehicle placard.
2. When the vehicle reaches the tower at the dump, the employee identifies the vehicle with the hand-held bar code reader.
3. The vehicle's identifying data is automatically displayed on the bar code reader screen.
4. The employee in the tower determines the load in the truck and communicates that information to the employee on the ground.
5. The employee on the ground enters the load on the handheld device.
6. The wireless (Bluetooth) handheld device transfers the ticket information to the printer.
7. The printer prints two copies of each ticket (one for the driver and a second for government records.
8. At the end of the day, the data from the handheld PDA is uploaded to a standard PC on-site, and the results are converted to an electronic data file that can then be e-mailed to a central site for import into the main system.

Problem

Debris removal is a major component of every disaster recovery operation. Every year natural disasters, such as fires, floods, earthquakes, hurricanes, and tornadoes generate large amounts of debris that cause considerable disposal challenges. The large amount of debris caused by Hurricane Katrina in August 2005 highlighted the need to improve paper-based recordkeeping processes used in the Corps of Engineers disaster debris removal program, which relies on load tickets hand-written in the field.

Left to right: the identified Inspector logs the driver and classifies the load in three quick steps.

U.S. Army Engineer Research and Development Center

December 2005
www.erdc.usace.army.mil

Expected Cost To Implement

A representative *Debris Removal Bar Code Tracking Database* (a geographically broad, county-wide, networked system) would cost approximately $20,000, assuming that customer requirements were:

- Equipment (five PDA/printers and one laptop PC) $15,000
- Software implementation (CERL's fee) $ 5,000

Benefits/Savings

The primary advantages of the debris removal bar code tracking database over the traditional paper-based system are that:

1. It greatly improves accuracy of all data in the debris management program by eliminating data transcription errors, redundant data, and discrepancies between contractor and government data.
2. The database system significantly reduces staffing requirements and program cost. During the Hurricane Katrina debris removal effort in Jackson County, MS, the system saved an estimated 5,500 hours of labor, or at least $150,000 per month.

Status

The *Debris Removal Bar Code Tracking Database* system has been successfully Beta-tested in New Orleans, LA during the Hurricane Katrina cleanup, and can be easily adapted and applied to other similar applications.

ERDC POC(s)

Stephen Hodapp	217 373-7228	Stephen.E.Hodapp@erdc.usace.army.mil
Tad Britt	217 373-7288	Tad.Britt@erdc.usace.army.mil
Lance Marrano	217 373-4465	Lance.R.Marrano@erdc.usace.army.mil
Timothy Isaacs	217 373-4468	Timothy.J.Isaacs@erdc.usace.army.mil

Distribution Sources

The *Debris Removal Bar Code Tracking Database* system is available on request from the listed ERDC-CERL POCs. CERL can provide basic customization to suit customer needs as part of the "software implementation" mentioned above.

Available Training

Formal training has not yet been authored for this Beta-tested product. However, classroom or field training can be made available through the listed ERDC-CERL POCs, on a reimbursable basis.

Available Support

Corps customers may request support for this beta-tested product (e.g., data base customization or hardware configuration to suit customer needs) on a reimbursable basis through the listed ERDC-CERL POCs.

Appendix 2: Web Based Survey

Simulation

Survey

Please fill out this form to the best of your ability. This is completely confidential so please be honest.

Please provide the following contact information:

Name

Title

Organization

E-mail

Your experience in the Coast Guard (years):

(Select one)

Your experience in Engineering (years):

(Select one)

Please describe what components you have chosen.

Please explain why you have chosen these components.

What is the approximate replacement cost for each component?

What is the associated cost per hour of down time for each component?

Appendix 2: Web Based Survey

What is the average time spent on a planned replacement for each component?

What is the average time spent on unplanned replacements for each component?

Please list your change out schedule for each component that is not run til failure.

Please list any historical failure information?

May I contact you with follow up questions?

(Select one)

Submit Form | Reset Form | Submit Query

Appendix 3: ISC Alameda Background

A more detailed background on ISC Alameda as provided by Global Security.

> Coast Guard Island is in the Oakland Estuary between Oakland and Alameda. The 68-acre island is situated in the historic Brooklyn Basin, now known as Embarcadero Cove. It is within the Alameda city limits, however, and only accessible via Campbell Boulevard in Oakland. The Island supports a number of government facilities, including the Pacific Commander Station (U.S. Coast Guard District Eleven), an industrial service center, the San Francisco Marine Safety Office, a training center for reserve and enlisted coast guard personnel (class-rooms), living quarters, four 378-foot long high-endurance cutters, a medical and dental clinic, and public works facilities to service the island (i.e., sewage treatment, wastewater treatment).
>
> Originally known as Government Island, this artificial island was formed in 1913 by the dredging project that extended the Oakland Estuary to San Leandro Bay. The Coast Guard first came to the island in 1926 when it established Base 11. An Executive Order signed in September 1931 gave title to a 15 acre tract for a permanent base. Improvements were started at that time and by 1933 included streets, utilities, spur tracks, a trestle bridge from Oakland, a transformer station, and rebuilding of the existing wharves. The cost was more than one and a half million dollars and provided facilities for Base 11 and the Coast Guard Store (warehouses).
>
> The shore establishment expanded in 1939 with the amalgamation of the Lighthouse Service. A training center was established in 1940 to meet the service's increased personnel needs.
>
> Thirty-five acres were acquired from the city of Alameda in 1939 with an additional 17 acres purchased by the Coast Guard in 1942. The entire island of 67 acres was devoted to training center facilities. The first contract awarded February 21, 1942, provided for five barracks, mess hall and galley, engineering and administration buildings, an infirmary, roadways, heating, plumbing, electrical and fire protection. The contract was completed June 30, 1942 at a cost of $1,680,082.94. Additional contracts for another half million dollars provided for additional barracks, clothing issue building, paving a drill field, band room, incinerator, anti-aircraft trainer building, and docks for small boats.
>
> The training center was first opened in June 1, 1942 with accommodations for 900 men. It was solely to train recruits. Specialty training was added later to include fireman, signalman, laundryman, radioman, boatswain's mate, cooks and bakers, and volunteer port security.
>
> After the war Government Island remained a Coast Guard Training Center with addition of the Weather Bureau, Internal Auditors, and the Bureau of Roads. During the late 1960's the Training & Supply Center was the Coast Guard's largest field unit on the West Coast. The Training Center graduated 60-100 seaman and fireman apprentices each week. The Supply Center provided support to the western area districts including Squadrons One and

Three in Viet Nam. The cutters TANEY, GRESHAM, and BARATARIA were homeported at the island.

In 1982 the Training Center was closed and recruit training was accomplished exclusively at Cape May, NJ. Support Center Alameda was established June 1, 1982 and the island was renamed Coast Guard Island. The Pacific Area Command, Twelfth Coast Guard District, and Marine Safety Office San Francisco Bay moved from downtown San Francisco to the island. On June 24, 1987 the Maintenance & Logistics Command Pacific was established and located on the island. The Support Center was redesignated as Integrated Support Command Alameda on March 15, 1996.

The City of Alameda, incorporated in 1884, is an island community located in the heart of Northern California's San Francisco bay. Alameda is home to Coast Guard Island and Alameda Point (formerly Naval Air Station Alameda) which is 2800 acres, comprising 1/3 of the city's area and is being developed as an important source of new businesses, jobs, housing, recreational facilities, community and cultural services. A significant portion of the City of Alameda is devoted to parks, shoreline, marinas and beaches.

Appendix 4: Sample Data- Electrical shop

tblWorkOrder

Prio	Buildi	Request	Bra	Cost
4		Perform Ec Cape Mendocino Dgps Battery Upgrade	4	
2	549	Install "shore Power" 3-phase (+neutral & Ground) Power In Hanger 1 For New Comm	4	
4	549	Remove Old And Install New Battery Chargers At Dgps Sites Pt. Loma, San Diego, Ar	4	
2	549	Install A Battery Back-up Power Supply For Group San Francisco's Hf Radio At Pt. Bo	4	
3	488	Request Ind Ems Tap Into Sandblaster Power Supply And Run Conduit Inside Of Sand	4	$0.00
3	488	Provide Power Of 120 Volt Ac From Sandblasting Power Supply And Run Conduit And	4	
3	359	Two Phases Of Three Have Failed On Coast Guard-owned Portable Makita Generator	4	
1	549	Replace Power Cabling To Power Mound One; Rec.1,2 Power Mound Two; Rec. 1,2,3	4	
2	665	Troubleshoot And Resolve Loss Of 440v Power On Berth 1 Receptacles 1 And 2. Wo	4	
2	665	Repair/replace/troubleshoot And Make Operational All Power To Cgc Pier North Side.	4	
3	488	Provide One 120 Volt Ac Outlet With 20 Amps And 4 Receptacles From The Power Su	4	
3	549	Cgi Building # 5 Electricl Rehab Temp Gen- Set, Install New Gen Set Up-grade Electri	4	
4	549	Install A Battery Back-up Power Supply □□Address: Pt. Bonita	4	
4	549	Install New Conduit As Needed And Secure Along Concert Retaining Wall. Provide (d	4	
5	466	Remove Existing Gen-set Procure And Install New Emergency Generator Up Grade E	4	
3	549	Install Outlets As Discussed For Buoy Depot. Sand Blaster Tent.	4	
3	368	Need A Grounding Rod Placed For A Ready Service Pyrotechnics Locker And A Meta	4	
4	665	Estimate Cost To Repair/replace Power Cable To Power Mounds South End Of Cgi Pi	4	
3	665	Install Transformer Onbd Sherman.	4	
3	359	Bldg. 15 Has Inadequate Power To Supply Tools & Equipment. Request New, Larger,	4	
2	665	Replace Approx 150 Feet Internal Shore Tie Cable Onbd Cgc Sherman Per Casrep 05	4	
4	549	Replace/install New Conduit/drill Access Hole/disconnect Electrical/remove Hut From :	4	
2		A Hot Wire (120v) Was Exposed During A Recent Digging Project. Poc Cannot Seem	4	
5	448	Need Additional Electrical And Switchable Sipr/nipr Drops, 8 Total, 4 On The North, 4	4	
3	468	Electrical Plug-in Broken And Hanging Off The Wall. Potential Safety Hazard.	4	$0.05
3	549	Repair Hot Broken Electrical Wires And Install New Crissy Box & Conduit As Needed.	4	
3	453	Request Isc Industrial Procure And Install Conex Box In Conjunction With Bay 51-3 Re	4	
3	549	Install foundations for Six Video Cameras At Six Remote Locations And Network Equip	4	
4	549	Install Electrical Hot Water Heater Bldg. 5a Head. Make Operational. Lead Shop Indu	4	
3	342	Need To Install Electrical Service To An Additional Temporary Office Space Behind Bl	4	
4	549	1. Remove Landline & Poles As Environmental Mitigation Effort Between The Old Rad	4	
4	549	Conduct Ir Survey & Correct Discrepancies Or Submit Work Order As Appropriate On	4	
4	488	Install 2 lights that are already purchased that require 115 Volt AC along with conduit a	4	
4	553	Replace paramiter lighting on the Eagle Rd. side of medical and behind bldg 10	4	
3	531	Relocate light pole located at the main gate entrance. Move to new location in front of	4	
3	549	VTS building equipment room provide 6 electrical circuit from UPS service panel to equ	4	
3	549	Install 6 electrical circuits from the UPS service panel to eqpt racks. Identify existing cir	4	
4	549	The flat orange trailer has several lighting problems, such as a broken turn signal/brak	4	$0.00
3	492	Provide up-lighting to new palm trees to be installed on Campbell Blvd. Coordinate wit	4	$0.00
3	665	Test shore-tie electrical cables for grounds & open conductors. Remove and/or replac	4	$0.00
3	359	Deliver Ditch Witch mdl 3500 trencher to Ditch Witch for repairs to engine.	4	$0.00
4	599	POC is installing some new equipment in the radio vault near the Pt. Reyes lighthouse	4	########
3	549	Remove buried sub cable from VTS site 1 each Fab 7' ladder sections. Anacortis, WA	4	########
3	359	Troubleshoot and repair an electric vehicle. This is a secondary mode of transportatio	4	$0.00
4	549	Assemble exterior light post for Admiral's house.	4	$0.00
4	359	Relocate 3 receptacles by the welding booths.	4	$0.00
4	549	Relocate receptacles in Housing office.	4	$0.00
4	593	Install as requested lighting, tower, dehumidifier, fire alarm @ site. Funded 02/21/06 $	4	$0.00
3	492	Assist in determining status of H.V. wire tht could impact project scheduled.	4	$0.00
3	599	This work was estimated on Service Request Form 37565 The microwave radio vault r	4	$0.00

Page 1

Appendix 4: Sample Data- Electrical shop

tblWorkOrder

3	0	Request ISC Electrical run a new GFI receptical to the outside of our station laundry fa	4	$0.00
3	0	Request ISC Electrical install new lighting in station's BEQ rooms, training room, mess	4	$0.00
3	342	INSTALL ELECTRICAL SERVICE TO OFFICE SPACES. FUNDED 3/15/06 2/6/601/1:	4	$300.00
3	596	Request the assistance with pulling DB cable on-site through possibly collapsed condu	4	$0.00
3	665	COST ESTIMATE TO POWER UP POWER REEL LOCATED ON THE NORTH END (	4	$0.00
3	448	Core drill the hole in wall larger as required.	4	$0.00
4	549	Request ISC Electrical install new lighting fixtures on the roofs of the Engineering Shop	4	$0.00
4	549	Requesting Industrial EM shop to Troubleshoot firepump on Station Rio Vista boat doc	4	$0.00
4	549	Request that ISC Industrial EM shop remove faulty firepump and install new one.	4	$0.00
3	549	request industrial em's investigate electrical system in laundry and berthing areas for C	4	$0.00
3	342	Request to install a conduit between Building 10 and new sub trailer (10b), so that pho	4	$0.00
4	359	Request the Following Spaces to be Painted in the Engineering Building. Office Space	4	$0.00
3	448	I need to have to existing holes in an interior concrete wall made larger to accommoda	4	$0.00
3	341	Buoy Depot has 2 Explosion Proof Fans that were ordered for the Paint Tent due to Ve	4	$0.00
3	341	Un-Wire Deadman Switch which is 2 Counductor 16 Gauge SEOW Wire from Soleoid	4	$0.00
3	434	There is a hut within the MLCP(t) portion of bldg. 42 (northeast corner). This hut has p	4	$0.00
4	549	Request assistance with wiring 03 emergency lights. Lights are mounted just need to b	4	$0.00
4	448	install 4in. conduit with j box	4	$0.00
4	549	wire 5 space heaters in various locations	4	$0.00
4	549	replace exterior lighting fixture 10ea. with energy efficient lighting and add 1ea receptic	4	$0.00
4	342	INSTALL CONDUIT FROM CGI BLDG. 10 TO THE WSS TRAILER FOR COMPUTER	4	$800.00
4	488	Request Industrial EM's (EM1 Donovan and WG-10 Apollo) come over to the Buoy D	4	$0.00
3	532	Call box for Station Golden Gate's front gate was hit by a vehicle bending the bottom p	4	$0.00
4	368	In the auto hobby shop two lights are needed in the main office and the new air compr	4	$0.00
4	673	Need one 1 and 1/2 inch pipe installed at Novato Housing office, ground floor from the	4	$0.00
4	368	Installation of two overhead light fixtures with one switch, and two outlets in the office.□	4	$0.00
4	549	Quarters A&C electrical panel upgrade to include emergency generator plug for emerg	4	$0.00
4	633	Radio Equipment Room□□□□Description of Work to be performed: Add three each 2(	4	$0.00
4	549	Mt. Tamalpais Radio Vault Room□□□□Description of Work to be performed: Add thre	4	$0.00
4	549	Mt. Diablo Radio Vault Room□□□□Description of Work to be performed: Add six each	4	$0.00
4	549	Station Rio Vista Room□□□□Description of Work to be performed: Add three 20 amp	4	$0.00
4	453	Add six each 20 amp 120 VAC circuits	4	$0.00
5	430	Install emergency generator, provided by Facilities. Scope of work will include, concret	4	$0.00
5	341	Construct concrete slab to permanently mount emergency generator out side of Medic	4	$0.00
3	359	Install covered and safer lighting in our office space.	4	$0.00
3	434	There is a hut within the MLCP (t) portion of bldg 42 (northeast corner) the hut needs a	4	$0.00
4	617	GOOD MORNING, REQUEST INSTALLATION OF FLOODLIGHT IN THE VICINITY C	4	$0.00
4	617	GOOD MORNING, REQUEST VERIFICATION OF LIGHTING/WIRING/HARDWARE I	4	$0.00
4	359	Replace Existing Light Fixture with New Light Fixture on Separate Branch Circuit. Relc	4	$0.00
4	617	REQUEST REMOVAL OF EXISTING WALL MOUNT HEATER IN STATION GYM AN	4	$0.00
4	385	Install new receptacle for freezer, possible new circuit and conduit.	4	$0.00
4	455	REPLACE TWO (2) 2.5 TON AC UNITS WITH 7 TON UNITS. FUNDED 08/02/06 $8K	4	$0.00
4	617	REQUEST REMOVAL OF WALL MOUNTED HEATER AND WIRING IN THE DC SHC	4	$0.00
4	617	REQUEST ADDITIONAL ELECTRICAL OUTLETS BE INSTALLED IN ALL BEQ/DUTY	4	$0.00
4	549	PERFORM ADDITIONAL NEEDED CAMERA WORK F/VTS SAN FRANCISCO AND '	4	$0.00
4	0	THERE IS AN OPENING FROM INSIDE THE TOWER AT GROUND LEVEL UNDER	4	$0.00
4	617	Install 6 New Electrical Outlets f/Microwave Radio System Funded 08/24/06 26601133	4	$300.00
4	456	Install 3 New Electrical Outlets f/Microwave Radio System. Funded 08/24/06 2660113:	4	$0.00
4	517	REPAIR/REPLACE MAKE OPERATIONAL HELO LANDING LIGHTS NORTH END O	4	########
4	617	REQUEST ELECTRICIANS HARD WIRE NEW AIR COMPRESSOR IN MAIN ENGINI	4	$0.00
5	549	Location of work to be performed: 1106□□Room # at work location (if applicable): Lea	4	$0.00

Page 2

Appendix 4: Sample Data- Electrical shop

tblWorkOrder

3	0	Request ISC Electrical run a new GFI receptical to the outside of our station laundry fa	4	$0.00
3	0	Request ISC Electrical install new lighting in station's BEQ rooms, training room, mess	4	$0.00
3	342	INSTALL ELECTRICAL SERVICE TO OFFICE SPACES. FUNDED 3/15/06 2/6/601/1:	4	$300.00
3	596	Request the assistance with pulling DB cable on-site through possibly collapsed condu	4	$0.00
3	665	COST ESTIMATE TO POWER UP POWER REEL LOCATED ON THE NORTH END (	4	$0.00
3	448	Core drill the hole in wall larger as required.	4	$0.00
4	549	Request ISC Electrical install new lighting fixtures on the roofs of the Engineering Shoj	4	$0.00
4	549	Requesting Industrial EM shop to Troubleshoot firepump on Station Rio Vista boat doc	4	$0.00
4	549	Request that ISC Industrial EM shop remove faulty firepump and install new one.	4	$0.00
3	549	request industrial em's investigate electrical system in laundry and berthing areas for C	4	$0.00
3	342	Request to install a conduit between Building 10 and new sub trailer (10b), so that pho	4	$0.00
4	359	Request the Following Spaces to be Painted in the Engineering Building. Office Space	4	$0.00
3	448	I need to have to existing holes in an interior concrete wall made larger to accommoda	4	$0.00
3	341	Buoy Depot has 2 Explosion Proof Fans that were ordered for the Paint Tent due to Ve	4	$0.00
3	341	Un-Wire Deadman Switch which is 2 Counductor 16 Gauge SEOW Wire from Soleoid	4	$0.00
3	434	There is a hut within the MLCP(t) portion of bldg. 42 (northeast corner). This hut has p	4	$0.00
4	549	Request assistance with wiring 03 emergency lights. Lights are mounted just need to b	4	$0.00
4	448	install 4in. conduit with j box	4	$0.00
4	549	wire 5 space heaters in various locations	4	$0.00
4	549	replace exterior lighting fixture 10ea. with energy efficient lighting and add 1ea receptic	4	$0.00
4	342	INSTALL CONDUIT FROM CGI BLDG. 10 TO THE WSS TRAILER FOR COMPUTER	4	$800.00
4	488	Request Industrial EM's (EM1 Donovan and WG-10 Apollo) come over to the Buoy D	4	$0.00
3	532	Call box for Station Golden Gate's front gate was hit by a vehicle bending the bottom p	4	$0.00
4	368	In the auto hobby shop two lights are needed in the main office and the new air compr	4	$0.00
4	673	Need one 1 and 1/2 inch pipe installed at Novato Housing office, ground floor from the	4	$0.00
4	368	Installation of two overhead light fixtures with one switch, and two outlets in the office.	4	$0.00
4	549	Quarters A&C electrical panel upgrade to include emergency generator plug for emerg	4	$0.00
4	633	Radio Equipment Room□□□□Description of Work to be performed: Add three each 2(	4	$0.00
4	549	Mt. Tamalpais Radio Vault Room□□□□Description of Work to be performed: Add thre	4	$0.00
4	549	Mt. Diablo Radio Vault Room□□□□Description of Work to be performed: Add six eacl	4	$0.00
4	549	Station Rio Vista Room□□□□Description of Work to be performed: Add three 20 amp	4	$0.00
4	453	Add six each 20 amp 120 VAC circuits	4	$0.00
5	430	Install emergency generator, provided by Facilities. Scope of work will include, concret	4	$0.00
5	341	Construct concrete slab to permanently mount emergency generator out side of Medic	4	$0.00
3	359	Install covered and safer lighting in our office space.	4	$0.00
3	434	There is a hut within the MLCP (t) portion of bldg 42 (northeast corner) the hut needs a	4	$0.00
4	617	GOOD MORNING, REQUEST INSTALLATION OF FLOODLIGHT IN THE VICINITY C	4	$0.00
4	617	GOOD MORNING, REQUEST VERIFICATION OF LIGHTING/WIRING/HARDWARE I	4	$0.00
4	359	Replace Existing Light Fixture with New Light Fixture on Separate Branch Circuit. Relc	4	$0.00
4	617	REQUEST REMOVAL OF EXISTING WALL MOUNT HEATER IN STATION GYM AN	4	$0.00
4	385	Install new receptacle for freezer, possible new circuit and conduit.	4	$0.00
4	455	REPLACE TWO (2) 2.5 TON AC UNITS WITH 7 TON UNITS. FUNDED 08/02/06 $8K	4	$0.00
4	617	REQUEST REMOVAL OF WALL MOUNTED HEATER AND WIRING IN THE DC SHC	4	$0.00
4	617	REQUEST ADDITIONAL ELECTRICAL OUTLETS BE INSTALLED IN ALL BEQ/DUT'	4	$0.00
4	549	PERFORM ADDITIONAL NEEDED CAMERA WORK F/VTS SAN FRANCISCO AND '	4	$0.00
4	0	THERE IS AN OPENING FROM INSIDE THE TOWER AT GROUND LEVEL UNDER	4	$0.00
4	617	Install 6 New Electrical Outlets f/Microwave Radio System Funded 08/24/06 26601133	4	$300.00
4	456	Install 3 New Electrical Outlets f/Microwave Radio System. Funded 08/24/06 2660113:	4	$0.00
4	517	REPAIR/REPLACE MAKE OPERATIONAL HELO LANDING LIGHTS NORTH END O	4	########
4	617	REQUEST ELECTRICIANS HARD WIRE NEW AIR COMPRESSOR IN MAIN ENGINI	4	$0.00
5	549	Location of work to be performed: 1106□□Room # at work location (if applicable): Lea	4	$0.00

Page 2