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THESIS

A LOGISTIC LIFE CYCLE COST-BENEFIT ANALYSIS OF POWER QUALITY MANAGEMENT IN THE AVIONICS REPAIR FACILITY

by

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June 1998

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Our research identifies potential savings of $1.5 million from reduced test bench maintenance costs and productivity increases, and recommends the DOD institutionalize the use of power quality management.

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A LOGISTIC LIFE CYCLE COST-BENEFIT ANALYSIS OF POWER QUALITY MANAGEMENT IN THE AVIONICS REPAIR FACILITY

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ABSTRACT

The objective of this research is to investigate the impact that power quality management can have on the intermediate level of maintenance. Power quality management is a preventative process that focuses on identifying and correcting problems that cause bad power. Using cost-benefit analysis we compare the effects of implementing a power quality management program at AIMD Lemoore and AIMD Fallon. The implementation of power quality management can result in wide scale logistical support changes in regards to the life cycle costs of maintaining the DOD's current inventory of sensitive electronic equipment. Power quality management provides logisticians the opportunity to reduce maintenance costs, reduce maintenance cycle times, and improve fleet operational availability.

Our research identifies potential savings of $1.5 million from reduced test bench maintenance costs and productivity increases, and recommends the DOD institutionalize the use of power quality management.

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I. INTRODUCTION

A. BACKGROUND

"Naval Forces have five fundamental and enduring roles in support of the National Security Strategy; projection of power from the sea to land, sea control and maritime supremacy, strategic deterrence, strategic sealift, and forward naval presence." (*Forward, From the Sea*) The Navy and Marine Corps require reliable weapon systems to meet these missions. For the logistician this means fielding systems that are reliable and economically supportable for the system's programmed life cycle. Operating in today's fiscally constrained environment the logistician is challenged to develop systems that provide superior mission performance as well as safety and reliability at reduced costs.

The Navy and Marine Corps have to recognize these budget realities. They must be innovative in finding methods to make the best utilization of scarce funding resources while retaining fleet readiness and capabilities. One area in which they can conserve funds is through reducing the cost of maintaining Automatic Test Equipment (ATE). Due to its complexity, ATE is often taken for granted by the fleet sailor. When used in testing equipment the ATE is considered to work or to be faulty. This classification is declared without any regard for external factors, for example, the quality of the electrical power supplying the ATE.

The study of electrical power supplying ATE provides an opportunity for the DOD to conserve funds. Presently, there are no electrical power quality standards within the Department of Defense (DOD), particularly in the case of defining acceptable power inputs and grounds. Poor power quality input and the improper grounding results in high variability of voltage, current, and frequency deviations supplying equipment. Due to these lack of standards there is little understanding of the complexity of the problems being encountered at the customer level. The lack of power quality standards has led to the degradation and ultimate failure of Automatic Test Equipment within the Naval Aviation Systems Command (NAVAIRSYSCOM). As a result NAVAIRSYSCOM customers are burdened with increased equipment maintenance costs due to higher failure rates, personnel safety concerns, and unrealized decreases in operational availability. The implementation of power quality management practices presents an unexplored process improvement for NAVAIR and the DOD.

B. RESEARCH OBJECTIVES

The Aircraft Intermediate Maintenance Departments (AIMD) at Naval Air Station Lemoore (NAS Lemoore) and Naval Air Station Fallon (NAS Fallon) have been actively pursuing power quality management since 1995. This research will analyze the cost and benefits of applying electrical power quality management to the AIMD repair process at NAS Lemoore and NAS Fallon. For this thesis the Radar Station Test Set (RSTS), a piece of ATE at AIMD Lemoore, will be studied to determine maintenance costs, resulting cycle time reductions, and any resulting improvements to product quality. Additionally, the maintenance costs of ATE at NAS Fallon AIMD will be studied.

C. REVIEW OF PREVIOUS RESEARCH

This thesis is a continuation of work previously conducted by Valdyke (1998) in the area of power quality management. Using cost-benefit analysis he focused on the direct and indirect savings attributable to power quality management at AIMD Lemoore. His research quantified the reduced maintenance costs associated with a single piece of ATE, the AN/USM-470(V)1 Automatic Test Set, located within AIMD's 650 work center. Further, indirect savings were shown in the reduction in the average Turn Around Time (TAT) of components repaired on the ATS benches.

In our research, we try to generalize the results shown in Valdyke (1998). A separate piece of ATE used in a different work center at AIMD Lemoore will be studied to validate Valdyke's results. Additionally, this research will quantify improvements to product quality as a result of power quality management. Finally, AIMD Fallon will be studied to determine if power quality management savings are achievable military wide or if they are unique to AIMD Lemoore.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The scope of the research in this thesis is limited to a cost-benefit analysis of implementing power quality management at the AIMDs at NAS Lemoore and NAS Fallon. However, the logic and methodology used can be applied to any DOD organizations.

Cost-benefit analysis is an analytical technique that details the expected positive and negative effects of a given proposal. Once the expected benefits and costs of a proposal are thoroughly identified and delineated, the next step is to place a value on each benefit or cost. These expected costs and benefits are expressed in numerical or monetary terms to facilitate a comparison of the aggregate costs and benefits. Once all relevant factors are translated into monetary terms, the decision rule is to accept the proposal if its aggregate benefits exceed its aggregate costs. (GAO/HEHS, 1997)

Cost-benefit analysis, as applied in this research, will compare the maintenance processes and costs before and after the implementation of a power quality management program. To perform this comparison, the processes and associated costs will be baselined and measured against the resulting changes from initiation of the program. The measured outputs will be limited to ATE maintenance costs, reduced cycle time, and quality improvement.

The lack of sufficient data did limit this research to some extent. While sufficient data was available at NAS Lemoore and all of the above outputs are measured, at NAS Fallon the lack of sufficient data did limit this research. The cost-benefit analysis as applied to NAS Fallon will be limited to ATE maintenance costs. The data required to properly measure cycle time and quality improvement was incomplete and of insufficient quantity.

E. THESIS ORGANIZATION

This thesis is divided into six chapters including this Chapter I introduction. Chapter II provides an overview of the Naval Aviation Maintenance Program. Chapter III is an explanation of what power quality management is and the effects that poor grounding has on ATE. Chapter IV provides the data collection techniques and methodology used during the cost-benefit analysis performed on NAS Lemoore. Chapter V is an analysis of the results. Finally, Chapter VI will provide a summary with clear and concise conclusions and recommendations.

II. NAVAL AVIATION MAINTENANCE PROGRAM

A. NAVAL AIRCRAFT MAINTENANCE PHILOSOPHY

Navy and Marine Corps maintenance, guidance, and objectives are set forth in OPNAV Instruction 4790.2G, Naval Aviation Maintenance Program (NAMP). The NAMP's objective is "…to achieve and continually improve aviation material readiness and safety standards,…, with optimum use of manpower, material, and funds." (OPNAVINST 4790.2G) To achieve this objective the primary philosophy of the NAMP is to repair equipment and material at a level of maintenance which ensures the optimum economic use of resources. The methodology for achieving the spirit and intent of the NAMP objective is called performance improvement. The Chief of Naval Operations (CNO) provides specific performance improvement objectives for all echelons in the CNO strategic plan. In this plan the CNO calls upon naval aviation to "Identify the best practices and procedures of individual activities and implement them at other activities when feasible and cost effective…." (OPNAVINST 4790.2G) The implementation of power quality management at all levels of maintenance can support these objectives.

B. MAINTENANCE CONCEPTS AND LEVELS

In general terms, a maintenance concept describes the overall system support environment in which a system is to exist and sets the baseline for specific logistic support requirements. A maintenance concept delineates: anticipated levels of maintenance; repair policies; organizational responsibilities for maintenance; major elements of logistic support; effectiveness requirements associated with system support; and the maintenance environment. (Blanchard, 1992)

The Navy's maintenance concept is delineated in the NAMP. The NAMP splits naval maintenance into three distinct levels: organizational (O), intermediate (I), and depot (D). The division of maintenance into three levels allows management to easily classify maintenance functions by levels, assign maintenance functions to specific levels, consistently assign maintenance tasks, accomplish maintenance tasks at a level that ensures optimum economic use of resources, and allows for the collection of data for easy analysis (OPNAVINST 4790.2G). The following is a detailed description of the three levels of maintenance.

1. Organizational Maintenance

O-level maintenance is performed at the operational site by maintenance personnel assigned to the aircraft reporting custodian. The mission of O-level maintenance is to maintain aircraft and aeronautical equipment in a full mission capable status while improving their local maintenance process. Maintenance at this level is normally limited to inspections, servicing, handling, on-equipment corrective and preventative maintenance, incorporating technical directives, and record keeping. Personnel at the O-level normally do not repair removed components but forward them to an AIMD. From a maintenance standpoint, the O-level is thought of as the lowest and simplest level of maintenance. (OPNAVINST 4790.2G)

2. Intermediate Maintenance

I-level maintenance activities are established to provide both direct and indirect support for the O-level. At this level components may be repaired by removing and replacing major modules, assemblies, or piece parts. The I-level also performs calibration, manufactures parts not available through the supply system, provides technical assistance to using organizations, and performs on-aircraft maintenance when required. Maintenance personnel at this level are often better trained and utilize more complex test equipment not available to the O-level. I-level maintenance for the Navy is performed by Aircraft Intermediate Maintenance Departments ashore and afloat. In the Marine Corps I-level maintenance is performed by the Marine Aviation Logistics Squadron (MALS). AIMDs are the primary focus of this thesis, and are discussed in greater detail in subsequent sections. (OPNAVINST 4790.2G)

3. Depot Maintenance

D-level maintenance is the highest level and supports the O-level and I-level to ensure flying integrity of airframes and flight systems. Maintenance at this level includes the complete overhaul, rebuilding, and calibration of aircraft, engines, components, and support equipment. The D-level also supports the lower levels of maintenance by providing engineering assistance and technical training to maintenance personnel at the lower levels. Although not specifically studied in this thesis, the D-level uses the same type of ATE as the I-level. For this reason the D-level is a prime candidate for power quality management. (OPNAVINST 4790.2G)

C. AIRCRAFT INTERMEDIATE MAINTENANCE DEPARARTMENTS

The goal of the AIMD is to enhance and sustain readiness of user activities by providing high quality and timely direct and indirect support with the lowest practical expenditure of resources. An example of AIMDs direct support is work done on parts and equipment the squadron sends to the AIMD. Some examples include the testing and checking of avionics equipment, Non-Destructive Inspections (NDI), and the manufacturing of hydraulic lines. An example of AIMD providing direct support to squadron operations is the AIMD's Support Equipment (SE) pool. A significant amount of AIMD's effort is in indirect support. This type of support consists of repairing non-ready-for-issue (NRFI) repairable aircraft parts and equipment. Most of the items that an AIMD repairs are placed in the air station Supply Department's inventory. Squadrons then draw replacements from this inventory.

1. Locations

I-level support is accomplished at AIMDs both ashore and afloat. Aircraft carriers and amphibious ships have AIMDs to support shipboard aircraft operations, and naval air stations are located throughout the United States and the world to support aircraft operations ashore. There are 81 Navy AIMDs, and 34 MALS and MALS detachments operating throughout the world (NSLC 4790.A7065-01, 1996).

The focus of this thesis is on the power quality management programs at AIMD Lemoore, California and AIMD Fallon, Nevada. AIMD Lemoore is one of two major AIMDs that support the F/A-18 aircraft; the other is the AIMD at NAS

Cecil Field, which is located in Jacksonville, Florida[1]. AIMD Fallon is a smaller AIMD supporting the F/A-18 aircraft operating from NAS Fallon. Unlike AIMD Lemoore, which operates from a fixed structure, AIMD Fallon operates from Mobile Maintenance Facilities (MMFs). A MMF is a habitable, relocatable, and tactical purpose van that is designed to provide environmental control and to contain equipment and functions in support of aviation weapon systems maintenance. MMFs are used to augment permanent facilities ashore or afloat and in lieu of facilities when permanent facilities should not be constructed.

2. AIMD Repair Cycle

Naval Air Station Supply Departments (or "Supply") maintain an inventory of Ready for Issue (RFI) repairable aircraft parts to quickly meet the requirements generated by a squadron. This inventory is referred to as the rotable pool. AIMD capabilities and productivity are critical factors in maintaining the rotable pool depth to meet the requirements of the squadrons. The following discussion explains the basic procedures for repairing and processing non-RFI components.

The repair flow begins when a squadron orders a replacement item and turns in a non-RFI item to the Supply

[1] NAS Cecil Field is presently scheduled for closure. The support of the FA-18 on the East Coast will transfer to AIMD Oceana, Virginia.

Department's Aviation Support Division (ASD). If available, ASD will issue the squadron a RFI item from its pool. ASD will then assign a repair priority to the non-RFI item and pass the part to the Aeronautical Material Screening Unit (AMSU).[2] Accompanying the defective part will be a Maintenance Action Form (MAF). This form is used to document the discrepancy and all repair actions made to the component. AMSU screens the component and enters all the appropriate data, to include the received date, into NALCOMIS.[3] The defective component is then forwarded to the applicable work center for repair. The work center supervisor receives the component, screens the MAF, and assigns a worker to the maintenance action. When the worker begins working on the component the in-work date and time are annotated on the MAF. If during the repair process the worker decides that replacement parts are required to effect the repair the worker will annotate the required material blocks of the MAF with the required parts. These parts are then placed on order through the Supply Department. As with

[2] The repair priorities are: Priority 1, or Expeditious Repair (EXREP), which is assigned when there are no replacements items in the pool; Priority 2 which is assigned to items that have dropped below a specific depth; and Priority 3 which is assigned to items that have inventory levels above the specific depth.

[3] NALCOMIS is a computer information system that tracks all maintenance actions within an AIMD. Once entered into NALCOMIS the MAF is updated via computer terminals within the AIMD.

all actions the order and received dates are annotated on the MAF for record keeping purposes. Once maintenance is completed, the worker marks the MAF as job complete and awaits a Collateral Duty Inspector (CDI) to inspect the work. Once inspected the Work Center Supervisor reviews the MAF and then notifies AMSU that the component is RFI and ready for pickup. The component is then delivered to the Component Control Section (CCS) where it is staged in the rotable pool for future use by a squadron. The completed MAF is reviewed by the Maintenance Database Administrator/Analyst and then forwarded to the Data Services facility (DSF) for inclusion in the Naval Aviation Logistic Data base (NALDA).

3. AIMD Funding

AIMDs, through the air station, receive two major types of funds. The fund categories related to I-level maintenance are 1) Aviation Fleet Maintenance (AFM) fund, and 2) Aviation Depot Repairable (AVDLR) fund. AFM funds are primarily used to purchase consumable parts such as gaskets, screws, rivets, and diodes. AVDLR funds are used to purchase repairable components for repairable items, such as circuit cards, engine rotor assemblies, and ATE modules. AIMDs receive AFM and AVDLR funding from their Type Commander, such as Commander Naval Air Forces Atlantic (COMNAVAIRLANT). The Type Commander gets these funds based on the type of aircraft they support. The Type Commander then apportions these funds to air stations based on the type of aircraft that they support, and on the projected operations tempo.

D. NAVAL AVIATION AND POWER QUALITY MANAGEMENT

Electricity, or power, is the lifeblood of Naval Aviation. There is virtually no piece of equipment located at the O, I, or D levels of maintenance that does not depend on electricity in some form. Without electricity the maintenance productivity of an AIMD, for example, would be zero. With electricity there is productivity but one question remains: Is it good power or bad power? Bad power results in equipment malfunctions and equipment down time. Power quality management focuses on identifying and correcting problems that cause bad power. This process is a best practice that is feasible, cost effective, and one that meets the CNO's performance improvement objectives. Power quality management provides naval aviation maintenance managers the opportunity to increase ATE availability. By increasing ATE availability additional benefits will be realized. Some of these benefits include reduced repair cycle times, decreases to AFM and AVDLR maintenance expenditure costs, increases in fleet operational availability, and improvements in quality of life (e.g., increased leave/liberty and additional time for military/professional training).

III. POWER QUALITY MANAGEMENT

A. OVERVIEW OF POWER QUALAITY

Facility and equipment acquisition costs are minuscule in comparison to the life-cycle maintenance costs associated with their ownership. One of these costs stems from problems associated with poor power quality. Depending on who you are talking to, the term power quality has many different meanings. The Power Company will describe power quality in terms of reliability, the equipment manufacture in terms of the power supply, and the customer in terms of power efficiency. Power quality means: "… a consistent undistorted voltage available to all of your equipment …". (Power Quality Assurance Online, 1996) A power quality problem is "Any power problem manifested in voltage, current, or frequency deviations that result in the failure or misoperations of customer equipment". (Electrotek, 1998)

Today the managers and leaders in the civilian and military are well-trained in accounting, marketing, economics, logistics, and the use of statistical process control. However, they are not trained in power quality management nor do they give it consideration. These leaders need to understand that power quality management can provide them with a competitive advantage. To gain this competitive advantage and make power quality management a priority this program needs allocated resources. By instituting a power quality management program a company can "... benefit from savings in operations expenses (energy savings, reduced repair costs, reduced labor, longer equipment life) to increased productivity and customer satisfaction". (*PQ Today*, 1996) The following is a brief description of the common causes of power quality problems and methods that can be used to implement a power quality program.

1. Grounding

Improper grounding is the cause of numerous power problems for high technology equipment and, more importantly, is a serious safety hazard. The main problem with a improperly grounded facility or its equipment is it creates voltage potential differences between the equipment and the power source. Thus the main reason for grounding is to eliminate the voltage potential difference. There are three requirements for a proper ground: 1) to provide a low-impedance path for the return of fault currents, so that an overcurrent protection device can act quickly to clear the circuit, 2) to maintain a low potential difference between exposed metal parts to avoid personnel hazards, and 3) Overvoltage control (IEEE Std 1100, 1992). A ground is formed by a direct wire connection to a grounding electrode which is buried in the earth, or by a connection to some other conductive metallic element which is connected to a grounding electrode (*NEC Handbook*, 1987). Based on this definition there are two types of grounding: 1) Wiring system grounding, and 2) Equipment grounding. A wiring system ground consists of grounding one of the wires of the electrical system to limit the voltage upon the circuit which might occur through exposure to lightning or other higher voltages. An equipment ground is a permanent and continuos bonding together of all noncurrent carrying metal parts of equipment enclosures, boxes, cabinets, and the connection of this interconnected system to the system's grounding electrode. Both of these grounds must be properly installed and maintained for safety reasons and equipment reliability. "If care and attention are given to the grounding of a facility and the equipment within the facility, then the facility will take care of you: Ignore the facility and equipment grounding and the grounding gremlins will take care of you!". (*PQ Today*, 1997)

2. Harmonics

The phenomenon of harmonics has been known for some 40 years, however, until recently it has not been given much attention. Electricity in its purest state is a perfect sinusoidal waveshape, or a linear load. The equipment of yesterday all operated in a linear load. Today's equipment, by contrast, has changed the load characteristics of the electricity. Most of today's equipment contains a static power rectifier. The static power rectifier is a devise built within a piece of equipment which conducts current for part of a cycle through multiple paths in order to convert alternating current (AC) to direct current (DC), and the reverse (Power Quality Online, 1996). Harmonics then are "sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate". (IEEE Std 519, 1995) Harmonics are non-linear loads. The mere presence of harmonics is not a problem, but when harmonic currents interact with impedance in the distribution system it creates voltage distortion losses. When voltage distortion arising from harmonic currents become excessive then equipment malfunctions begin to occur (PQ Today, 1995). Examples of equipment that use a static power rectifier and thus create harmonics, are microwave ovens, laser printers, stereos, televisions, electronic lighting, personal computers, and ATE. One way to reduce or eliminate harmonics is through the use of harmonic filters. Types of filters on the market include line-reactors, passive harmonic filters, active harmonic filters, electronic feedback filters, and specialty transformers (Power Quality Online, 1996).

3. Methods for improving Power Quality

The best place to start improving power quality is through an aggressive education and training program. The Institute of Electrical and Electronic Engineers has published numerous recommended practices that address power quality monitoring, grounding, and harmonics.[4] By fully understanding these practices and then implementing them an organization can benefit from optimum facility and electronic equipment operations and ensure all safety codes are installed as specified in the National Electrical Code (NEC).

The basic premise of power quality management is preventative in nature. The first thing that should be done is a facility power quality survey. This survey should check the mechanical condition of important electrical circuits and equipment. Depending on the criticality of the facility this type of survey should be conducted on a scheduled basis (Holm, 1998). The second is power quality monitoring. Before implementing a monitoring program clear and concise objectives must be defined. These objectives will help in determining the choice of monitoring equipment, the method of data collection, data analysis techniques, and

[4] The IEEE recommended practices are the IEEE Std 1100 Powering and Grounding Sensitive Electronic Equipment, IEEE Std 1159 Monitoring Electric Power Quality, and IEEE Std 519 Harmonic Control in Electrical Power Systems.

the level of effort required. Additionally, monitoring should account for the tolerances of the various equipment needs so they can be matched with the monitored results. Monitoring will provide the baseline and database required to allow for system improvements. Finally, any time the facilities electrical system is altered, equipment is moved or added to a facility, or the monitoring results show problems, a thorough power quality investigation should take place to ensure power problems are eliminated. (IEEE 1159, 1995)

B. POWER QUALITY AT UNITED AIRLINES MAINTENANCE OPERATIONS CENTER

Seeking to compare and contrast the Navy's power quality management practices with a commercial facility, we toured the United Airlines Maintenance Operations Center. The Maintenance Operations Center is located in San Francisco at the San Francisco International Airport. The Maintenance Operations Center is the primary United Airlines component repair center, running two daily shifts repairing approximately 20,000 line items. The tour concentrated on the Avionics Maintenance Division where a general knowledge of the United Airlines repair processes and power quality problems was acquired. Although United Airlines uses two levels of maintenance: Organizational level (flight line), and Depot level (Maintenance Operations Center), the repair of avionics equipment in the Avionics Maintenance Division is very similar to that used in an AIMD. Technicians troubleshoot and repair a variety of aircraft components using specialized test equipment.

The Maintenance Operations Center does not have any formal program or group that is tasked to monitor power quality at their facility. While this may be the case, the Avionics Maintenance Division is practicing power quality management in numerous ways. The first example of their effort was a facility inspection that occurred two years ago. During this inspection the facilities electrical system was checked to ensure it complied with NEC. From this inspection they found that all but one of their maintenance work centers, a special clean room, was properly grounded. It should be noted that in this clean room they have implemented special precautions while awaiting a permanent grounding fix. The second and perhaps the biggest example of their practicing power quality comes in their efforts to ensure equipment grounds are proper. Due to the wide variety of equipment that is repaired and increases in technology, the Maintenance Center has a wide range of test equipment. This equipment ranges from older units to its newest piece of ATE, the ATEC 5000. Although their efforts were somewhat reactive at first, the center now constantly questions and looks for problems that may stem from equipment grounding. Their first encounter with equipment grounding occurred when they started noticing erratic *go, no go* test results on one of their older Honeywell test benches. Upon investigation they found that the benches had grounding problems. The center modified the benches by adding a grounding well bus that allowed all components to be bonded together. After modifying the bench all erratic testing ceased. The centers newest piece of ATE, the ATEC 5000, had similar problems. The company currently owns three of these benches. All of these benches had to be modified by adding individual grounding straps to allow each component to have a single point ground. As a result of United Airlines findings, the manufacture of the bench has changed the design specifications and incorporated this type of grounding on all new models.

Other forms of power quality management were observed at the Maintenance Center as well. Whenever any major work is performed on a bench or the benches are relocated, all grounding is checked to ensure it is in compliance before the bench is placed in operations. Additionally, their technicians and engineers constantly monitor test results and look for any variations in *go, no go* results. While touring the facility it was brought to my attention that they are currently trying to pinpoint one specific piece of equipment that erratically fails a very low resistance test on the ATEC 5000. Although not yet certain they think the results may be due to grounding.

An important difference between United Airlines and the Navy is that United Airlines does have electrical engineers on site that are power quality experts. These engineers are in constant touch with the technicians and can quickly investigate any abnormalities.

C. POWER QUALITY IN THE NAVY

Power quality management in the Navy is rooted in inter-service stovepipes. There are experts in the air community, experts in the surface community, and experts at the naval facilities command. These experts are primarily tasked with ensuring new weapons systems are properly designed and engineered to meet the requirements of that program. Once the weapon system is fielded power quality management is neglected. In addition, the equipment is installed in facilities that are maintained by another organization, the base Public Works Department. In most naval stations, the Public Works Department generally lacks the equipment or time to accomplish full-blown power quality management practices.

Upon reviewing DOD and Naval directives on power quality we found them to be inconsistent and vague. To fully understand and be in compliance with the military's program a base would need to weed through numerous directives. These directives include the Military Handbook for Grounding, Bonding, and Shielding for Electronic Equipment and Facilities (MIL-HNBK-419A), the Military Standard for Grounding, Bonding, and Shielding (MIL-STD-188-124B), the Naval Facilities Engineering Commands, Inspection of Shore Facilities (NAVFAC MO-322), the National Electrical Safety Code (NFPA-70), and various other supporting instructions and directives issued by type commanders, wings, and squadrons. These instructions and directives are very clear on the installation of equipment and facilities but are vague on upkeep and maintenance.

On the positive side, the Navy does have expertise in the field of power quality management and has put it to good use. Unfortunately, this expertise is limited to specific commands and tasks.

1. Electrical Power Interface Compatibility Team

The Electrical Power Interface Compatibility (EPIC) Team is a Naval Air Systems Command (NAVAIR) sponsored team of experts who are tasked to analyze power discrepancies within the NAVAIR claimancy. This team is involved in all decisions involving the electrical design, modification, and upkeep of aircraft and the test equipment used to maintain aeronautical parts. This team of experts has had a profound impact on the initial design of the electrical systems on both the aircraft and its test equipment. However, once these systems are in the field, the EPIC team's expertise is not used to its fullest potential. This occurs because of two basic reasons. 1) A command having electrical problems must request an EPIC inspection. In most cases the command is not aware it is having electrical problems, therefore they fail to request the inspection. 2) The EPIC team's travels are limited due to fiscal constraints. (Preissman, 1998)

2. Pre-Deployment Electrical Power Survey Inspection Program

The Pre-Deployment Electrical Power Survey and Inspection (PEPSI) program was established in 1988 and is overseen by the Fleet Technical Support Center, Pacific. This program was established in an effort to reduce repair costs while a ship is deployed. The purpose of this survey is to determine electrical power quality and isolate problems in the 60 and 400 hertz power systems feeding vital equipment loads. A PEPSI is scheduled prior to a ship deployment to identify and correct problems in an effort to increase combat readiness during deployments.

The PEPSI program has been of great success to Pacific Fleet Aircraft Carriers. The program has resulted in many electrical system design changes as well as providing valuable training to the fleet. Additionally, data from the PEPSI team's monitoring has proven that power disturbances aboard a ship do cause damage to electronic equipment. (Fleet Technical Center, 1996)

3. Power Quality at AIMD Lemoore

Power Quality Management at AIMD Lemoore was established after they moved in to a new building addition and noticed an alarming increase of ATE failures. These failures were attributed to numerous causes until the building's electrical ground was inspected and diagnosed as faulty. At its infancy the program was informal at best with education and training of personnel being its main focus. As the program matured AIMD Lemoore conducted electrical power distribution self-audits and hired independent contractors to survey the building's electrical system.[5] The self-audits and the surveys conducted by the contractors revealed many electrical safety hazards to include missing grounding cables, interior grounding cables routed improperly, missing neutral grounding straps, and inappropriate neutral-ground bonds in panels and equipment. Most of these problems are consistent with problems found in the civilian industry with the exception of the inappropriate neutral to ground bonding. According to Lyncole Technical Services "this is the number one problem that we encounter during military surveys". (Holm, 1998)

[5] Winzler & Kelly Consulting Engineers conducted a survey in May 1996 and Lyncole Technical Services conducted a facility assessment inspection in April 1997.

This type of bonding presents a huge noise problem because it puts 180 hertz harmonics on the grounding circuit (Holm, 1998). Many, but not all, of these hazards relate directly to the grounding of the AN/USM-470(V)1 ATS in the avionics repair shop, work center 650 (Valdyke, 1998). In addition to the above findings, in January of 1997, they found that the AN/APM-446 Radar Station Test Set (RSTS), located in work center 63D, had the neutral/ground connection mis-wired. This problem was later identified as a wire-coding problem that occurred during the bench manufacturing and resulted in a Support Equipment Bulletin (SEB) to correct the problem fleet-wide. (McClelland, 1995)

4. Power Quality at AIMD Fallon

AIMD Fallon's power quality program started after they too became alarmed by the number of ATS maintenance problems they were encountering. Being located relatively close to AIMD Lemoore, AIMD Fallon had heard of the success that AIMD Lemoore had with its power quality management program and requested a NAESU Technical Assist to help diagnosis these problems. The NAESU employee, who was involved in AIMD Lemoore's power quality management program from its onset, accomplished this technical assist.

The technical assist identified numerous equipment and Mobile Maintenance Facility (MMF) grounding problems. Among the problems noted were multiple grounded neutrals, missing ground bonding straps, MMFs grounded to aircraft tie-down fittings vice grounding rods, undersized neutral conductors and ground conductors, and cable service panels that had neutral conductors bonded to the chassis of the vans. All of the MMF electrical problems were corrected in accordance with applicable directives. Additionally, all of the ATE systems were tested to insure their internal power distribution system components were in proper condition. (McClelland, 1997)

IV. DATA COLLECTION AND METHODOLOGY

A. INTRODUCTION

This chapter will discuss the methodology and data used to measure the costs and benefits of implementing a power quality management program at AIMD Lemoore and AIMD Fallon.

B. DATA COLLECTION

1. Aviation Maintenance Material Management (3M) Data

Aviation Maintenance Material Management data was collected from the Naval Aviation Logistic Data Analysis (NALDA) phase I data set-up system. The data contained all Visual Information Display/Material Action From (VIDS/MAF) record type formats (Record Types A - Z) that where processed by AIMD Lemoore from the period of January 1996 to December 1997, and AIMD Fallon from the period of January 1997 to September 1997.

The data was converted from "text" into a Microsoft Access database to arrange and sort the data properly. Once the data was sorted it was imported into Microsoft Excel for statistical calculations.

2. Level of Repair Analysis Default Data Guide

The Level of Repair Analysis Default Data Guide is a NAVAIRSYSCOM sponsored guide that is used to calculate the value of parameters used in naval aviation. This guide provides two types of data element numbers, those that are "Established" and those that are "Forecast". Data elements that are "Established" are set by Navy policy and directives. Data elements that are "Forecast" may vary from system to system. For "Forecasted" elements the guide provides an average value that should cover most systems. Table 4-1 lists the default parameters used in this study. It should be noted that all parameters used in this study are "Forecast" parameters.

Default Data Parameters	
Discount Rate	7%
Labor Rate-Land Based Military (Avionics)	$22.33/hr.
Work Week-Land Based Military	32 hrs./wk.
Training Cost-One Man	$935.67/wk.

Table 4-1 LORA Default Data Parameters

C. COSTS OF PERFORMING POWER QUALITY MANGEMENT

The cost of implementing a power quality management program at AIMD Lemoore and AIMD Fallon have been primarily "in-house" costs. With the exception of two external surveys conducted by civilian contractors at AIMD Lemoore all of the labor has been provided by sailors and a NAESU employee.

The easiest costs to quantify are the costs attributable to the surveys. The survey conducted by Winzler & Kelley cost approximately $25,000. The cost of the survey conducted by Lyncole Technical Services was $6,000. (Valdyke, 1998) These costs are included because they identified problems that had an effect on AIMD Lemoore's electrical system.

A cost must also be assigned for the work performed by the NAESU employee. The NAESU employee assigned to NAS Lemoore is tasked to provide technical assistance to all AIMDs both ashore and afloat on the Pacific Coast. In this capacity his role is to advise and train military personnel in the performance of their duties. His role in implementing the power quality management programs at both AIMD Lemoore and AIMD Fallon was carried out in this capacity. However, his time spent on power quality management actions was time that could have been spent on other training functions. For this reason, an estimated opportunity cost will be assigned to time spent on power quality actions. For the purposes of this study the estimated opportunity cost will be determined by multiplying the hourly wage for a GS-11 by the number of hours spent directly working on power quality issues related to the RSTS bench. The cost to train the NAESU employee should also be accounted for since this was time that took him away from his primary duties. Since he did not attend any formal power quality schools this cost is hard to quantify. He is a trained avionics expert so most of the additional training he obtained was self-taught by reading manuals, obtaining material from the internet, and talking to other power quality experts. For the purposes of this study it is estimated that he spent approximately two weeks of his time on this type of training. Using the parameters from the Default Data guide the cost to train him would equate to $1871.34.

The last cost and the hardest to quantify is the cost of the sailors in the AIMDs. The time spent by sailors inspecting, training, and troubleshooting power quality problems was not documented and therefore unavailable. While it is safe to say that this time could have been spent on the repair of components, in training, or on liberty, this lost opportunity cost was indirectly measured. The lost opportunity cost was accounted for because the work the sailors performed was during the same time period of the analysis. This labor investment by the sailors is accounted for by the cost of the lost productivity in the same period.

D. BENEFITS OF PERFROMING POWER QUALITY MANAGEMENT

This analysis quantifies three main cost activities at AIMD Lemoore and AIMD Fallon. These activities are used to measure the benefits resulting from their power quality management program. The first is the cost of maintaining the AN/USM-446 Radar Station Test Set (RSTS) at AIMD Lemoore and the cost of maintaining all avionics benches at AIMD Fallon. The second benefit is the effect on cycle time. The third is the effect on the quality of the components being tested on the RSTS bench.[6]

1. Bench Maintenance Savings

The cost of maintaining the RSTS bench at AIMD Lemoore is easily accomplished by comparing the costs of maintaining the bench prior to the repair of the grounding problem against the cost of maintaining the bench after the repair. For the RSTS bench the data used was for the period of 1 January 1996 to 30 September 1997, with the division between these dates being midnight on 31 December 1996. Since the 1997 data only accounted for nine months, the costs were

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[6] The second and third benefits are only measured for AIMD Lemoore due to insufficient data being available to properly study AIMD Fallon.

averaged to represent a full 12-month period. These cost were measured by sorting the Aviation Maintenance Material Management data by the benches Work Unit Code (WUC), SWDF, and Date Completed. Once sorted the Total Price of all components ordered to repair the bench was summed for each period.

The cost of maintaining the benches at AIMD Fallon was derived in the same manner as described above. The data used in determining these costs was for the period of 1 January 1997 to 30 September 1997, with the division between the dates being 1 June 1997. Again, the data was averaged to ensure the totals represented the same unit of time.

2. Effects on Maintenance Cycle Time

To measure the effects that power quality management had on the maintenance cycle time, the maintenance downtime (MDT) of the five components repaired on the RSTS test bench was measured before and after the changes were implemented.[7] Since LDT and ADT can constitute a major element of total maintenance downtime (MDT), these time elements were removed from this study. Removing these elements ensured that the mean active maintenance time, $\overline{M}$, was the primary measure used to measure the effect that power quality management had

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[7] Maintenance downtime (MDT) constitutes the total time to repair a component to full operating status. MDT includes mean active maintenance time ($\overline{M}$), logistic delay time (LDT), and administrative delay time (ADT).

on the maintenance cycle time. Once $\overline{M}$ was calculated for the two periods, the two populations were compared against each other using a hypothesis test know as the pairwise *t* test.

The pairwise *t*-test is one of two methods of hypothesis testing used with dependent samples. The desire is to directly estimate difference between two population means. For dependent samples, $\overline{D}$ is an unbiased estimator of $\mu_1 - \mu_2$. Thus, $\overline{D}$ can be used as a point estimate of the difference, or to construct a confidence interval for the difference. To estimate the difference between two population means requires five steps. (Glenberg, 1996) These steps are outlined below.

a) Step 1: Assumptions

There are three assumptions that must be satisfied to use the pairwise *t*-test. The first is that the two samples must be dependent pairs. By using the same five components in a before and after design this assumption is satisfied. The second is that the two populations are obtained using independent random sampling. The five components, listed in Appendix A, used in this study are independent and were chosen because the RSTS bench only tests these five specific components. The third assumption is that $\bar{D}$ is normally distributed. This assumption would be satisfied if the sample size is large enough. To determine this the population D values were plotted using a histogram. Appendix B contains these histogram plots of the D values and shows they are normally distributed.

b) Step 2: Set the Confidence Level, 1-α

The confidence level, denoted by $1-\alpha$, is the probability that the null hypothesis is not rejected when in fact it is true and should not be rejected. The probability of committing a type I error, denoted by α, is referred to as the level of significance. The level of significance is decided by determining the risk level α that one is willing to tolerate in terms of rejecting the null hypothesis when it is in fact true. Small values of α increase the probability that the interval includes $\mu_1 - \mu_2$. However, as α decreases to a small value (e.g., .01) there is an increased risk of committing a type II error. A type II error occurs when the null hypothesis is not rejected when in fact it is false and should be rejected. This study utilized an α value of 5 percent (α=.05) to ensure a high confidence level and to reduce the risk of committing a type II error.

c) Step 3: Obtain the Random Samples

AIMD Lemoore work center 63D houses the RSTS bench that is used to repair the five components of the F/A-18 radar. This study selected these components from the period of 1 January 1996 to 30 December 1997. The populations were then divided by separating them on 31 December 1996. The populations are then defined as 1 January 1996 to 31 December 1996 and 1 January 1997 to 31 December 1997. The data was assembled in fields that were used to build the sample statistic. The fields included the in-work date and time, completed date and time, and total supply time. By utilizing these database fields the sample statistic was limited to the actual time it took to repair a component on the RSTS bench. We are unsure whether there is any awaiting maintenance time that could have taken place between the time the component was placed in work and completed. The data to track this awaiting maintenance time is tracked by the 3M system; however, this data field was blank for all samples. We could not determine whether this was an error in the database or if there was not any awaiting maintenance time documented. For the purposes of this study we assumed that there was not any awaiting maintenance time. Thus the test statistic is limited to strictly the time required to repair and restore the component to a full operating status, or $\overline{M}$.

d) Step 4: Construct the Interval

The formulas for the limits are:

$$\text{Lower Limit} = \bar{D} - S_{\bar{D}} \times t_{\alpha/2}$$

$$\text{Upper Limit} = \bar{D} + S_{\bar{D}} \times t_{\alpha/2}$$

$t_{\alpha/2}$ is the value of the t statistic with n-1 degrees of freedom that has $\alpha/2$ of the distribution above it. Thus the $1-\alpha$ confidence limit is:

$$\text{Lower Limit} \le \mu_1 - \mu_2 \le \text{Upper Limit}$$

where:

$$D_i = X_{1,i} - X_{2,i}$$

X_1 and X_2 are the random variables that have mean μ_1 and μ_2.

$$\bar{D} = \frac{\sum_{i=1}^{n} D_i}{n}$$

$$S_D = \sqrt{\frac{\sum_{i=1}^{n} D_i^2 - \frac{\left(\sum_{i=1}^{n} D_i\right)^2}{n}}{n-1}}$$

$$S_{\bar{D}} = \frac{S_D}{\sqrt{n}}$$

n = number of pairs of observations in the sample

The quantities of the component repaired are not constant across the five components. Failing to appropriately weigh the summation of the D and D^2 values for the actual presence of each component in the system would unfairly bias the resulting interval. For this reason, each D and D^2 value was counted in their summations on a one to one proportional basis with the quantity of the components repaired during the two-year period. This weighting results in D and D^2 values based directly on the 2538 components repaired among the five different type of components run on the RSTS bench.

e) Step 5: Interpretation

The probability is 1-α that the interval includes the real difference between the population means. In other words, the probability is .95 that the calculated interval contains the true difference between the two populations. Since an α of .05 was selected there is a .05 probability that the interval does not include the real difference between the population mean, but that probability is very small. While a smaller α value (e.g., .01) would increase the probability that the interval does include the real difference, the cost is a wide confidence interval. A wide confidence interval does not help pinpoint the value of the difference, and increases the chance of committing a type II error.

The resulting interval is represented in units of days when computed. This unit of days represents the total elapsed time required to repair and restore a component to a full operating status. To make this a more meaningful measure this interval is converted to a dollar amount by multiplying the unit by the appropriate cost of labor. This cost will then be the basis for determining the effect power quality management has on maintenance cycle time reduction.

3. Effects on quality output

The quality of the component being issued RFI was measured to see what effect, if any, power quality management has on quality. If the quality was improved this of course would be a benefit; if it degraded it would be a cost. The two measures of quality that were selected were the supporting squadrons "Y" code rates, and the mean time between failures (MTBF) of the components repaired.

a) "Y" Code Rates and Quality

A "Y" code is a "when discovered code" that is placed in block 58 of the VIDS/MAF. This code is used by organizational squadrons to document a component that is received from supply in a non-RFI status. For a component to be "Y" coded it must fail its maintenance operational check upon installation in the aircraft. There are many reasons for an item being "Y" coded. The component can be broken in storage or transit, passed on by the AIMD as RFI when in fact an undetected fault still exists, or is unknowingly damaged upon installation by the organizational level. The RSTS bench is highly sensitive to electrical currents, therefore, the "Y" code rate was studied to determine if power quality management had an affect on the probability of a component passing a test on the bench when in fact it was bad.

A before and after comparison of the "Y" code rates was used to determine if there was a significant shift in the rate. The data used for this analysis was for the period of 1 January 1996 to 31 December 1997. The cut-off date was 31 December 1996. This analysis was based on all five components that are tested on the RSTS bench. The data was obtained by using the 3M database and sorting the data based fields on the when discovered code. All VIDS/MAFs with a "Y" code in block 58 of the VIDS/MAF were totaled for each period. This number was then used to determine the total "Y" code percentage for each period. The following formula was utilized for these calculations:

$$\text{Percent "Y" code} = \frac{\#\ \text{"Y" codes}}{\text{Total}\ \#\ \text{Repairs}}$$

The fact that an item is "Y" coded does not always mean the component is in fact faulty. Poor trouble-shooting by the organizational level can lead to "Y" codes and result in an unfair bias against the AIMD. To ensure that this bias was removed, the malfunction code, block 36, of the VIDS/MAF was studied. A malfunction code of "A799" indicates that the component was tested on a bench by an AIMD and determined to have zero defects. Any component that was "Y" coded and later determined to be "A799" was not counted against the AIMD as a valid "Y" code.

b) MTBF and Quality

MTBF is a reliability factor that is used to determine the frequency of maintenance. The frequency of maintenance for a component is highly dependent on the reliability of that component. In general, as the reliability of a system increases, the frequency of maintenance will decrease, and as the reliability of the system decreases, the frequency of maintenance will increase. To determine if power quality management had an effect on the MTBF of components, a before and after comparison was made of the five radar components tested by the RSTS bench. A comparison of MTBFs over time does not strictly isolate the effect that power quality management has on components. Other factors such as modifications can drastically change the MTBF of a component. For this reason every attempt was made to ensure that the components selected would not have other factors that would bias the results.

Strike Fighter Squadron 125 (VFA-125) was chosen from the available organizational squadrons that operate from NAS Lemoore for this analysis. VFA-125 is the F/A-18 training squadron for the Pacific Coast and operates approximately 42 F/A-18 aircraft. As a training squadron VFA-125 is permanently based at NAS Lemoore. VFA-125 does send detachments to aircraft carriers and other shore bases for student training, however, these detachments are supported by parts pack-up with the non-RFI retrograde being returned to AIMD Lemoore. Therefore, VFA-125 was the ideal candidate of study to determine if power quality management had an effect on MTBF of the F/A-18 radar components.

The 3M system was used to collect the data for this analysis. The analysis was based on data from the period of 1 January 1996 to 31 December 1997. The cut off date was 31 December 1996. All five components tested on the RSTS bench were included in this analysis. The data was obtained by sorting the data base fields on VFA-125 organization code (PE4) and the five different radar WUCs. This sort determined the total number of failures that VFA-125 had for each component during the selected periods. For these same periods, VFA-125's total flight hours were calculated. These two numbers were then used to compute the rate at which failures occur in a specified interval, or the failure rate. The failure rate (λ) is expressed as:

$$\lambda = \frac{\text{Number of failues}}{\text{Total Flight Hours}}$$

The failure data for VFA-125 consisted of all failures to include those failures due to primary defects of the component, failures due to manufacturing defects, and failures due to operator and maintenance errors. The failure rate was then used to determine the MTBF for the selected radar components. MTBF can be calculated as:

$$MTBF = \frac{1}{\lambda}$$

MTBF was then studied to determine what affect power quality management had on the reliability of the five radar components.

V. ANALYSIS OF THE RESULTS

A. INTRODUCTION

This chapter will present the costs and benefits attributable to the implementation of power quality management at AIMD Lemoore and AIMD Fallon. The first part of this chapter will present the costs incurred by both AIMDs. The second part of this chapter will show the benefits that have been gained at AIMD Lemoore and AIMD Fallon. The cost and benefits will then be presented together to summarize the total effect that power quality management has had on each AIMD. Finally, the costs and benefits of this study will be combined with those presented in Valdyke (1998) to show the net effect the program has had on the budget of the Commander, Naval Air Forces Pacific Fleet.

B. COSTS

1. Costs at AIMD Lemoore

The cost of implementing power quality management at AIMD Lemoore has come from four primary sources. The first is from their contracting outside experts to perform electrical power surveys of the AIMD facilities. The second cost is the estimated opportunity cost assigned to the NAESU employee. The third quantifiable cost is the cost of training incurred to fully understand and become an expert in power quality management practices. The final cost is the opportunity cost of AIMD personnel performing self-audits and repairing the discrepancies in the facility. These costs, while not presented here, are accounted for in the measures of change of productivity. Table 5-1 lists these costs and their present values as of 1 June 1998.

Description	Date	Cost	Present Value (6/98)
Winzler & Kelley Inspection	May-96	$25,000	$28,946
Lyncole Inspection	Apr-96	$6,000	$6,987
NAESU Rep Cost	Jan-97	$976	$1,080
NAESU Rep Training	Jan-95	$1,871	$2,371
Total Present Value (discount rate:7%):			$39,384

Table 5-1 AIMD Lemoore Costs

2. Costs at AIMD Fallon

The costs of implementing power quality management at AIMD Fallon come from two sources. The first cost that must be accounted for is the cost of training. The second is the cost of performing audits and repairing the equipment. Since there were not any measures of productivity changes studied at AIMD Fallon these costs must be assigned. The time to survey and then make the necessary repairs to AIMD Fallon's MMFs took 14 days (McClelland, 1997). It is estimated that it took two sailors and the NAESU employee to perform these tasks. Using the default parameter defined in

Chapter IV these costs were then computed. Table 5-2 presents these costs and their present values as of 1 June 1998.

Description	Date	Cost	Present Value (6/98)
NAESU Rep Cost	Apr-May 97	$10,931	$11,696
NAESU Rep Training	Jan-95	$1,871	$2,371
Personnel Costs	Apr-May 97	$20,008	$21,408
Total Present Value (discount rate:7%):			$35,476

Table 5-2 AIMD Fallon Costs

C. BENEFITS

Three primary benefits were derived from the implementation of the power quality management programs. The first benefit was the reduced cost of maintaining the test benches at both sites. The second and third benefits were only studied at AIMD Lemoore. These benefits were the reduction in the average TAT of components repaired on the RSTS bench and the resulting improvement in the quality of the components repaired by the RSTS bench.

1. Test Bench Maintenance Savings

a) AIMD Lemoore Savings

Power quality management was implemented at AIMD Lemoore due to abnormally high failure rates on its test benches. To determine the effect that power quality management has on the failure rate of the RSTS bench a before and after comparison of test bench maintenance costs was quantified. After the repairs were made to the RSTS bench, test bench maintenance costs dropped 65 percent. Table 5-3 displays the costs to repair the RSTS benches and the number of repairs made each year.

Year	# Discrepancies	Total Cost of RSTS Repairs	Present Value (6/98)
1996	134	$247,811	$293,481
1997	47	$86,010	$95,197
		Savings (discount rate:7%):	$198,284

Note:1997 Data is normalized to represent 12 months.

Table 5-3 AIMD Lemoore RSTS Repair Costs

b) AIMD Fallon Savings

AIMD Fallon initially requested a NAESU technical assist because of the excessive maintenance problems they were having with their Avionics Test Set (ATS). After examining AIMD Fallon's MMFs it was determined that there were numerous electrical grounding problems to the entire MMF complex. A before and after comparison of AIMD Fallon's test bench maintenance costs show that there was a 76 percent drop after the repairs were made. Table 5-4 summarizes the repair costs for all of AIMD Fallon's benches and the number of repairs made during the measured period.

Year	# Discrepancies	Total Cost of All Bench Repairs	Present Value (6/98)
Jan-May97	42	$218,914	$259,258
Jun-Sep 97	21	$53,395	$59,098
		Savings (discount rate:7%):	$200,160

Table 5-4 AIMD Fallon Test Bench Repair Costs

Based on the test bench maintenance cost savings alone, the implementation of power quality management at AIMD Lemoore and AIMD Fallon can be considered economically justifiable. If these savings were further compounded to include all AIMDs in the Navy, a significant dollar amount could be reduced or reprogrammed within the Navy's Operations and Maintenance budget.

2. Cycle Time Reduction

A constant metric used in Naval Aviation is the availability or operational readiness of a squadron. Operational availability is defined as the probability that a weapon system, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. (Blanchard, 1992) Operational availability, or A_o, is expressed as:

$$A_o = MTBM \div (MTBM + MDT)$$

where:

MTBM (Mean Time Between Maintenance) $= 1/MTBM_p + MTBM_c$

MDT (Maintenance Down Time) $= \bar{M} + LDT + ADT$

where:

$MTBM_p$ is the mean interval of preventive maintenance

$MTBM_c$ is the mean interval of corrective maintenance

$\overline{M}$ (Mean active maintenance time) is the mean time required to perform preventative and corrective maintenance

LDT (Logistic delay time) is the maintenance downtime that is expected as a result of waiting for spare parts, test equipment, transportation, facilities, and so on.

ADT (Administrative delay time) is the portion of downtime during which maintenance is delayed for administrative reasons.

Looking at the equation for A_o we see that the time to repair and restore an item to full operational status, or $\overline{M}$, affects MDT which is in the denominator of the equation for A_o. Thus by decreasing the time it takes to repair a component, or the TAT, system A_o can be increased. The implementation of power quality management at AIMD Lemoore did in fact decrease $\overline{M}$. While A_o was not quantified in this study, the potential to increase A_o is considered a significant benefit of power quality management.

Another benefit was the labor savings realized by AIMD Lemoore. A before and after parametric analysis of the mean TAT of the components repaired on the RSTS bench shows a decrease of .1566 and .1684 days after the repairs were made. This equates to a reduction in $\overline{M}$ of between 3 hours 46 minutes and 4 hours and 2 minutes. The average reduction to $\overline{M}$ was 3 hours 54 minutes. Since AIMD Lemoore operates three shifts 8 hours a day no time is lost in the conversion from days to hours and minutes. The annual labor savings that can be attributed to this reduction in TAT and their present values as of 1 June 1998 are summarized in Table 5-5.

Year	Avg. TAT Reduction	Qty Components Repaired on RSTS	Cost/Hr. Labor	Labor Annual Savings	Present Value (6/98)
1996	0hrs. 0mins.	1251	$22.33	$0 (baseline year)	$0 (Baseline year)
1997	3hrs. 54mins	1287	$22.33	$86,647.21	$95,903
Total Present Value (discount rate 7%):					$95,903

Table 5-5 AIMD Lemoore Savings from Productivity Increases

Placing a dollar amount on a sailor's labor, while correct in accounting practices, is often hard to justify. In reality, the Navy does not benefit from paying less salary to its personnel due to this program. It does, however, gain benefits that are tangible. The reduced TAT provides AIMD Lemoore with surge capabilities, it also allows additional time for sailors to perform other military duties (e.g. professional/general military training, PT), and the added opportunity to allow sailors to go on leave and liberty. This quality of life improvement could possibly lead to the ultimate benefit of increased retention rates.

3. Effects on Quality

Two measures were selected for analysis to determine the benefits that power quality management has on the quality of the components being tested on the RSTS bench.

The first was the supporting squadrons "Y" code rate and the second was the MTBF of the components repaired.

A before and after comparison was made of the squadron's "Y" code rate to determine if the supported squadrons were receiving less defective components. Appendix C contains the calculations used in this analysis. The results of this analysis proved to be negligible. In fact the "Y" code rate increase by .001. This suggests that power quality management does not have an effect on this measure of quality.

The F/A-18 Radar consist of five main components, all of which are tested on the RSTS bench. The MTBF of these five components was measured to see what affect power quality management had on the ability of the RSTS bench to properly diagnose and effect repairs on these five components. The hypothesis is that if power quality management affected the performance of the RSTS bench then a corresponding increase in the reliability of the components should also be seen. Appendix C contains the calculations used in this analysis. The results from this analysis proved to be negligible. Of the five components, three showed slight increases in their MTBF and two showed slight decreases. The results of this study are not surprising. For most electrical equipment a negative exponential distribution is assumed. If the system is mature, the failure rate is considered to be very constant during normal operations. The only variations seen in these system's failure rates occur during the initial debugging or burn-in periods, or when the system reaches a certain age. Additionally, the system's failure rate can change dramatically if the system is continually being modified or operating in a different operational profile than it was designed to operate in. Therefore, while power quality management does affect failure of the components installed in the RSTS bench, it does not have any affect on the components being tested by the RSTS bench.

D. COMBINED COST-BENEFIT RESULTS

Table 5-6 summarizes the total net present value that can be assigned to the implementation of power quality management at AIMD Lemoore and AIMD Fallon. Table 5-7 then combines these benefits and adds the benefits found by Valdyke (1998) during his power quality management study of AIMD Lemoores AN/USM-470(V)1 Automatic Test Set to represent the total benefits received from this program.

Category	Description	Dollar Value Lemoore	Dollar Value Fallon
Total Costs as of 6/98	Costs:	($39,384)	($35,476)
Total Benefits as of 6/98	Savings from Repairs:	$198,284	$200,160
	Savings from Productivity:	$95,903	*Unqunatified*
	Savings from Quality:	*Negligible*	*Unquantified*
Total PV of Power Quality Management:		$254,803	$164,684

Table 5-6 Total Present Value of Power Quality Management

These totals show that AIMD Lemoore and AIMD Fallons' decisions to pursue power quality management were successful. The electrical problem with the RSTS bench was minor compared to other electrical problems within AIMD Lemoore and this work center still showed savings of $254,803. Additionally, the savings encountered at AIMD Fallon are equally impressive. AIMD Fallons net benefit only contains the maintenance costs associated with repairing the bench. While not quantified this researcher feels it is safe to assume that AIMD Fallon would also have the additional benefit of a reduced TAT.

Category	Description	Total Dollar Value
Total Costs as of 6/98	Total Costs:	($72,488)
Total Benefits as of 6/98	Savings at AIMD Lemoore:	$255,833
	Savings at AIMD Fallon	$176,380
	Savings at AIMD Lemoore, (Valdyke, 1998):	$1,172,335
Combined Total PV of Power Quality Management:		$1,532,060

Table 5-7 Combined Total Present Value of Power Quality Management

When the net present values from this study are added to those computed by Valdyke (1998) the results are very favorable. The implementation of power quality management at the two COMNAVAIRPAC AIMDs has saved $1,532,060 in Operations and Maintenance funds. In the current austere defense budgetary climate, the investment in power quality management can yield significant savings. These savings include reduced maintenance costs, increases in availability and quality of life enhancements for the Navy's sailors.

VI. CONCLUSIONS AND RECOMMENDATIONS

This thesis studied the impact that power quality management has had on the intermediate level of maintenance. AIMD Lemoore and AIMD Fallon were used as examples. The data and information collected for this study provides ample material to draw conclusions pertinent to the objectives of this thesis and identify areas that warrant further research. This chapter begins with conclusions and recommendations, followed by issues that are valid candidates for later research.

A. CONCLUSIONS

1. The implementation of power quality management at AIMD Lemoore and AIMD Fallon results in savings of $1,532,060 over a two year period.

This is savings is attributable to the combined savings from reduced test bench maintenance costs and productivity increases. Additionally, there are unquantified savings attributed to quality of life improvements (e.g., additional time for leave/liberty and professional/military training)and improvements in operational availability

2. Power quality management results in a one time maintenance cost savings of $407,630.

The cost savings are in the form of reduced test bench maintenance costs. After implementing power quality management processes, the cost of maintaining the Radar Station Test Set at AIMD Lemoore dropped 65 percent and the cost of maintaining all test benches at AIMD Fallon dropped 76 percent.

3. The implementation of power quality management results in a reduced maintenance cycle time.

The mean active maintenance time (the time it takes to perform scheduled and unscheduled maintenance) at AIMD Lemoore was reduced by 3 hours and 54 minutes or 7%. This cycle time reduction potentially improves aircraft operational availability, or readiness in the fleet.

4. Power quality management has proven to be a useful process in the civilian industry as well as in the DOD.

The adoption of power quality management practices at the United Airlines Maintenance Operations Center and by the Fleet Technical Support Center's Pre-Deployment Electrical Power Survey Inspection (PEPSI) program has resulted in numerous electrical system design changes and reduced damage to electronic equipment.

5. Current civilian industry power quality management practices are more comprehensive and provide clearer guidance than that stated in current DOD instructions.

The Institute of Electrical and Electronic Engineers has published numerous practices that clearly address the who, what, when, why, and where questions pertaining to power quality management. While the DOD instructions are very clear in regards to system design they lack guidance on how to monitor and implement a power quality management program.

B. RECOMMENDATIONS

1. Institutionalize the use of power quality management for all DOD maintenance activities.

Power quality management has been proven to reduce the costs of maintaining test benches, reduce maintenance cycle time, and correct many electrical safety problems. While power quality management is currently practiced at a limited number of sites, more widespread use would yield additional benefits for all DOD activities.

2. Review and consolidate the current DOD and Naval directives pertaining to power quality and adopt, as appropriate, industry standards and guidance on power quality management.

Current DOD and Naval directives are outdated, confusing, and do not provide clear policy and direction with regards to the upkeep of sensitive electronic equipment. The consolidation of current directives and incorporation of civilian standards and guidance will provide a single source of clear and up-to-date directives which DOD activities can follow.

3. Incorporate a Power Quality Module in the current Training pipelines for all electrical ratings.

Although not directly discussed in this thesis, a training pipeline exists for all electrical ratings within the Navy. Introduction to power quality practices at the earliest possible time in the training pipeline will result in an increased understanding of power quality problems. In the end, this will result in the quicker identification and subsequent repair of power quality problems occurring in the field.

4. Incorporate ATE related power quality training for all ATE NAESU representatives.

NAESU personnel are often relied upon to diagnose ATE problems by field activities. Proper training must be provided to NAESU representatives to ensure they have sufficient technical knowledge to diagnose ATE site power and then recommend customer involvement with cognizant experts, like the EPIC team, to resolve site power problems.

5. Disseminate to all NAVAIR field activities the current phone numbers and points of contact for the EPIC team with a brief description of their mission.

NAVAIR currently has a team of technical experts that are funded for site power investigations and who can determine the nature and specific causes of power quality problems. Many NAVAIR activities lack the knowledge that a team of this nature team exists.

C. AREAS FOR FURTHER RESEARCH

This research did not look at any of the technical aspects of electrical test bench design or effects that power-conditioning equipment could have on sensitive electrical equipment. We found that the F/A-18E/F Facilities Requirements Document currently references an August of 1975 Design Guide for Avionics Shop Power Distribution (NAVAIR 01-1A-512). Research and study of this and other documents pertaining to facility electrical requirements by an electrical engineer could provide NAVAIR with a means of ensuring that all facilities and avionics power distribution requirements are properly written and meet the current electrical standards.

APPENDIX A. WUC POPULATION COMPOSITION

F/A-18 Radar Work Unit Code List

Work Unit Code	Nomenclature	Total Qty (1996 - 1997)	1996	1997
742G100	F/A-18 Radar Transmitter	807	404	403
742G200	F/A-18 Radar Receiver	600	309	291
742G300	F/A-18 Radar Processor	340	148	192
742G400	F/A-18 Computer Power Supply	330	152	178
742G600	F/A-18 Radar Antenna	461	238	223

APPENDIX B. TAT CALCULATIONS AND DISTRIBUTIONS

AIMD Lemoore TAT Calculations

WUC	# Actions 1996	# Actions 1997	1996 Mean Days	1997 Mean Days
742G100	404	403	2.40841584	2.382134
742G200	309	291	2.61812298	2.24054983
742G300	148	192	2.47972973	2.2083333
742G400	152	178	2.76315789	2.55617978
742G600	238	223	1.80252101	1.79372197
	Σ 1251	Σ 1287		

$\sum D = 201.0094826$

$\sum D^2 = 61.76174398$

$\bar{D} = 0.160679043$

$S_D = 0.153528454$

$S_{\bar{D}} = 0.004340705$

$\alpha = 0.05$

$t_{\alpha/2} = 1.96$

Formulas

$$\bar{D} = \frac{\sum_{i=1}^{n} D_i}{n}$$

$$S_D = \sqrt{\frac{\sum_{i=1}^{n} D_i^2 - \frac{\left(\sum_{i=1}^{n} D_i\right)^2}{n}}{n-1}}$$

$$S_{\bar{D}} = \frac{S_D}{\sqrt{n}}$$

Lower Limit= $\bar{D} - S_{\bar{D}} \times t_{\alpha/2}$

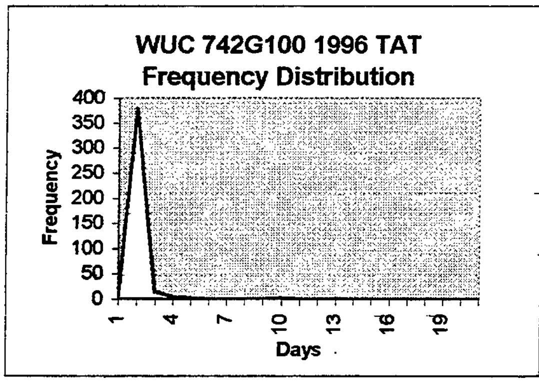
Upper Limit= $\bar{D} + S_{\bar{D}} \times t_{\alpha/2}$

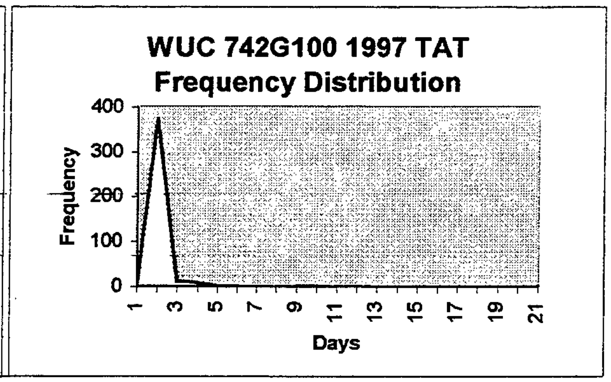
We are 95% confident that the difference lies between the lower and upper limits

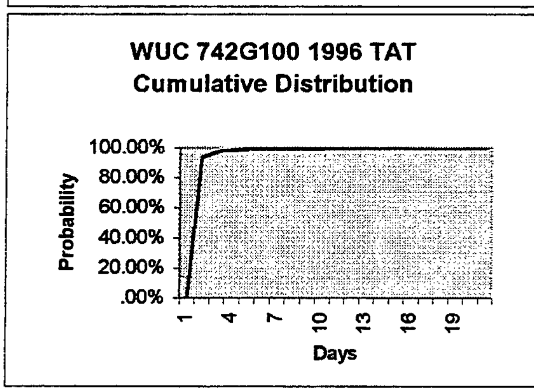
$0.152171262 \leq u_1 - u_2 \leq 0.169186824$

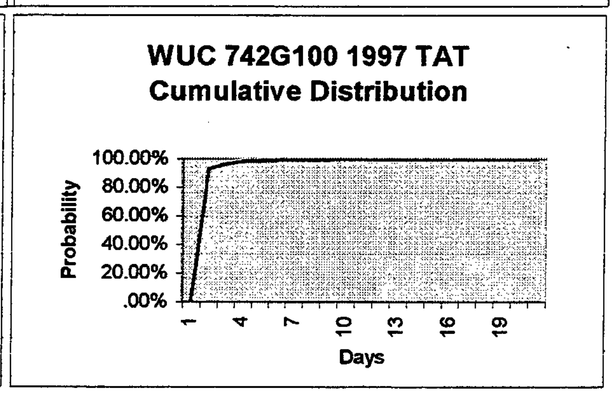
WUC: 742G100 FA-18 A/B/C/D Radar Transmitter

Bin	*Frequency 1996*	*Cumulative % 1996*	*Frequency 1997*	*Cumulative % 1997*
0	0	.00%	0	.00%
5	378	93.56%	375	93.05%
10	15	97.28%	13	96.28%
15	5	98.51%	8	98.26%
20	2	99.01%	2	98.76%
25	0	99.01%	2	99.26%
30	0	99.01%	0	99.26%
35	0	99.01%	0	99.26%
40	0	99.01%	1	99.50%
45	2	99.50%	1	99.75%
50	0	99.50%	0	99.75%
55	0	99.50%	0	99.75%
60	1	99.75%	0	99.75%
65	0	99.75%	0	99.75%
70	0	99.75%	0	99.75%
75	0	99.75%	0	99.75%
80	0	99.75%	0	99.75%
85	0	99.75%	0	99.75%
90	0	99.75%	0	99.75%
95	0	99.75%	0	99.75%
100	0	99.75%	1	100.00%
More	1	100.00%	0	100.00%



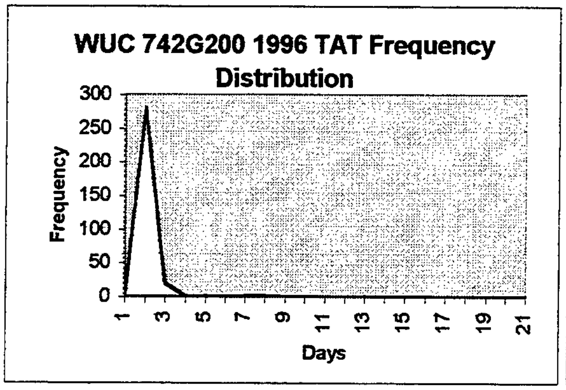


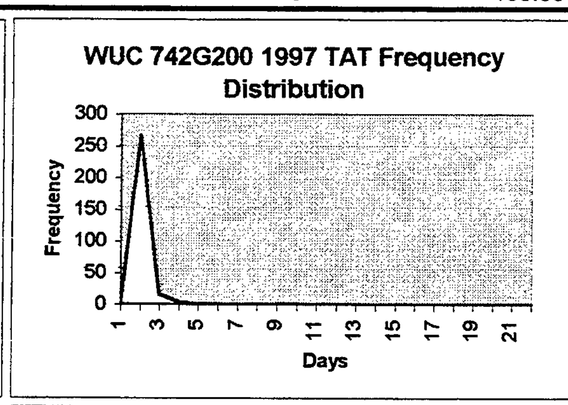


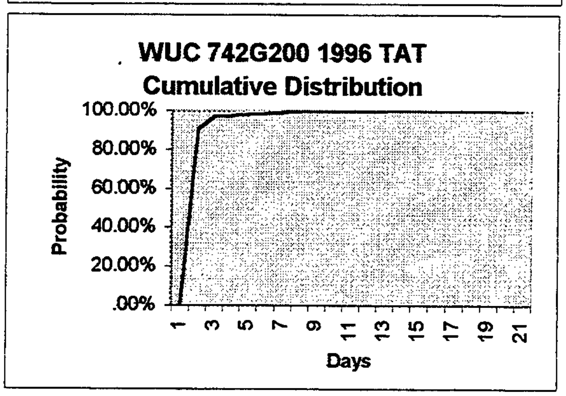


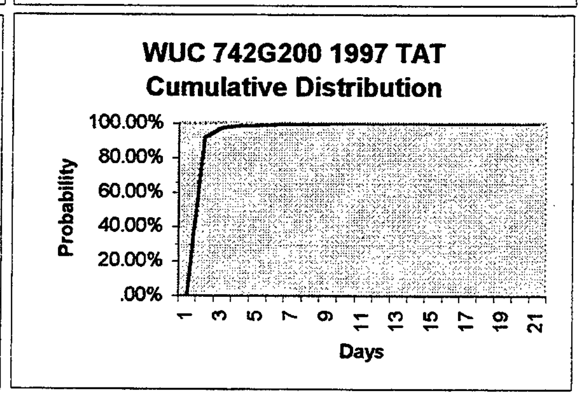
WUC 742G200 FA-18 A/B/C/D Radar Receiver

Bin	*Frequency 1996*	*Cumulative % 1996*	*Frequency 1997*	*Cumulative % 1997*
0	0	.00%	0	.00%
5	280	90.61%	267	91.75%
10	20	97.09%	16	97.25%
15	1	97.41%	4	98.63%
20	2	98.06%	1	98.97%
25	1	98.38%	1	99.31%
30	2	99.03%	0	99.31%
35	2	99.68%	0	99.31%
40	0	99.68%	1	99.66%
45	0	99.68%	1	100.00%
50	0	99.68%	0	100.00%
55	0	99.68%	0	100.00%
60	1	100.00%	0	100.00%
65	0	100.00%	0	100.00%
70	0	100.00%	0	100.00%
75	0	100.00%	0	100.00%
80	0	100.00%	0	100.00%
85	0	100.00%	0	100.00%
90	0	100.00%	0	100.00%
95	0	100.00%	0	100.00%
100	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%



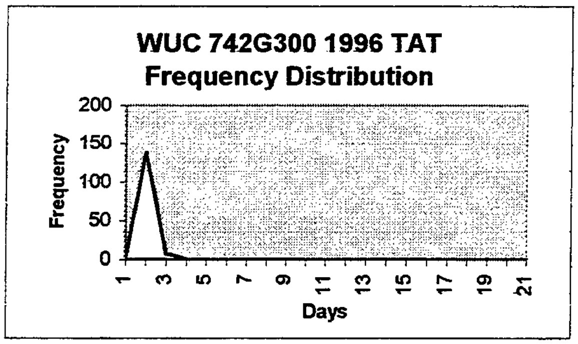


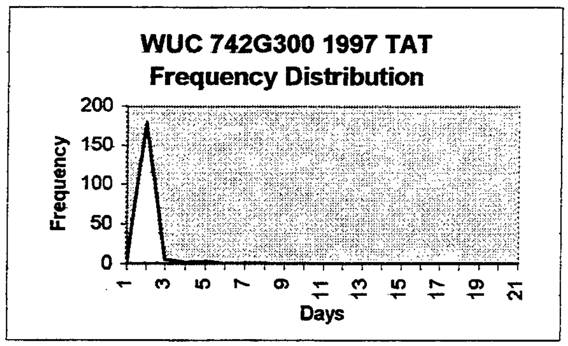


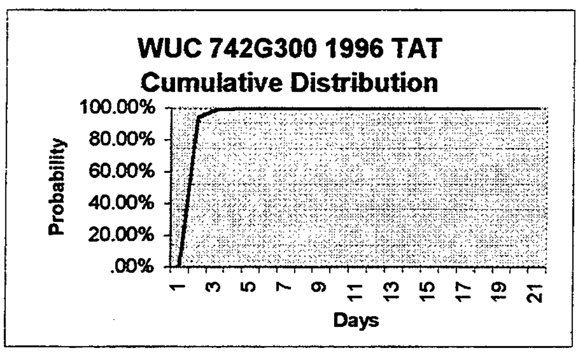


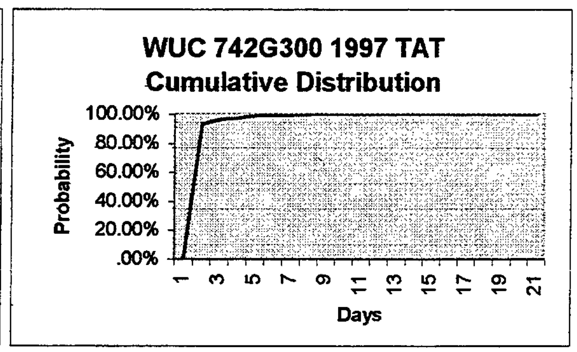
WUC 742G300 FA-18 A/B/C/D Radar Processor

Bin	*Frequency 1996*	*Cumulative % 1997*	*Frequency 1997*	*Cumulative % 1997*
0	0	.00%	0	.00%
5	139	93.92%	179	93.23%
10	7	98.65%	6	96.35%
15	1	99.32%	2	97.40%
20	0	99.32%	3	98.96%
25	0	99.32%	0	98.96%
30	0	99.32%	1	99.48%
35	0	99.32%	1	100.00%
40	0	99.32%	0	100.00%
45	0	99.32%	0	100.00%
50	0	99.32%	0	100.00%
55	0	99.32%	0	100.00%
60	0	99.32%	0	100.00%
65	0	99.32%	0	100.00%
70	0	99.32%	0	100.00%
75	0	99.32%	0	100.00%
80	0	99.32%	0	100.00%
85	0	99.32%	0	100.00%
90	1	100.00%	0	100.00%
95	0	100.00%	0	100.00%
100	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%



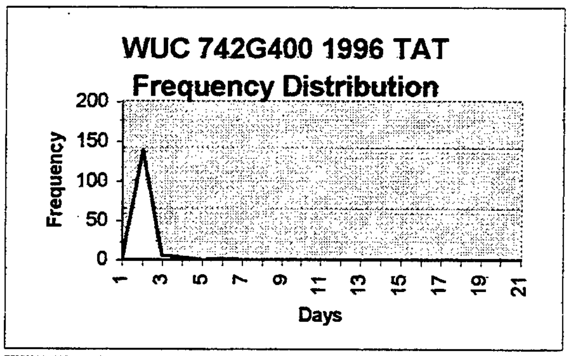


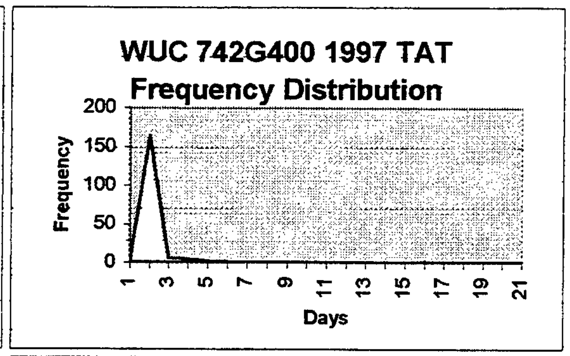


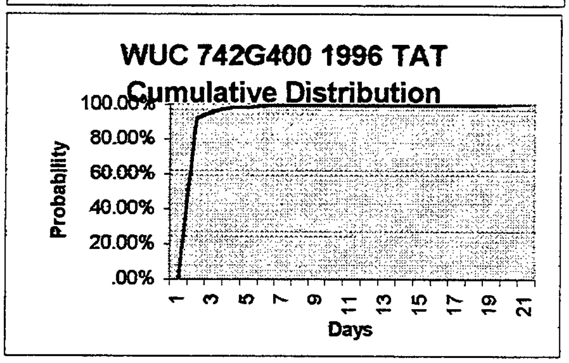


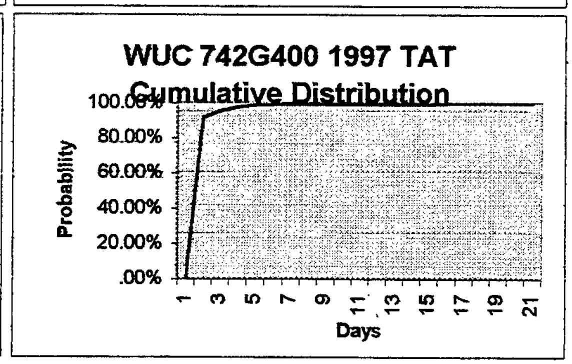
WUC 742G400 FA-18 A/B/C/D Computer Power Supply

Bin	Frequency 1996	Cumulative % 1996	Frequency 1997	Cumulative % 1997
0	0	.00%	0	.00%
5	140	92.11%	164	92.13%
10	6	96.05%	6	95.51%
15	3	98.03%	4	97.75%
20	0	98.03%	2	98.88%
25	2	99.34%	1	99.44%
30	0	99.34%	0	99.44%
35	0	99.34%	0	99.44%
40	0	99.34%	0	99.44%
45	0	99.34%	0	99.44%
50	0	99.34%	0	99.44%
55	0	99.34%	0	99.44%
60	0	99.34%	0	99.44%
65	0	99.34%	0	99.44%
70	0	99.34%	0	99.44%
75	0	99.34%	1	100.00%
80	0	99.34%	0	100.00%
85	0	99.34%	0	100.00%
90	0	99.34%	0	100.00%
95	1	100.00%	0	100.00%
100	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%



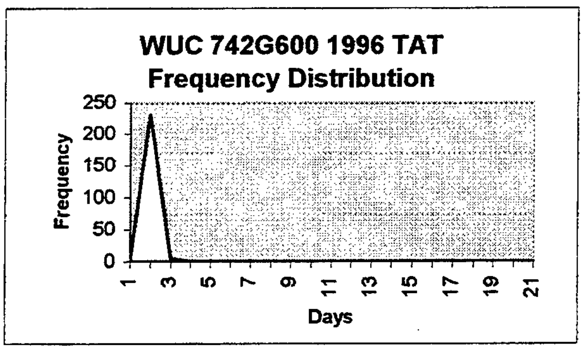


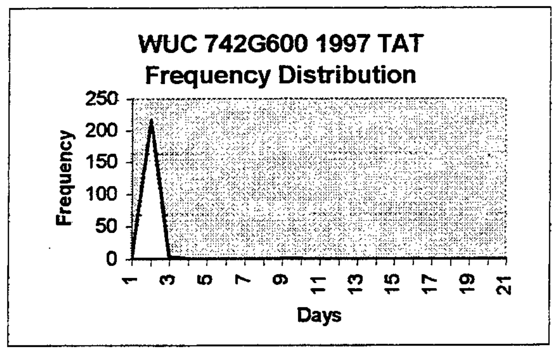


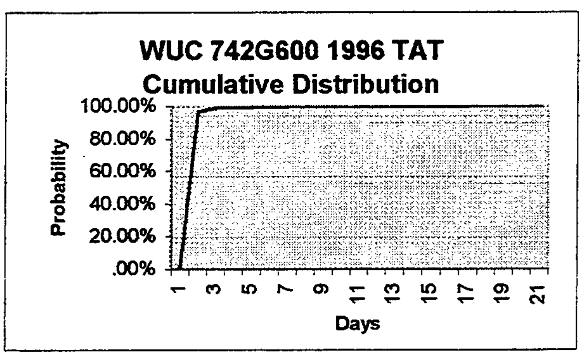


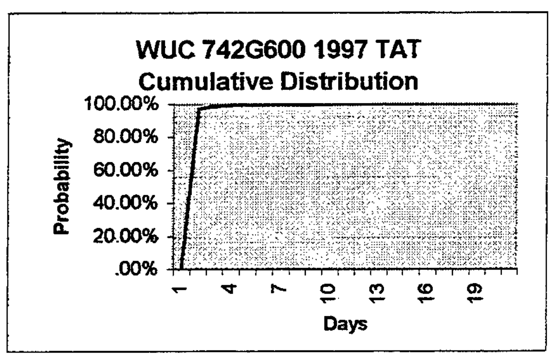
Bin	Frequency 1996	Cumulative % 1996	Frequency 1997	Cumulative % 1997
0	0	.00%	0	.00%
5	230	96.64%	216	96.86%
10	5	98.74%	4	98.65%
15	0	98.74%	1	99.10%
20	1	99.16%	0	99.10%
25	0	99.16%	0	99.10%
30	1	99.58%	0	99.10%
35	0	99.58%	0	99.10%
40	0	99.58%	1	99.55%
45	0	99.58%	1	100.00%
50	0	99.58%	0	100.00%
55	0	99.58%	0	100.00%
60	0	99.58%	0	100.00%
65	0	99.58%	0	100.00%
70	0	99.58%	0	100.00%
75	0	99.58%	0	100.00%
80	1	100.00%	0	100.00%
85	0	100.00%	0	100.00%
90	0	100.00%	0	100.00%
95	0	100.00%	0	100.00%
100	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%

WUC 742G600 FA-18 A/B/C/D Radar Antenna









APPENDIX C. "Y" CODE AND MTBF CALCULATIONS

AIMD Lemoore Y Code Calculations

Year	# Y Codes	Total # Actions	Y Code %	# A799	Y Codes less A799	Y Code %
1996	35	1251	0.028	7	28	0.022
1997	41	1287	0.032	11	30	0.023

AIMD Lemoore MTBF Calculatiuons

WUC 742G100
VFA-125 FA-18 A/B/C/D Radar Transmitter

Year	# Failures	Total Hrs	λ	MTBF
1996	100	14723	0.006792094	147
1997	107	16235	0.006590699	152

WUC 742G200
VFA-125 FA-18 A/B/C/D Radar Receiver

Year	# Failures	Total Hrs	λ	MTBF
1996	91	14723	0.006180806	162
1997	85	16235	0.005235602	191

WUC 742G300
VFA-125 FA-18 A/B/C/D Radar Processor

Year	# Failures	Total Hrs	λ	MTBF
1996	44	14723	0.002988521	335
1997	62	16235	0.00381891	262

WUC 742G400
VFA-125 FA-18 A/B/C/D Computer Power Supply

Year	# Failures	Total Hrs	λ	MTBF
1996	56	14723	0.003803573	263
1997	64	16235	0.0039421	254

WUC 742G600
VFA-125 FA-18 A/B/C/D Radar Antenna

Year	# Failures	Total Hrs	λ	MTBF
1996	54	14723	0.003667731	273
1997	52	16235	0.003202957	312

Formulas

$$\lambda = \frac{\text{number of failures}}{\text{total hours}}$$

$$MTBF = \frac{1}{\lambda}$$

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