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DESIGN FOR MAINTAINERS PROGRAM PLAN

CONTRACT N62269-79-C-0235

TASK ORDER NO. 0003

ITEM REFERENCE 5.3.4/4.2.3.1

Submitted To:

NAVAL AIR DEVELOPMENT CENTER

Warminster, Pennsylvania

Prepared By:

TELCOM SYSTEMS INCORPORATED

Arlington, Virginia

Under Subcontract To:

ANALYTICS, INCORPORATED

Willow Grove, Pennsylvania

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SECTION 1.0

PROGRAM DEFINITION

GENERAL INTRODUCTION

There is nothing new about the importance of problems involving the dependability of the performance of equipment; this has always been a high-priority engineering concern. Likewise, engineers and technicians have always been concerned with the problem of fixing equipment in the event it fails. In response to this problem, typically, engineering approaches have also been of prime importance. With the recent advent of today's complex equipments, however, it has become increasingly obvious that something other than the traditional engineering approach to the maintenance problem must be tried; a new approach requiring inputs from a variety of disciplines seems required. It is the goal of the present effort to initiate such a multi-discipline approach to the problem from a **design-for-maintainers standpoint**. Specifics of this approach are outlined in the following:

STATEMENT OF THE PROBLEM

The concept of maintainability evolved from results of reliability programs of the late 1940's and early 1950's. The U. S. Military formally adopted this concept in 1954. These early reliability programs, while demonstrating the effectiveness of prolonging the life of systems and equipment, also indicated that maintenance requirements could not be overlooked because 100% reliability was, at that time, an unobtainable goal.

The problem of maintaining military systems in a state of readiness has grown considerably in the past two decades.

With the increased size and complexity of modern military systems, the estimates for maintaining them have ranged between 1/4 to 1/3 of all operating costs. Additionally, it has been established that 1/3 of all military personnel are engaged in maintenance and support functions.

This increasing cost of maintenance has greatly concerned the upper echelons of the Armed Services as well as legislators. An even greater problem than the excessively high maintenance costs, is the reduction of operational readiness. In fact, this latter problem is of grave concern since the consequence is a significant increase in the system/equipment acquisition dollars required to maintain or obtain a given level of operational readiness. The other possible consequence is a lower defense posture if sufficient funds cannot be appropriated (i. e., to overcome a lower level of operational readiness).

Consider, for example, the impact that maintenance has on the F-14A (one of our major weapons systems). The F-14A has an operational readiness of only about 58%. However, even this figure is somewhat misleading. When only the full systems capability is considered, operational readiness reduces to about 52%.

Again, the primary cause of this present maintenance problem appears to be the progressive and rapid increase in systems complexity requiring the skills of a technician having about five years of training in engineering to keep the system ready. The typical military technician, however, spends perhaps a year in school-training and maybe an additional three years in mission environments, and thus, cannot achieve the skill level required to maintain current systems. This training problem represents only one small, but not insignificant, aspect of the myriad of problems plaguing a design for maintainers effort. One other possible and very likely contributer to the problem is inadequate attention given maintainers during the design stage of systems. Despite claims to the contrary by the equipment vendors, maintenance is seldom given much consideration during equipment design and/or modification. Even when "maintainability checklists" are used, the guidelines are so general that most designs will pass such specifications. There are reasons to suspect that such neglect of the maintainers' problems has contributed greatly to the high cost of maintenance. Typical approaches that have been taken, up until now, to improve maintainability may be classified under three categories: (1) technician skills, (2) trouble-shooting aids, and (3) equipment design.

Formerly, the prime emphasis to the problem of system-maintenance was aimed at technician skills with a secondary emphasis on designing effective performance aids. The main deficiency with this approach is the limited training time available during a technician's enlistment; and despite on-going efforts to provide better training, all evidence indicates that these efforts are not succeeding in reducing, to any significant extent, the maintenance problem. For example, inadequacies are especially evident in trouble-shooting behavior, which has been shown to comprise more than 60% of any given corrective electronics maintenance activity. Surveys have shown that most technicians employ little or no logic in trouble-shooting. Further, attempts to enhance trouble-shooting behavior by developing aids have not significantly alleviated the maintenance problem. An alternative approach obviously needs to be taken. One possible solution to the maintenance problem is a multifaceted program approach aimed at increasing the development of concepts in human engineering design principles, which when implemented, will aid the future maintainers of systems. The goal of this "Design for Maintainers" program is to develop a philosophy and a set of guidelines to be used by engineers in designing equipment and systems for ease of maintenance.

The following "maintainability-related parameters" in developing such a program must be taken into account:

Problems related to Diagnosis/trouble-shooting -- relevant here are issues related to various sensors (scopes, testers, etc.), fault detection strategies, symptomatology enhancement, etc.; accessibility of components; stand-by purchase and storing spares; automatic diagnostic equipment; and equipment pecularities.

Many other pertinent factors must be taken into account in planning an overall design for maintainers effort. These include, but are not limited to, the following: (1) maintainability/cost-effectiveness design trade-offs, (2) safety considerations, (3) tool development, and (4) maintenance-performance environments.

The above system-maintainability considerations must be designed into equipment in the very early stages of development if costly life-cycle maintenance and system redesign is to be avoided. Once the development model is fairly well along, it is typically difficult, and sometimes impossible, to change design decisions to improve maintainability. Thus, at the outset of systems development, a design schedule for maintainability should be mapped out.

Examination of current doctrine regarding maintainability, such as that which appears in MIL-STD-1472, reveals two extremes with respect to design guidelines ranging from such broad generalization, e. g., that regarding accessibility: "Structural members of units or chassis shall not prevent access to or removal of components"; to such specific minutia such as: "fasteners for mounting assemblies and subassemblies shall require only one complete turn, provided stress and load considerations are not compromised"; regarding the use of fasteners. While these matters are by no means unimportant, they do not give the maintenance designer the comprehensive tool required to perform his functions.

A means must be found to provide the maintenance designer with a sophisticated tool, useable at all stages of multi-attribute systems development which will allow him to predict specific fault occurrences so that proper design decision can be made at system inception.

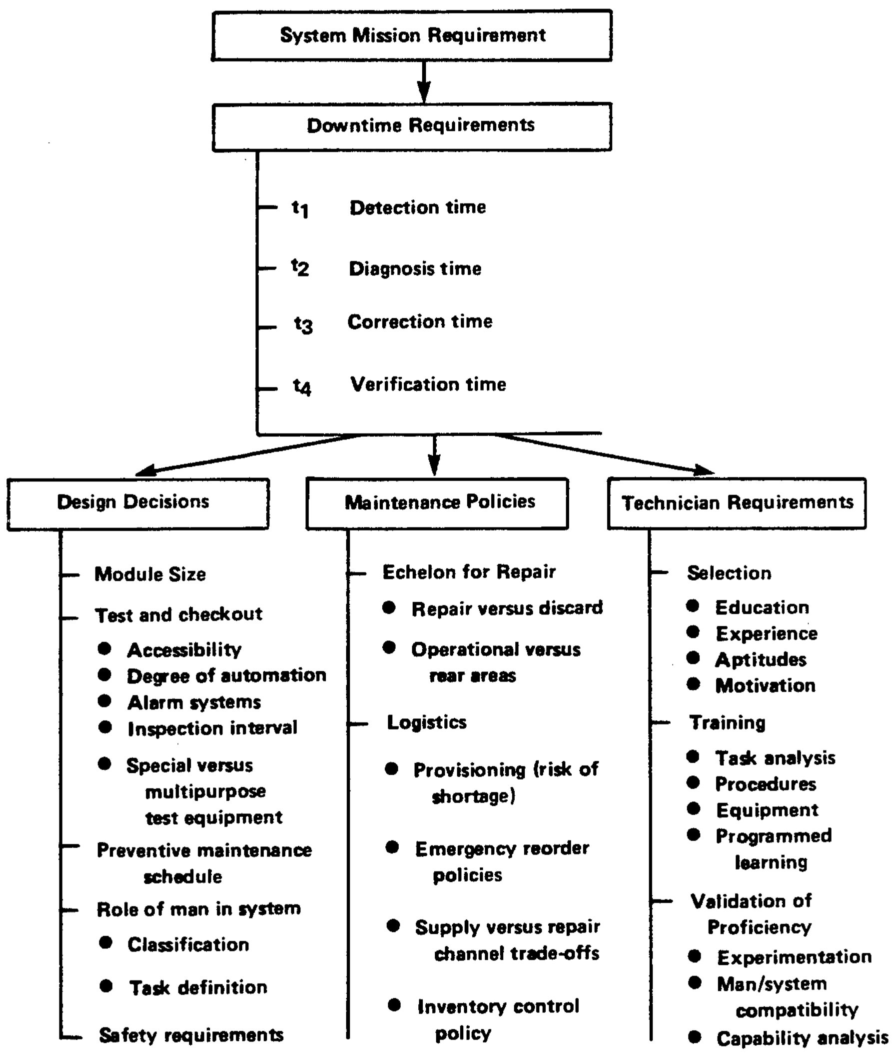
To sum up, rapidly developing technologies allowing for the establishment of increasingly more complex systems require that we update our thinking as to how maintainability design for these modern systems should be determined.

The objective of this effort is to revise and update system maintainability design concepts to meet current and projected airborne systems developments.

The ultimate product of this entire effort, after transitioning to 6.3 and beyond, is envisioned to be a revision, where necessary, of Specifications, Standards, Data Item Descriptions, Philosophies and Organizational Policies, cast in the form of a "bible" of "design-for-maintainers" tools, guidelines and principles useable by DOD, NASA, Contractors and Industry.

GENERAL CONSIDERATIONS

A "Design-for-Maintainers" Program effort must be responsive to dealing with the following System/Mission related factors which include such variables as are outlined below:



Elements of Maintainability. From Goldman & Slattery, 1977, **Maintainability.**

PROGRAM PROVISO

The development of any truly effective design-for-maintainers program will, of necessity, hinge upon convincing top-level Navy Commanders of the importance of maintaining optimal fleet readiness. Once the powers-that-be have been convinced of the cost-effectiveness of maintaining fleet equipment readiness near the 100% level, as opposed to the current 50-60% level, they, and they alone, can implement procurement philosophy such as to insist upon a design-for-maintainers stress at each and every stage of system-development. Once such a commitment has been obtained, the appropriate "tools" to implement such a program can be developed.

The sponsors of this effort, from its inception, recognize this foremost reality.

SECTION 2.0

GENERAL REQUIREMENT

A DESIGN FOR MAINTAINERS PROGRAM EFFORT

GENERAL REQUIREMENT

Historically, both human factors personnel and training resources have emphasized the operators', over the maintainers', interface with hardware. This state of affairs is especially obvious with respect to the aircraft pilot.

Perhaps as a reflection of our deeply-rooted cultural bias against any individual or group who get dirty hands while earning a living, DOD still fosters elements of a caste system which relegates maintenance personnel to the status of "grease monkey." This bias is especially obvious in academic circles and in the upper levels of management. Despite mounting costs, the operator of systems has almost always been provided with the necessary hardware and hardware simulators to ensure that he is effectively trained and aided in the performance of his job. To the contrary, the importance of the maintainer's role has been consistently downgraded as seen by the limited allocations of resources to ensure that he can perform job tasks. The consequence of these policies has been an effective, albeit, an inefficient and costly maintenance system. This costly maintenance is directly translatable into excessive life cycle costs of hardware-ownership. To reiterate, traditionally the military service has allocated much more attention and resources aimed at optimalizing **operator** task performance at the expense of **maintainer** task performance. This differential emphasis, in light of current systems realities, is rapidly changing. Life cycle costs (LCC's) of such hardware systems are extremely high and continue to rise. Some important factors that contribute to LCC are high maintenance personnel costs, high spare-parts costs, as well as unnecessary usage of spares. Something positive must be done to reverse this costly life cycle trend produced by these maintenance-related factors.

The goal of this proposed research is to describe several state-of-the-art concepts and technologies, as well as to suggest possible means whereby these might be incorporated and implemented in a "**design**-for-maintainers" effort -- an effort, the aim of which, is to employ up-to-date concepts and technologies in the **design** of hardware for ease of maintenance.

Foley has outlined the development of many aids to assist the maintainers of electronic and mechanical equipments, such as, FPJPAs (Fully Proceduralized Job Performance Aids), MDCs (Maintenance Dependency Charts), etc. He also points up the difficulties inherent in making these part of the institutionalized tools employable by the maintenance community.

More importantly, he further argues for the primacy of Performance Measurement (PM), as the ultimate tool in assessing all manner of maintenance-related variables. He proceeds to note the many problems involved in adopting PM over traditional paper and pencil, theory related tests, e.g., greater funding required, no adequate PM technology available, etc.

He goes on to show how the employment of the above methods and tools will reduce maintenance costs with both first and second enlistment (DOD) personnel, This, of course, obtains for already existing to-be-maintained systems.

These methods and tools constitute what are probably the most up-to-date thinking with regard to the state-of-the-art of maintainability. It would appear to be quite cost-effective to attempt to see whether they are amendable to being incorporated, in some way, into design principles for a "design-for-maintainers" research program.

The products of this effort will be twofold:

(1) A performance measurement (PM) technology will be developed, refined, and employed in a design-for-maintainers effort which will have utility, over-and-above that possible with traditional, e.g., paper and pencil technology. This effort will have spin-off to other Human Engineering efforts in the Navy.

(2) State-of-the-art maintainability materials will be perused for assessment of design principles for ease of maintenance.

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SECTION 3.0

PROGRAM DATA SHEET

DESIGN FOR MAINTAINERS

DATA SHEET

PE No. and Title: 62757N, Training and Human Engineering

Project No. and Title: 55-525, Human Engineering

Subproject No. and Title: WF55-525, Human Factors Engineering Technology

Task Area/Block No. and Title: WF55-525-492, Human Factors Engineering Technology for Advanced Airborne Systems

Subtask No. and Title: DESIGN FOR MAINTAINERS

Technology Area: Weapon System Design

Responsible Activity: NAVAL AIR DEVELOPMENT CENTER

Associate Activity: None

DESCRIPTION OF EFFORT

The concept of maintainability evolved from results of reliability programs of the late 1940's and early 1950's. The U. S. Military formally adopted this concept in 1954. These early reliability programs, while demonstrating the effectiveness of prolonging the life of systems and equipment, also indicated that maintenance requirements could not be overlooked because 100% reliability was, at that time, an unobtainable goal.

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This increasing cost of maintenance has greatly concerned the upper echelons of the Armed Services as well as legislators. An even greater problem than the excessively high maintenance costs, is the reduction of operational readiness. In fact, this latter problem is of grave concern since the consequence is a significant increase in the system/equipment acquisition dollars required to maintain or obtain a given level of operational readiness. The other possible consequence is a lower defense posture if sufficient funds cannot be appropriated (i.e., to overcome a lower level of operational readiness).

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Again, the primary cause of this present maintenance problem appears to be the progressive and rapid increase in systems complexity requiring the skills of a technician having about five years of training in engineering to keep the system ready. The typical military technician, however, spends perhaps a year in school-training and maybe an additional three years in mission environments, and thus, cannot achieve the skill level required to maintain current systems. This training problem represents only one small, but not insignificant, aspect of the myriad of problems plaguing a design for maintainers effort. On other possible and very likely contributor to the problem is inadequate attention given maintainers during the design stage of systems. Despite claims to the contrary by the equipment vendors, maintenance is seldom given much consideration during equipment design and/or modification. Even when "maintainability checklists" are used, the guidelines are so general that most designs will pass such specifications. There are reasons to suspect that such neglect of the maintainers' problems has contributed greatly to the high cost of maintenance. Typical approaches that have been taken, up until now, to improve maintainability may be classified under three categories: (1) technician skills, (2) troubleshooting aids, and (3) equipment design.

Formerly, the prime emphasis to the problem of system-maintenance was aimed at technician skills with a secondary emphasis on designing effective performance aids. The main deficiency with this approach is the limited training time available during a technician's enlistment; and despite ongoing efforts to provide better training, all evidence indicates that these efforts are not succeeding in reducing, to any significant extent, the maintenance problem. For example, inadequacies are especially evident in trouble-shooting behavior, which has been shown to comprise more than 60% of any given corrective electronics maintenance activity. Surveys have shown that most technicains employ little or no logic in trouble-shooting. Further, attempts to enhance trouble-shooting behavior by developing aids have not significantly alleviated the maintenance problem. An alternative approach obviously needs to be taken. One possible solution to the maintenance problem is a multi-faceted program approach aimed at increasing the development of concepts in human engineering design principles, which when implemented, will aid the future maintainers of systems. The goal of this "Design for Maintainers" program is to develop a philosophy and a set of guidelines to be used by engineers in designing equipment and systems for ease of maintenance.

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Many other pertinent factors must be taken into account in planning an overall design for maintainers effort. These include, but are not limited to, the following: Maintainability/Cost-effectiveness Design Trade-offs, Safety considerations, tool development, maintenance-performance environments and Planned and Corrective Maintenance, PM and CM, respectively.

The above system-maintainability considerations must be designed into equipment in the very early stages of development if costly life-cycle maintenance and system redesign is to be avoided. Once the developmental model is fairly well along, it is typically difficult, and sometimes impossible, to change design decisions to improve maintainability. Thus, at the outset of systems development, a design schedule for maintainability should be mapped out.

Examination of current doctrine regarding maintainability, such as that which appears in MIL-STD-1472 reveals two extremes with respect to design guidelines ranging from such broad generalization, e.g., that regarding accessibility: "Structural members of units or chassis shall not prevent access to or removal of components;" to such specific minutia such as "fasteners for mounting assemblies and subassemblies shall require only one complete turn, provided stress and load considerations are not compromised," regarding the use of fasteners. While these matters are by no means unimportant, they do not give the maintenance designer the comprehensive tool required to perform his functions.

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The ultimate product of this entire effort, after transitioning to 6.3 and beyond, is envisioned to be a revision, where necessary, of Specifications, Standards, Data Item Descriptions, Philosophies and Organizational Policies, cast in the form of a "bible" of "design-for-maintainers" tools, guidelines and principles useable by DOD, NASA, Contractors and Industry.

APPROACH

Quantitatively assess, in current (and projected) Navy systems, as to the true extent of the maintainability problem with respect to the above outlined parameters.

Outline any deficiencies in our present concepts and procedures for maintainability design; and update these when found, e.g., those found in MIL-STD-1472B, MIL-STD-470 and MIL-STD-471. Prepare design for maintainability criteria and procedures. Interface the resulting criteria and procedures with such efforts as the procuring of a system for specific Navy aircraft maintenance training courses, as a partial validation of the derived design criteria and procedures.

PROGRESS

None; FY-79 new start

CURRENT APPLICATION

None

PROPOSE EFFORTS

Initially, this effort will concern itself with determining whether present data bases, such as the 3M system, lend themselves to the development of a model employing all relevant maintenance parameters. This model is envisioned to be used to predict maintainability problems at the inception of all manner of systems development so that corrective designs can be made at the beginning of the developmental model.

The overall effort of this program, however, is to thoroughly assess the full state-of-the-art of design for maintainability, and develop a multi-faceted program which will ensure that all manner of design for maintainability criteria and procedures are being researched, prepared, published and employed in such specific Naval settings as the procurement of simulation systems and airborne weapon systems and subsystems.

The overall effort will consist of multiple thrusts in the following areas:

- Acquire relevant documents to assess current maintenance philosophies and the impact upon these a "Design-for-Maintainers" program will have. Examples of such documents are: Integrated Logistics Support Implementation Guide, NAWMAT P-4000, and MIL-STD-1338, Logistics Support Analysis.
- Assess from above collection, how, if at all, Navy maintenance way-of-doing-business must be altered to meet "design-for-maintainers" effort.
- Assess, quantitatively, the present extent of the problem in the Navy systems.
- Set up a communications network between Maintainers and Systems Managers via "workshops" and "guidebooks."
- Develop a "Taxonomy for Design"--a distribution of tasks for both corrective and preventive maintenance.
- Devise updated training and symptomatology packages to enhance trouble-shooting ability and general information processing presentation capabilities.
- Assess role of computers in fault-isolating diagnosis and trouble-shooting.
- Design effective software formatting in automated maintenance trouble-shooting.
- Set up technological forecasting studies for projected future systems.
- Devise means of reducing non-replacement activities in the maintenance process.
- Determine what can, and cannot, be done with present state-of-the-art maintenance-related materials.

PRIOR AND RELATED EFFORTS

A related effort is anticipated to be underway at the Office of Naval Research.

UNFUNDED/UNDERFUNDED REQUIREMENTS

None for FY-79

COORDINATION

This effort is being planned in coordination with one anticipated at the Office of Naval Research.

COST BENEFITS; COST AVOIDANCE; POTENTIAL PAYOFF

The updating of maintainability design criteria and procedures will have the effect of significantly decreasing future system maintenance costs because maintainability considerations will be adequately addressed very early in the system development process.

SPONSORS AND USERS

Sponsor of this task is the Naval Air Systems Command (AIR-340F). The tri-service, NASA, and industry.

IN-HOUSE/CONTRACTOR EFFORTS

None; FY-79 new start

LAYOUT OF ESTIMATED (6.2) COSTS IN MAN-MONTHS
(80K/man-years)

- Quantitative Assessment of Maintainability Problems in Navy Systems . . . 1-3 man-years
- Assessment of Appropriations of Present Navy: Organization, Philosophy, and Materials for Successful Effort . . . 3-4 years

The combined results of the above two efforts will constitute sufficient documentation to provide go, no-go rationale for the efforts' continuation in terms of the following sub-thrusts.

- Initial Designers, Maintainers, and Systems' Managers Communications Network . . . 2-3 years
- Trouble-Shooting/Information Processing Thrust . . . 2-3 years
- Role of Computers in Design for Maintainers . . . 1-2 years
- Design for Life Cycle Thrust . . . 1-2 years
- Technological Forecasting Studies . . . 1-3 years
- Non-Replacement Activity Enhancement . . . 1-2 years

SECTION 4.0

STATEMENT OF WORK

DESIGN FOR MAINTAINERS PROGRAM

EXPANDED SUBTHRUSTS
STATEMENTS OF WORK

Contractors shall provide the required personnel, facilities and travel to conduct research and analyses as described below:

1. Quantitatively assess the extent of the problem in Navy Systems.

Analyze types of maintainers' errors in generic systems (electronics, mechanical, hydraulic, etc.), so as to be able to predict what types of "design-for-maintainers" improvements can be made in each type of system. The product of this effort will be a document which calls-out major Navy maintenance systems problems in quantitative terms; as well as a listing of suggestions as to how and what kind of **design** considerations can impact systems development positively.

2. Assess use of presently-available state-of-the-art materials for design suggestions.

Assess, relative to the maintainability-design problem, what effectively can be done with present state-of-the-art materials. For example, one possible use of some procedures outlined in the Air Force's FJPAs, having to do with trouble-shooting, involves the potential use of Checkout Procedures and Action Trees as **designed-in** trouble-shooting aids. In addition, the relevance, for design, of the following instruments should be examined: Human Reliability Prediction Systems Users Manual 1977, Elementary Reliability Unit Parameter Technique (ERUPT) and the Functionally Oriented Maintenance Manual (FOMM). The product of this effort will be a document outlining what can effectively be done, for design purposes of present maintainability material, as well as a reading of current Navy philosophy in these matters, with a statement of feasibility of how the latter might be changed, if necessary. These and other concepts should be explored in a **design** context.

This would also require the acquisition of pertinent Navy and DOD documents to be perused so as to determine what current maintainability design philosophy is, as well as an assessment as to the degree this philosophy actually impacts current system development. Also, this effort would be aimed at assessing the feasibility of (and problems inherent in) changing design-organizational philosophy in such cases as needs suggest changes therein.

3. Designers, Maintainers, and System Managers Communication Network

A Clear need exists for establishing a communications network, for purposes of surfacing mutually perceived problems in maintenance design, between designers, maintainers, system managers and performance measurement experts via a series of "workshops" and "guidebooks."

During these workshops, participants would be tapped for inputs as to what the problems, limitations and possibilities are for a design-for-maintainers program implementation. First-cut design "guidebooks" would also be forthcoming from this effort; these should address such issues as: tools design, test bench design and access design.

4. Trouble-Shooting/Information-Processing Thrust

Review for adequacy, previous trouble-shooting research efforts. Assess information-processing literature for principle guidelines of ease-of-trouble-shooting equipment designs. Test these designs. Explore means of enhancing equipment-failure symtomatology.

Assess extent to which trouble-shooting guides and manuals are of assistance to maintainers; if these are found to be ineffective (from above research), devise means to improve them. Explores means to ensure that effective trouble-shooting guides are produced from systems inception in future systems' developments. The product of effort will be a "guidebook" of ease-of-trouble-shooting design principles to be used by design engineers.

5. Assess Possible Role(s) of Computers in Design-for-Maintainers Program

Evaluate the state-of-the-art of computer technology as it potentially impacts upon maintenance-design parameters. These parameters will include, but not necessarily be limited to, the following:

Diagnosis/trouble-shooting, accessibility, personnel considerations, training requirements, stand-by purchase and storing (spares), automatic diagnostic systems, equipment design, equipment pecularity, safety, tool development, and operational, intermediate and depot maintenance conditions, as well as to determine the feasibility of developing computer-aided maintainability access and arrangement design tools such as WOLAP, etc. The product of this effort will be a document detailing the manner whereby computers can be more effectively employed in the design-for-maintainers process.

6. Design for Life Cycle

The Russian Navy has adopted a Design for Life Cycle systems philosophy. At the core of this philosophy is the notion that systems should be designed, maintenance free, for the intended life cycle of the system and subsequently discarded. The feasibility of taking this 100% reliability approach to Navy system design should be explored for the 1980's-2000's time frame.

The product of this effort will be a document containing the rationale(s) for instituting and not instituting "design-for-life-cycle" program efforts in generic Navy systems for the 1980-2000 time frame.

7. Technological Forecasting Studies

Do, as a possible adjunct to the preceding efforts, forecasting studies aimed at predicting the effects of technological advances on "design-for-maintainers" efforts. Studies should employ state-of-the-art capability in Similar System Analysis to forecast design-for-maintainers consideration for future systems from those presently employed. The results of these studies would assist future designers in identifying potential stumbling-blocks that may arise in designing future systems for ease of maintenance in both traditional and more exotic environments.

8. Non-Replacement Activity Enhancement Studies

Simple remove-and-replace maintenance activities have been shown to ease maintenance logistics considerably. Adding to the maintainers tasks such activities as: adjust, calibrate, etc., make the task much more complex and time consuming. A means must be found to increase remove-and-replace activities and to decrease other, non-replacement activities in the maintenance task. The product of this effort will be a set of design guidelines for increasing remove-and-replace maintenance activities.