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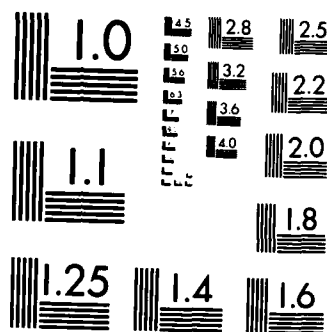
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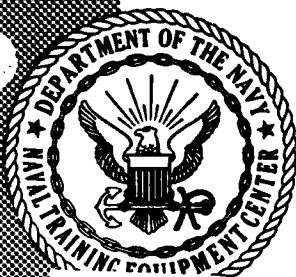
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ALLEVIATING FLEET MAINTENANCE PROBLEMS THROUGH  
MAINTENANCE TRAINING AND AIDING RESEARCH

Frans Nauta  
Logistics Management Institute  
6400 Goldsboro Road  
Bethesda, Maryland 20817

May 1985

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This study reviews the factors influencing maintenance performance in the Fleet; assesses their relative impacts, using several combat systems as case examples; and identifies inadequate maintenance skills as one of the top two contributing factors, equipment design being the other one. Based on future technology and manpower trends, it concludes that the gap between maintenance skill requirements and those available in the Fleet will widen further, unless drastic action is taken to improve technical training and maintenance job aids. The report presents an outline of the steps the Navy must take to improve maintenance performance, including specific research and development projects in maintenance training and aiding technology.				
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Frans Nauta

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LOGISTICS MANAGEMENT INSTITUTE  
6400 Goldsboro Road  
Bethesda, Maryland 20817

## EXECUTIVE SUMMARY

Poor maintenance is the foremost cause of operational readiness shortfalls in today's Navy, and inadequate skills are the root-cause. The gap between required and available maintenance skills is explained, in part, by a shortage of senior petty officers in combat systems maintenance ratings. The primary factor, however, is inadequate technical training. This is evidenced by an increasing dependence of the Fleet on nonorganic technical assistance for casualty repairs. Even more overwhelming evidence is provided by indicators of maintenance skill deficiencies, such as excessive no-fault removals.

Case studies of several combat subsystems confirm that the Navy's formal training approach does not provide a sufficient foundation of knowledge and skill for technicians to develop maintenance job proficiency through experience. In essence, the training graduate entering the Fleet today is a novice, not an apprentice-level technician as was the case ten years ago.

The Navy is caught in a vicious cycle of declining self-sufficiency and skill stagnation. Simple repairs must be done by senior petty officers (E-5 and E-6) because the junior petty officers (E-4) do not possess the needed maintenance skills. Shipboard manning is not designed for this substitution, consequently, no skilled man-hours are left to cope with complex repairs. Complex repairs, therefore, must be done with nonorganic technical assistance. As a consequence, skilled technicians stagnate at whatever skill level they possess, while apprentice technicians do not grow in proficiency at a rate required to attain journeyman-level skills during their first terms. This cycle feeds on itself with the consequences becoming increasingly pronounced. The cycle must be stopped if the Navy is to continue meeting its mission requirements. The only way to turn the situation around is through significant improvements in technical training.

Several critical issues in maintenance training and aiding technology should be addressed by research and development (R&D). For example, the present knowledge about cost-effective training of cognitive skills (such as troubleshooting) is embryonic. Acquisition and use of effective maintenance training equipment or training delivery systems suffer from a lack of knowledge about the interactions among design characteristics, training objectives, training sequence, and individual differences. Implementation of job-aiding technology is limited by incomplete understanding of what technical information in what format is needed by the technician and how tutorial software should be structured to maximize on-the-job skill acquisition.

Based upon the results of this study, it is recommended that the Navy:

- Adopt a coordinated R&D program in maintenance training and aiding technology with the single objective of ensuring that maintenance technicians acquire and maintain the knowledge and skills required for proficient job performance.

- Give high priority to projects on the following subjects:
  - technical information needs in maintenance performance,
  - expert troubleshooting strategies,
  - specifications and guides for job-aiding software,
  - a Fleet training delivery system,
  - expanded task-analysis procedures to fill the voids in current instructional system development (ISD) guides,
  - relationships among training equipment design characteristics, transfer-of-training, and training objectives,
  - a decision support system (training equipment acquisition manual and supporting data base) to assist Systems Command program managers and Office of the Chief of Naval Operations sponsors in training equipment acquisition,
  - specifications for general-purpose and generalized maintenance training equipment, including standardized modules for student and instructor stations.

These R&D efforts will be necessary, but not sufficient. Significant improvements in maintenance skills require a much broader program, addressing other key factors influencing job performance: occupational structure, job design, training philosophy, instructional systems development, individual performance monitoring, personnel management, human factors engineering, and design for maintainability. Skill-deficiency is a systemic problem influenced by numerous interrelated factors. Better maintenance training equipment and job aids will pay off in improved job performance only if comparable improvements are made in the other factors. The Navy has several R&D efforts underway to foster improvements in selected areas. Included are the Enlisted Personnel Individualized Career System, the Navy Technical Information Presentation System, the Design for Maintainability Program, and the Testing Technology Program. What appears to be lacking is a coordinated plan of action addressing all of the chief contributors to poor maintenance performance.

On a more global basis, it is recommended that the Navy:

- Institute a comprehensive Maintenance Improvement Plan for management action on the chief contributors to poor maintenance performance.
- Appoint a task force to review and manage execution of the Maintenance Improvement Plan.

- Create a permanent office in Headquarters, Naval Material Command responsible for monitoring technology trends, assessing their impacts on maintenance skill requirements, and disseminating that information among the manpower, personnel, training, and logistics support communities.

PREFACE

This study, which was performed during the 1982-1984 time frame, was co-sponsored by the Naval Training Equipment Center (Human Factors Division) and the Navy Personnel Research and Development Center (Training Research Directorate) by direction of the Deputy Chief of Naval Operations (Manpower, Personnel, and Training), Research, Development and Studies Branch (OP-01B7, formerly OP-115). The purpose of the study was to: (1) develop a descriptive model of Navy maintenance, defining and assessing known factors which influence maintenance performance, and (2) develop, on the basis of this model, a systematic research and development (R&D) program in maintenance training and aiding, responsive to current and projected needs, to improve maintenance skills and performance. This Final Report presents the study findings and conclusions and describes the recommended R&D program.

In the conduct of this study, Logistics Management Institute (LMI) was supported by the following subcontractors in the subject areas indicated: Applied Science Associates, Inc. (Dr. Andrew P. Chenzoff and Mr. Reid P. Joyce): technical data and maintenance job aids; Parker Consultant Associates, Inc. (Mr. Edward L. Parker and Mr. Richard I. Merrell): maintenance training equipment; and Advanced Research Resources Organization (Dr. Edwin A. Fleishman and associates): individual abilities.

In the formulation of specific R&D recommendations, LMI benefitted from the experience, ideas, and comments of many individuals beyond the subcontractors listed above. While LMI assumes responsibility for the final product, we gratefully acknowledge the following contributors: Dr. Gerard M. Deignan (Air Force Human Resources Laboratory), Dr. Ralph DePaul, Jr. (DETEX Systems, Inc.), Mr. Daniel J. Dwyer (Naval Training Equipment Center), Dr. John D. Fletcher (University of Oregon), Dr. John D. Folley (Applied Science Associates, Inc.), Dr. Kay Inaba (XYZYX Information Corporation), Dr. William E. Montague (Navy Personnel Research and Development Center), Mr. William A. Rizzo (Naval Training Equipment Center), Dr. Robert J. Seidel (Army Research Institute for the Behavioral and Social Sciences), and Dr. Wallace H. Wulfeck, II (Navy Personnel Research and Development Center).

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individual skill proficiency, and the quality of job aids. Individual proficiency is a function of experience, training, and individual abilities. "I"-level maintenance performance is influenced by the same factors and, additionally, by the availability of automated test equipment (ATE) and the quality of test program sets (TPS) for checkout and fault isolation of components and modules from the prime equipment. "D"-level maintenance is classified as indirect maintenance and is not of interest to this study.

Figure 1 (page 10) shows only the primary interactions between the various factors (ultimately, all factors are interrelated), and identifies those interactions which are the weak links in weapon system acquisition and support. Strengthening those links would alleviate much of the maintenance performance problem.

#### SUMMARY OF CASE STUDIES

The maintenance support of several combat systems/subsystems was examined during this study. Systems/subsystems from the surface, air, and subsurface communities were included in the sample. The findings and observations, which are based on information collected through Fleet visits, 3-M data, and previous Navy and contractor studies, are summarized in the following subsections.

**READINESS SHORTFALLS.** Any discussion of readiness shortfalls is open to arguments about the measurement of readiness, specification of goals, and true mission capabilities. The subject of readiness measurement is complex; many studies have been conducted on improving current readiness indicators as well as readiness management (relating resource inputs to valid output measures of readiness). This study is not intended to address these issues, but cannot avoid commenting on current measures in order to clarify what is meant by "readiness shortfalls." Arguments about the adequacy or inadequacy of current measures and goals for material readiness are inspired essentially by the following three points:

a. Multimission platforms with combat systems possessing multi-operational modes are acquired exactly for that purpose: to be capable of performing multiple missions exploiting many different operational modes. Yet, the Navy's formal goals (and, therefore, the readiness measures reported) are stated in terms of selected (primary) missions and require only selected (mostly one) operational modes to be "up."

b. Reaching for stated MC goals, which invariably happens in the Fleet, may conflict with goals that are more meaningful for the Fleet. For example, in the case of Naval aircraft, it may be operationally more desirable to have 50 percent of the squadron in FMC status and 50 percent in NMC status than achieving the stated MC goal with all aircraft in PMC status.

c. The criteria applied in operational tests and acceptance tests generally reflect the true operational requirement; i.e., the reason why the weapon system was developed. Yet, the criteria applied in readiness reporting

TABLE 1. STANDARD READINESS MEASURES

UNIT READINESS	<p>C1 (fully ready): A unit fully capable of performing the mission for which it is organized or designed.</p> <p>C2 (substantially ready): A unit has minor deficiencies which limit its capability to accomplish the mission for which it is organized or designed.</p> <p>C3 (marginally ready): A unit has major deficiencies of such magnitude as to limit severely its capability to accomplish the mission for which it is organized or designed.</p> <p>C4 (not ready): A unit not capable of performing the mission for which it is organized or designed.</p> <p>C5: Applies to weapon systems in overhaul.</p>
MATERIAL CONDITION	<p>FMC (fully mission capable): When all mission-essential subsystems are installed and operating as designated by the Service.</p> <p>PMC (partial mission capable): When systems can perform one or more but not all assigned missions because one or more of their mission-essential subsystems are inoperative for maintenance or supply reasons.</p> <p>MC (mission capable): The summation of FMC and PMC.</p> <p>NMC (not mission capable): When none of the assigned missions can be performed either due to maintenance (NMCM) or supply (NMCS).</p>
OPERATIONAL AVAILABILITY	<p><math>A_o = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}} = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}}</math>, where:</p> <p>MTBM = mean time between maintenance</p> <p>MDT = mean down time = MTTR + MLDT + MADT</p> <p>MLDT = mean logistics delay time (awaiting parts)</p> <p>MADT = mean administrative delay time</p> <p>MTTR = mean time to repair.</p>

SUMMARY DESCRIPTION OF THE MODEL. By virtue of its definition,  $A_o$  (see Figure 1) is determined directly by equipment reliability, spares availability or responsiveness of the supply system, availability of tools and operable (calibrated) test equipment, Fleet support, and organizational ("O"-level) maintenance performance. The higher levels of maintenance, intermediate ("I"-level) and depot ("D"-level), interact with the "O"-level both directly and indirectly. Directly, poor "O"-level maintenance overburdens the higher levels and vice versa. Indirectly, the various maintenance levels interact through test equipment and spares availability because "I"- and/or "D"-level maintenance determine the turnaround time for test equipment repair/calibration and module repairs. "O"-level maintenance performance is further influenced by equipment characteristics (reliability, maintainability, and maintenance concept), operational environment, organization and job design, Fleet practices, and maintenance capability (available skills). The latter, in turn, is determined by the availability of maintenance personnel, their

**READINESS MEASURES.** Maintenance is not an end in itself. The sole purpose of maintenance is to achieve and sustain combat readiness; i.e., the ability of a unit to perform the missions or functions assigned. Combat readiness is the composite of personnel readiness (determined by personnel availability and training) and materiel readiness (determined by logistics support). A measure of combat readiness is provided by the "C" ratings of the unit status and identity reporting (UNITREP) system, a standard Department of Defense (DoD)-wide reporting system instituted by the Joint Chiefs of Staff (JCS). UNITREP combines resource-specific (personnel, supply, equipment, and training) and mission-area (antisubmarine warfare, antisurface warfare, antiair warfare, and mobility) ratings in reporting an overall readiness ("C") rating in terms of five levels of readiness (see Table 1).

Material readiness is also measured and reported separately through different systems. One is the DoD Materiel Condition Reporting System which measures material readiness in terms of mission capable (MC) rates; i.e., the percentage of time (hours) spent in each of the three material conditions: fully mission capable (FMC), partially mission capable (PMC), and not mission capable (NMC) (see Table 1)<sup>11</sup>. (For Army and Marine Corps ground equipment, time is measured in terms of days, not hours, such that downtimes of less than 12 hours duration are not counted.) MC reporting in the Navy has been implemented, so far, only for naval aviation. Another measure is operational availability ( $A_0$ ); i.e., the probability that equipment will be ready for use when needed at any given time (in the operational environment).  $A_0$  can be measured in different ways; the standard equation is shown in Table 1. The MC rate is primarily an operational (and historical) measure of material readiness, while  $A_0$  is a logistics (and, perhaps, more predictive) measure of material readiness. The two differ as a result of different definitions and accounting rules. Limited operating hours tend to inflate MC rates but have less impact on  $A_0$ . In general, the computed  $A_0$  for a weapon system is less than the reported MC rate. Furthermore, the norm in the Navy is to compute the  $A_0$  for multimission systems separately by mission area.

In sum, readiness or availability data must be interpreted with great caution, giving due consideration to the definitions applied. The model uses  $A_0$  as the output measure of the maintenance system.

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<sup>11</sup>DoD Instruction 7730.25, "Materiel Condition Reporting For Mission-Essential Systems and Equipment," May 1980. The MC rates defined in this instruction replace the operational readiness rates defined in the 1972 version of the same instruction. The revised instruction requires each Service to: (1) establish MC goals, (2) monitor the rates actually achieved, (3) identify the top five problems at the subsystem level causing nonachievement of goals, and (4) develop remedial actions necessary to correct those problems.

CRITERION MEASURES. Maintenance performance can be measured in many different ways: on an individual, team, or unit basis. The model uses the following four measures on an aggregate, unit basis:

a. Capability. Measured in terms of the percent of maintenance tasks accomplished without outside, nonorganic assistance.

b. Proficiency. Measured in terms of the repair time (including diagnostic time but excluding parts awaiting or logistics delay time) observed (denominator) compared to that required by an expert technician (numerator).

c. Quality. Measured in terms of three benchmarked scales capturing the following dimensions of quality of maintenance performance.

(1) Effectiveness. Extent to which maintenance returns the equipment to fully operational performance capability.

(2) Efficiency. Extent to which good modules are erroneously removed and replaced (NFR rate) as evidenced by retest okay data at the intermediate or depot levels of maintenance.

(3) Reliability. Extent to which maintenance-induced damage is inflicted on the equipment or the reliability of the equipment is degraded following maintenance action.

d. Sustainability. Measured in terms of three benchmarked scales capturing the following dimensions of wartime sustainability.

(1) Self-sufficiency. Extent of capability to perform emergency repairs with no outside support, including repairs routinely allocated to higher maintenance levels.

(2) Battle Damage Repair. Extent of capability to return battle damaged equipment to operation, even if degraded.

(3) Endurance. Extent to which battle conditions (intensity and duration) can be endured.

These measures are theoretical constructs which cannot be quantified from the maintenance data routinely collected by the Navy (the Maintenance and Material Management (3-M) System, Casualty Reporting (CASREP) System, and technical assistance data from MOTUs and contractors). As a result, the model can only be descriptive, not quantitative. The case studies were used to establish rough orders of magnitude of maintenance performance and to rank order the various factors influencing maintenance performance in terms of the first three measures. The fourth, and perhaps the most important criterion measure, is influenced by factors beyond the scope of this study (e.g., wartime scenarios, Naval Reserve issues, etc.).

## SECTION II

## COMBAT SYSTEMS MAINTENANCE PERFORMANCE

## FACTORS AND INTERACTIONS

The factors influencing maintenance performance and the interactions between these factors are illustrated in Figure 1. A summary description of the model is included here in order to explain the study approach and the terminology used in this report.

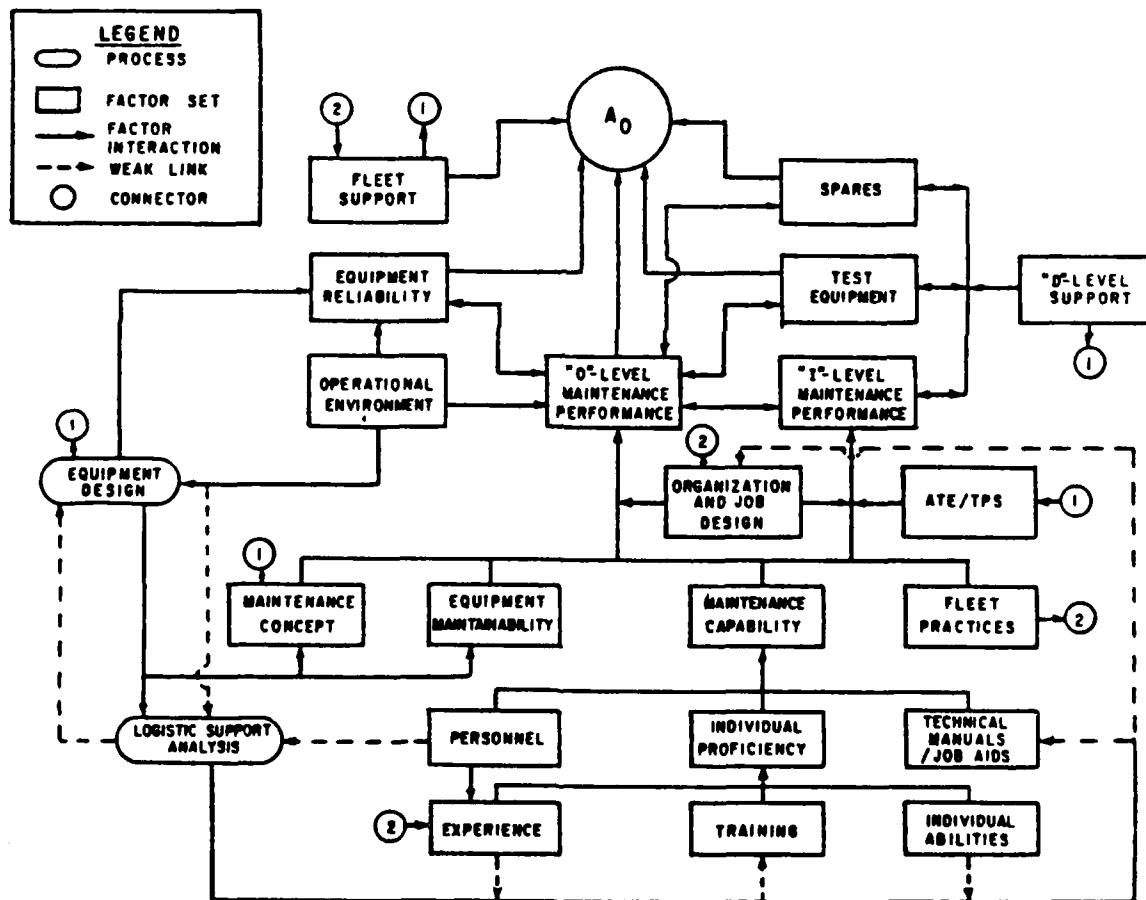


Figure 1. Simplified Model of Maintenance Performance.

c. Recommendation #3. Create a permanent office in Headquarters, Naval Material Command, responsible for monitoring technology trends, assessing their impacts on maintenance skill requirements, and disseminating this information among the manpower, personnel, training, and logistics support communities.

d. Recommendation #4. Revise the Navy Training Improvement Program to include the specific R&D projects in maintenance training and aiding technology identified in this report.



factors influencing maintenance performance, e.g., inadequacies in training philosophy, job-task analysis, job design, and instructional systems development. These factors appear to be beyond the specific research issues addressed by NAVTIP. The effective date of NAVTIP, originally planned for October 1983, was deferred by lack of funding.

ONLY A BALANCED AND COMPREHENSIVE PROGRAM CAN OFFER A SOLUTION TO THE PROBLEM. The data provided in this report demonstrate that maintenance deficiencies are now reaching critical proportions. The problem is systemic, yet the Navy has, time and again, attempted to solve the problem through piecemeal actions. In our opinion, there has been little noticeable improvement in maintenance performance; we believe the same may also be true for NAVTIP because of its exclusive focus on training and aiding technology. What is needed is a broad and balanced program addressing all key factors influencing maintenance performance. Section IV describes how current job design, organization design, maintenance philosophy, training philosophy, instructional system development, personnel utilization and classification, maintenance data, technical manuals, and supply support all play a key role which may inhibit achieving the improvements in maintenance performance expected from such initiatives as design for maintainability, NAVTIP, and advanced-technology, maintenance training equipment and aids. Until and unless the Navy is committed to tackle the problem in all its dimensions, the situation will probably deteriorate further. The short-term impacts are susceptible to compensation through unusual and expensive efforts by the Fleet; the long-term consequences, however, bode ill for the future support of more complex combat systems.

## RECOMMENDATIONS

The present study has attempted to consolidate the current state-of-knowledge with regard to Navy combat systems maintenance today and in the mid-1990s; the factors influencing maintenance performance; the cause-effect relationships which are key to today's performance shortfalls; and the voids in knowledge requiring R&D efforts to improve maintenance. Undoubtedly, the study is incomplete; however, it may serve as a start for a Navy-wide effort to improve combat system maintenance. The Navy possesses considerable in-house R&D capabilities which should be more fully utilized through a coordinated and focused plan in support of the needs of the Fleet. This study provides the blueprint for such a plan. The study also identifies the impact future technology may have on maintenance skill requirements. Section V presents recommendations which are summarized as follows:

- a. Recommendation #1. Institute a comprehensive Combat System Maintenance Improvement Program for management action on the chief contributors to poor maintenance performance.
- b. Recommendation #2. Appoint a task force to review and manage execution of the program; use the results of the present study in formulating the Plan of Action and Milestones to execute the program.

perform the routine maintenance tasks expected, so the E-5 and E-6 must do these tasks instead. Due to the shortage of skilled E-5/E-6 technicians,<sup>10</sup> these experienced technicians are preoccupied with routine maintenance tasks and need help for the less-frequent complex tasks, and chief petty officers have become managers too busy with paperwork. The end result is that outside assistance is necessary and skills are stagnating at all levels. It is only very recently that one Type Commander, Naval Surface Force, U.S. Atlantic Fleet (COMNAVSURFLANT), has recognized that top-level action is necessary to break this cycle of skill-stagnation. The resulting Combat Systems Improvement Program (CSIP) is focused on meeting technical training shortfalls, but this program is still in an embryonic stage.

THE NAVY'S APPROACH TO THE PROBLEM HAS BEEN LARGELY ONE-SIDED. There are two sides to the problem: a demand side (skills and knowledge requirements as determined by system design characteristics and technical manuals (TM) or aids available to the maintainers) and a supply side (skills and knowledge possessed by technicians as determined by training, experience, and individual abilities). To close the existing gap between the two, both offer opportunities for improvement. The Navy, so far, has focused its initiatives on the demand side of the problem and has chosen to downplay the supply side. Programs such as design for maintainability and design for testability have resulted in new standards, specifications, and design guides for use in acquisition of new weapon systems. If enforced, one might expect future reduction in maintenance task difficulty compared to what otherwise might have resulted (not necessarily a reduction compared to today's maintenance tasks as a result of increasing complexity). Similarly, the Navy Technical Information Presentation System, if implemented, would improve the quality of technical information available to the maintainer. Both types of programs will permit an improvement in maintenance performance.

On the supply side, however, similar initiatives have been lacking. While the Navy has spent large amounts on R&D in personnel and training, it has been largely unable or unwilling to transfer results into use. This phenomenon was, once again, noted by the Defense Science Board (DSB) in the 1982 Summer Study on Training and Training Technology (see Appendix B for a summary of this study and Appendix C for the decision memorandum from the Secretary of Defense approving the DSB recommendations). A number of circumstances (increasing complaints by the Fleet, the DSB 1982 Summer Study, and the Chief of Naval Research's urging that the Navy utilize results from past R&D investments) have led to the recent creation of the Navy Training Improvement Program (NAV TIP). Appendix D describes how this program is currently structured. NAV TIP represents the first Navy-wide program addressing the supply side of the maintenance problem. NAV TIP points in the right direction but still leaves unaddressed some key, training-related

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<sup>10</sup>Caspar W. Weinberger (Chairman), Military Manpower Task Force Report to the President on the Status and Prospects of the All Volunteer Force, Washington, DC, October 1982.

designed as an emergency program to fill voids in organic maintenance capabilities, it has become a permanent fixture in today's Navy.

Third, skill deficiencies resulting in inefficient troubleshooting and high no-fault removal (NFR) rates have little impact on combat system  $A_0$  as long as the supply system supports this with adequate stockage of spares. In this sense, the supply system, if funded well, can compensate for poor maintenance performance. Problems arise only when funding limitations and/or long turnaround times for depot-level repairs limit this option, as happened in the second half of the 1970s. Available data indicate that the Fleet is relying heavily on the supply system's ability to compensate for poor maintenance: depending on combat system, 30 to 50 percent of weapon replaceable assemblies and 60 to 80 percent of printed circuit boards returned to higher maintenance levels for checkout and repair are found ready for issue; i.e., were unnecessarily removed from the combat system.<sup>9</sup> While this high NFR rate has several contributing causes (e.g., maintenance concept, tolerance incompatibility between the combat system and test program sets (TPS), operational environment), lack of troubleshooting skills is the chief cause. With the steep cost increases of spare parts experienced with successive generations of increasingly complex combat systems, the affordability of this option to compensate for skill deficiencies is becoming less and less.

In sum, the costs incurred by the Navy, to compensate somehow for maintenance deficiencies, is impossible to determine accurately. A conservative estimate is that it runs into several billions of dollars annually, just for combat systems.

LEAVING THE PROBLEM UNSOLVED HAS STARTED THE NAVY ON A VICIOUS CYCLE OF COMBAT SYSTEM MAINTENANCE SKILL STAGNATION AND DEGRADATION. Because the Fleet must meet its mission requirements in peacetime, it has attempted to compensate for maintenance skill deficiencies as noted above. Compensating for, rather than tackling the root-causes of the problem, however, may be leading the Navy down the path of ever-decreasing self-sufficiency -- one of the key characteristics in which the U.S. Navy has excelled, and still excels, over the Soviet Navy.

Essentially, what is happening is that the most complex maintenance tasks (system-level failure diagnostics) are performed by nonorganic technicians, routine corrective maintenance by senior petty officers, and preventive maintenance (which is limited to simple, proceduralized tasks in the case of Navy electronics equipment) by junior (E-4) personnel. The whole concept of apprentice training and skill enhancement on the job is defeated because the typical graduate from entry-level training ("A" + "C" School) entering the Fleet is a novice, not an apprentice. Often, the pipeline graduate cannot

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<sup>9</sup>CINCLANTFLT message to Chief of Naval Technical Training, Subject: Training of Technical Ratings for Fleet Maintenance; date time group 071410Z, Oct 81.

First, when poor maintenance performance results in excessive equipment downtime (low  $A_0$ ), one option is to carry more equipment in inventory than otherwise necessary to meet mission requirements. For large end items, such as aircraft, this is not normally an option, because the acquisition objective is based on force structure and attrition/training requirements. Nevertheless, using the F-14A aircraft as an example, the same mission capability achieved today (15 squadrons of 12 aircraft each with a mission-capable rate of 58 percent vice the 70 percent goal) could be achieved with roughly 30 less aircraft if maintenance support met Navy goals. On this basis, one may impute the cost of maintenance deficiencies for the F-14A to be roughly one billion dollars in excess procurement costs and several hundred million dollars annual operating and maintenance (O&M) costs, as suggested by several other studies.<sup>5,6,7</sup>

Second, Fleet support in the form of technical assistance is available from Mobile Technical Units (MOTUs), Systems Command field activities, and contractors. The available data show that the Fleet is relying increasingly on this option to compensate for organic maintenance shortfalls: requests for assistance have increased 30 percent from 1977 through 1981, a period during which the actual number of surface combatants declined.<sup>8</sup> Moreover, since 1980, a combat system maintenance team (approximately 22 technicians) has been embarked on each Pacific Fleet carrier battle group that deploys. (This team assists in combat system maintenance and provides on-the-job training to maintenance personnel aboard the units of the battle group. In addition to the 50-75 civilian personnel (Navy and contractor) normally embarked with each battle group, this team is aboard each carrier in support of the air wing, providing maintenance assistance for aircraft and support/test equipment. Another type of technical assistance, the so-called "combat system groom," has become standard practice Navy-wide. Scheduled periodically by the Type Commanders, groom teams provide a direct work force to the ship or squadron to correct equipment malfunctions and ensure the equipment is in highest operating condition ("peaked") prior to deployment or exercises. Originally

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<sup>5</sup>F. Fuchs and K. Inaba, "Design for the Maintainer," Technical Report NADC-79218-60 (Warminster, Pennsylvania: Naval Air Development Center, March 1981).

<sup>6</sup>F. Fuchs, K. Inaba and F. Siskel, "Performance Improvement for Navy Training Organizations," Technical Report NAVTRAEQUIPCEN 77-C-0166 (Orlando, Florida: Naval Training Equipment Center, July 1979).

<sup>7</sup>D. K. McBride and J. V. Lambert, "A Human Factors Design-for-Maintainers Technology Development Program," Proceedings, Design for Maintainers Conference (Warminster, Pennsylvania: Naval Air Development Center, March 1982).

<sup>8</sup>Unpublished data, Naval Sea Support Center, Atlantic (NAVSEACENLANT), Norfolk, VA.

## OBSERVATIONS

Applications of new technology in maintenance training equipment and job aids will have a positive effect on maintenance skills and performance. However, the improvements attainable from such applications alone appear limited. To fully exploit the promise of new technology for training and aiding, the Navy must address a number of other, fundamental factors determining maintenance skill acquisition and performance. This judgment is based on the following observations.

**POOR MAINTENANCE PERFORMANCE IS A SYSTEMIC PROBLEM.** Numerous factors, other than training equipment and aids, influence maintenance skill acquisition and performance. Poor maintenance performance is a systemic problem which defies solution through piecemeal action. For the same reason, the problem is hard to solve. Concerns about a growing gap between maintenance skills required and those available in the Navy enlisted force were first expressed over 20 years ago in a study reviewing Department of the Navy management:

The Department is encountering extreme difficulties even at present to effectively man the ships and aircraft of the Operating Forces with qualified and experienced officers and technically qualified enlisted personnel. The increasing complexity indicated in the ships and aircraft of the future Navy will demand larger numbers of these talented and highly trained people. According to the predictions, the shortage will continue to increase. If this condition persists, the Navy can well become ineffectual. The possibilities indicated in this study present a problem of very serious proportions.<sup>4</sup>

That study group advocated adoption of a mix of solution approaches, including: providing better incentives to improve retention, improving personnel programs and training, and reducing nonessential complexity in new weapon systems. These recommendations were accepted by the Secretary of the Navy, but the effects of any actions taken to date have been minimal; the above quotation applies without change to today's situation.

**SOLVING THE PROBLEM IS FAR CHEAPER THAN COMPENSATING FOR IT.** Compensating for the effects of maintenance performance shortfalls is easier than solving the problem, and this is what the Navy has traditionally attempted to do. Compensating actions fall in three categories: (1) redundancy of equipment, (2) reliance on nonorganic Fleet support, and (3) excess supply of spares. All of these are very expensive, but the costs are never attributed to maintenance deficiencies.

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<sup>4</sup>RADM H. J. Kossler, USN, Study Director, "Review of Management of the Department of The Navy," Volume II, Study 5 of 7 Studies: Manpower Management Study, (26 October 1962) p. 112.

Installations, and Logistics.<sup>3</sup> Also examined was the impact of the Navy's planned growth in terms of electronics maintenance manpower requirements and the Navy's ability to meet these requirements under present manpower recruitment policies and known demographic trends. Section III summarizes these findings and conclusions about future trends.

#### SUMMARY OF RESULTS

The need for additional R&D in maintenance training and aiding was confirmed by the conclusions drawn as a result of this study:

- a. Combat system maintenance performance is weak and inhibits the Navy from achieving peacetime material readiness goals.
- b. Lack of individual maintenance skills is one of the top three factors causing maintenance performance deficiencies; in turn, inadequate technical training is the top-rated factor explaining lack of skills.
- c. Future technology, by itself, is not going to alleviate the maintenance skill gap. The most probable trend is a continued increase in the cognitive "load" of the organizational-maintenance job, requiring system-level understanding, a mental model of the symptom-failure process, and cognitive abilities related to information processing and decision-making skills. However, the intermediate-maintenance level, as known today for avionics, will, in all probability, disappear, thereby reducing the need for intermediate-maintenance technicians.
- d. Present manpower recruitment and personnel policies do not accommodate the planned growth of the Active Navy. Changes will be required in personnel policies to improve retention, and in manpower recruitment policies to maintain the minimum, Congressionally mandated, accession quality standards. Electronics maintenance personnel requirements are growing at a rate more than double that Navy-wide. Cost-effectiveness of technical training is becoming the single most critical issue in meeting future operational requirements.

Based on an examination of the factors influencing acceptance, utilization, and effectiveness of maintenance job aids and maintenance training equipment, certain voids in the current state of knowledge were identified. Candidate R&D projects in maintenance training and aiding technology are identified in Appendix A.

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<sup>3</sup>"Steps Toward Improving the Materiel Readiness Posture of the Department of Defense," a joint Office of the Secretary of Defense (OSD)-Services-Industry study, commissioned by the Under Secretary of Defense for Research and Engineering, managed by the Institute for Defense Analyses (IDA), and completed in September 1983. This 30-volume study is commonly referred to as the OSD-IDA R&M Study.

which drive maintenance training/aiding requirements and to provide an assessment of how these requirements may change in the future.

#### STUDY OBJECTIVE

The objective of this study was threefold:

- a. To define the factors affecting maintenance requirements and performance in the Navy, and evaluate their impacts and interrelationships.
- b. To project how these factors may change in the future, both short-term (1980s) and mid-term (1990s), and assess the impact of those changes on maintenance requirements and performance.
- c. To identify those key factors which the Navy's maintenance training technology research program should address to maximize payoff from R&D investments.

#### STUDY APPROACH

The study effort focused on combat systems maintenance (i.e., primarily electronics) and examined three key questions:

- a. Are maintenance performance deficiencies causing a serious shortfall in peacetime material readiness or projected wartime sustainability of the Navy's mission-essential combat systems?
- b. To what extent is inadequate maintenance skill training (in formal schools or on the job) the root cause of maintenance performance deficiencies?
- c. Will technology applied in future weapon systems eliminate the maintenance skill-deficiency problem?

To examine the first two questions, several case studies were conducted on a small sample of combat systems currently installed on air, surface, and subsurface platforms. Section II documents the findings and conclusions on the extent of maintenance performance shortfalls, the untoward impact on operational availability ( $A_0$ ), and the "band-aid" programs developed by the Fleet to work around these deficiencies. In order to aid an assessment of cause-effect relationships in maintenance performance, a descriptive model of maintenance performance was developed, showing the interactions of known factors directly or indirectly influencing maintenance skill requirements or maintenance performance, and their relationships to  $A_0$ . Section II summarizes this assessment of cause-effect relationships based on observations from the case studies and a simplified version of the descriptive model.

To examine the third question, trends in electronics technology were reviewed as described in the literature and in a parallel study sponsored jointly by the Office of the Under Secretary of Defense for Research and Engineering and the Office of the Assistant Secretary of Defense for Manpower.

SECTION I

SYNOPSIS

BACKGROUND

The Navy, like the other Military Departments, is facing the fact that the human element has become the most critical, problematic, and costly component of its war-fighting capability. At the same time, the hardware being developed and fielded is becoming increasingly complex. This trend has raised concerns about the Navy's ability to recruit, train, and retain the numbers and quality of personnel required to operate and support the Fleet. For example, the former Chief of Naval Material, Admiral A. J. Whittle, Jr., expressed his concern as follows:

The reason that I, as the Chief of Naval Material, worry about the supply of people is that I worry about whether or not we are building the right Navy; whether or not we will be able to man the fleet we are building.<sup>1</sup>

The Naval Research Advisory Committee (NRAC), commissioned to examine this problem, concluded that this concern was justified:

Given present trends, the Navy will find itself unable to operate and maintain its systems, in either the short or long term, with the numbers of skilled personnel necessary for effective mission accomplishment.<sup>2</sup>

The NRAC Study Group developed a number of recommendations to improve the application of man-machine technology in the design of new systems and the retrofit of current systems, to reduce operator and maintainer task complexity, to increase standardization, to improve shipboard productivity through labor-saving methods and automation, to enhance shipboard individual and tactical team training, and to increase the Navy's emphasis on training systems research and development (R&D).

As one response to the latter recommendation, the Naval Training Equipment Center (NAVTRAEQUIPCEN) and the Navy Personnel Research and Development Center (NAVPERSRANDCEN) jointly formulated a Plan of Action and Milestones for research on maintenance training and aiding (April 1981). The present study is one of the research efforts identified in that plan. The study is intended to provide a better understanding of the numerous factors

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<sup>1</sup>Office of the Assistant Secretary of the Navy (Research, Engineering and Systems), "Man-Machine Technology in the Navy," NRAC 80-9, (December 1980).

<sup>2</sup>Ibid.



are different and sometimes inconsistent or incompatible with those former criteria.

The case examples illustrate these points. For Naval air, the MC goal for deployed squadrons, as stated by the Chief of Naval Operations (CNO), is 70% for both the S-3A and the F-14A. Thus, as long as the aircraft can be flown 70% of the time, the squadron is meeting its goal. The reported MC rates (which vary over time) are typically close to this goal. However, reported FMC rates for deployed squadrons are somewhat less than CNO's goal which is defined as 80% of MC rates. The gap between MC and FMC rates (i.e., the percent of time aircraft are in PMC status) is explained primarily by the "down" status of mission avionics. Yet, the raison d'etre of the F-14A is its high-performance radar system (the AN/AWG-9); that of the S-3A, its avionics required for the antisubmarine warfare mission. Either can be down permanently without affecting reported MC rates. Both systems were acquired based on demonstrated mission reliability and re-fly reliability criteria. Applying those same criteria in periodic operational readiness evaluations might provide a better picture of the extent of material readiness shortfalls than that provided by reported MC rates.

For shipboard combat systems/subsystems, the situation is somewhat different because  $A_0$  goals are specified and  $A_0$  achieved is monitored (insofar as possible with available 3-M data). But, again, validity of these data is confounded by the different operational modes possessed by these systems. For example, the Mk 86 Gun Fire Control System (GFCS) has four operational modes; in two modes (direct and indirect Naval gunfire support),  $A_0$  is reaching the stated goal; in one (surface mode),  $A_0$  is below the goal but above the threshold; and in one (air mode),  $A_0$  is some 50 percent below the goal.<sup>12</sup> Visibility of this shortfall is diminished because, in 1980, the anti-air warfare mission for many platforms equipped with the Mk 86 was reduced from a primary to secondary mission; i.e., those surface combatants can report "C1" status for material, while the air mode of the Mk 86 is inoperable. The AN/WSC-3 Satellite Communications Set, in the satellite-communications mode, reaches its readiness goal because only 50 percent of the multiple units installed aboard a surface platform need to be operable to satisfy peacetime communications requirements. The line-of-sight version, however, may be down. The AN/BQQ-5 sonar system has many different operational modes divided among two major mission modes: active and passive. Most of the equipment associated with the active mode (roughly 50 percent of the system) can be down without affecting the passive mode. Because the latter is the mode commonly used, and the system is designed for "graceful degradation," the reported MC rate is relatively high, especially considering the complexity of the system. Data are not even collected on the up or down status of the active mode. The Mk 117 Fire Control System (FCS) also has a relatively high reported availability rate, but these data may be equally

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<sup>12</sup>This information is based on LMI's analysis of the data available as of December 1981.

misleading because, as a fire control system, the system is seldom exercised in peacetime.

In sum, available readiness indicators ("C"-ratings and reported MC rates) provide neither insight nor precise measures of  $A_0$  shortfalls. The interpretation made, based on the analysis, of the evidence collected, is that there are  $A_0$  shortfalls; that these shortfalls are serious; but that the extent of the shortfalls is not adequately reflected in the readiness indicators. Therefore, the term  $A_0$  shortfalls is used to avoid potential arguments about whether or not reported MC rates are in consonance with CNO goals. Such arguments are not germane to this study.

**TRENDS IN OPERATIONAL AVAILABILITY.** The  $A_0$  demonstrated by the case examples exhibit two trends of interest to the study. One trend is the increase of  $A_0$  with time since first Fleet introduction. The current  $A_0$  achieved by each case example is much superior to that achieved earlier. Three factors are responsible for this improvement: improved supply support, engineering changes improving the reliability and maintainability characteristics of the equipment, and actions taken by the Fleet (primarily, technical assistance for equipment "grooming" and on-the-job training (OJT)). The second trend, across all case examples, is an increase in  $A_0$  with decreasing complexity, with some notable exceptions.

The term "complexity" refers to two dimensions. One is the inherent complexity of a system, which can be measured in terms of parts counts and interconnectivity. Inherent complexity is influenced by operational capabilities (number of different modes), technology, and level of integration. The second dimension is maintenance complexity, the complement of testability; i.e., the percent of failure symptoms which the technician must solve (without the use of automated, built-in diagnostics), and the difficulty of this task (number of paths, number of steps).

Table 2 shows our rank order of the equipment reviewed as case examples in terms of inherent complexity, maintenance complexity, and  $A_0$ . Our rank ordering in terms of  $A_0$  represents a subjective judgment, however, our assessment is based on inputs received from the Fleet and an examination of the available 3-M data during 1983. The simplest equipment, the AN/WSC-3 satellite communications (SATCOM) set, has the lowest maintenance complexity and the highest  $A_0$ , as one would expect. The AN/BQQ-5 sonar system, on the other hand, has the highest inherent complexity but scores lower in maintenance complexity than most of the other examples; as a result, its  $A_0$  is the next highest, after that of the AN/WSC-3. At the risk of being accused of comparing apples and oranges, the table illustrates two points:

- a. Proper design for testability (functional partitioning, elimination of feedback loops, both in hardware and software, proper test point locations, highly reliable built-in test (BIT) hardware, and many other design features) can transform an inherently very complex system into a system with much-reduced maintenance complexity (compare rank orders in first two columns).

TABLE 2. OPERATIONAL AVAILABILITY VERSUS COMPLEXITY

EQUIPMENT	RANK ORDER IN TERMS OF DECREASING:		
	Inherent <sup>1</sup> Complexity	Maintenance <sup>2</sup> Complexity	Operational Availability
AN/BQQ-5 Sonar	(1)	(5)	(2)
Mk 117 FCS	(2)	(2)	(3)
Mk 86 GFCS	(3)	(1)	(4)
ASW Avionics (S-3A)	(4)	(3)	(6)
AN/AWG-9 Radar (F-14A)	(5)	(4)	(5)
AN/WSC-3 SATCOM	(6)	(6)	(1)

<sup>1</sup>Module count and interconnectivity.

<sup>2</sup>Complement of testability.

b. Factors other than maintenance complexity influence  $A_0$  (compare rank orders in the last two columns). These other factors are explained next.

**RANK ORDER OF CONTRIBUTING CAUSES.** We have ranked inadequate maintenance performance as the foremost cause of the  $A_0$  shortfalls. Without changing current supply support budgets and equipment reliability characteristics, it appears possible that requirements could be met if maintenance would be performed proficiently. Some years ago, poor supply support may have been as significant a cause as poor maintenance; this is no longer true today. Much of the reported spares shortage is actually the result of poor maintenance: 20 percent of avionics weapon replaceable assemblies (WRAs) and 60 percent of shipboard combat system lowest replaceable units (LRUs), replaced by "O"-level maintenance, are NFRs; 50 to 70 percent of the shop replaceable assemblies (SRAs), replaced by "I"-level maintenance in avionics components, are NFRs; and according to information provided during the Fleet interviews, approximately 20 to 25 percent of repaired WRAs, and 10 to 15 percent of SRAs and LRUs, do not work when installed in the system.<sup>13</sup> (The latter reflect

<sup>13</sup>The discussion adheres to Navy terminology. Physically, WRAs may be thought of as "black boxes"; SRAs and LRUs as circuit boards, wiring, and other electronic modules. The term "component" for WRAs and LRU assemblies, and "module" for SRAs or LRUs, will be used whenever these more general terms cannot cause confusion. The NFR rates reported here are based on the case examples. They differ slightly from those noted in Section I, which are based on Navy-wide data as reported by the Navy.

inadequate repairs and/or poor quality control at "D"-level or vendors, which is partly due to limitations of the shop test equipment; e.g., inconsistent tolerances and inability to simulate the dynamic operational environment by a static testing approach.) The elimination of these inefficiencies could nearly halve the requirement for spares.

This assessment does not imply that equipment reliability is unimportant. Quite the contrary: by virtue of the definition of  $A_0$ , reliability is the most important factor influencing  $A_0$ . Low reliability must result in low availability, even with perfect maintenance, and the higher the reliability, the less impact logistic resources have on  $A_0$ . The point is that the demonstrated  $A_0$  shortfalls for Navy combat systems are due chiefly to inadequate maintenance performance, much less so to lower reliability than specified, less supply support than needed, or any shortcomings in Fleet support.

In turn, inadequate maintenance performance is caused by many factors (refer back to Figure 1). The contributions of these factors cannot be quantified exactly from the available data, but can be ranked in order of importance. Table 3 shows the rank order found for each example based on our analysis of the available 3-M data and Fleet interviews we conducted during 1983. The top-rated factor differs from case to case; for some (e.g., avionics), the operational environment is the most important factor responsible for poor maintenance performance; for others, it is technical training, Fleet practices, or poor equipment design (maintainability).

TABLE 3. RANK ORDER OF FACTORS CAUSING POOR MAINTENANCE PERFORMANCE

FACTOR	CASE EXAMPLE						
	F-14A: AMC-9	S-3A: Avionics	Mk 86 GPCS	WSC-3 Radio	BQQ-5 Sonar	Mk 117 PCS	Fleet Average
Technical Training	(2)	(2)	(2)	(1)	(3)	(1)	(1)
Equipment Maintainability	(3)	(4)	(1)	(3)	(4)	(3)	(2)
Fleet Practices	(6)	(3)	N/A	(6)	(1)	(5)	(3)
Job Design	(5)	(6)	N/A	(7)	(2)	(2)	(4)
Personnel Availability	(4)	(7)	(3)	(5)	(5)	(6)	(5)
Technical Manuals	(9)	(8)	(5)	(2)	(6)	(4)	(6)
Parts Availability	(7)	(5)	(7)	N/A	(7)	(7)	(7)
Support and Test Equipment	(8)	(9)	(6)	(8)	(8)	(8)	(8)
Operational Environment	(1)	(1)	N/A	N/A	N/A	N/A	(9)
Maintenance Concept	N/A	N/A	(4)	N/A	N/A	N/A	(10)
Operator Skills	N/A	N/A	N/A	(4)	N/A	N/A	(11)

NOTE: N/A = Not applicable; i.e., factor has no special impact on maintenance performance for the (sub) system indicated.

Overall, across all case examples, we have rank ordered the factors contributing to inadequate maintenance performance as follows:

1. Technical Training. Inadequate maintenance skills is the first factor. This deficiency is attributed mostly to lack of individual proficiency which, in turn, is attributed chiefly to inadequate training.

2. Maintainability Characteristics. Poor design for maintainability, especially manifested in poor testability, is the second most important contributor to poor maintenance performance.

3. Fleet Practices. Excessive diversions from the maintenance job, and especially the practice of using school graduates for mess duty during their first three to six months, detract from maintenance performance. The impact, however, is more a delay in skill acquisition. More important is the fact that maintenance is accorded a much lower priority than operations, which, in selected cases, inhibits proper maintenance.

4. Job Design. The traditional allocation of maintenance tasks among different ratings and the absence of system-level technicians is a major factor explaining poor maintenance performance in the case of integrated systems.

5. Personnel/Experience. The shortage of experienced technicians (percent fill of authorized billets for petty officers by rating/Navy Enlisted Classification (NEC)) is the fifth factor.

6. Technical Manuals/Job Aids. The next factor is shortcomings in technical information. Shortcomings include: inaccurate, incomplete, or out-of-date information; and difficult to interpret, poor accessibility to, or the inability to use manuals at the job site.

7. Spares. Spares shortages have a direct influence on  $A_0$ , but also affect maintenance performance. Shortages may cause additional maintenance downtime (e.g., workaround procedures), additional maintenance actions (e.g., for fault isolation and verification), cannibalization (to place the "hole" where it hurts least; e.g., by removing a needed spare from another system which is already "down" for other reasons), or emergency repairs (doing maintenance normally assigned to higher echelons, which by lack of tools, parts, and training, invariably affects the integrity of the system). In short, lack of needed spares makes the maintenance task more difficult.

8. Tools/Test Equipment. Lack of available, calibrated test equipment is the next factor. As in the case of spare parts, part of the test equipment problem is caused by inefficient maintenance at higher echelons and/or user-inflicted damage.

9. Operational Environment. Operational tempo (time available for maintenance turnaround) is the most important factor in the case of avionics maintenance aboard deployed carriers. For nondeployed units, this factor has little impact on maintenance performance. For the mix of equipment examined, this factor rates ninth overall (Navy-wide).

10. Maintenance Concept. The maintenance concept for nonavionics electronics equipment is essentially two-level. Effectiveness of this concept depends on supply support. Ship's force is frequently required to repair electronic modules because it is short of spares, but such emergency repairs

are hindered by lack of piece parts and test equipment. (The Navy is currently evaluating a better-managed approach to emergency repairs.)

11. Operator Skills. For most shipboard systems, the operator tasks and maintenance tasks are combined into one job (billet). One notable exception is surface-ship communications equipment, operated by the Radioman (RM) rating, maintained by the Electronics Technician (ET) rating. In this case, the job design approach has resulted in maintenance problems due to excessive operator-inflicted damage.

Two factors identified in the model are missing from the above listing: individual abilities and equipment reliability. The case studies did not permit a quantitative assessment of individual abilities, therefore it is not known how important they are with regard to maintenance performance. Reliability has little impact on maintenance performance. It determines the maintenance workload, which supposedly determines maintenance manning requirements and authorizations. A potentially important factor is the discrepancy between planned and actual reliability achieved in the operational environment. While the case examples exhibit substantial discrepancies, the additional workload is judged well within maintenance capabilities if maintenance was performed proficiently. In short, the impact of reliability is primarily on  $A_0$ , not on maintenance performance.

The above listing applies to "O"-level maintenance performance, the subject on which this study concentrates most. With respect to "I"-level maintenance, only that maintenance performed afloat aboard carriers by the Aircraft Intermediate Maintenance Department (AIMD) was examined. "I"-level maintenance performed by intermediate maintenance activities such as tenders, or shore intermediate maintenance activities (SIMAs), was beyond the scope of this study because such activities are little involved in combat system maintenance or repairs of combat systems components or modules. All shipboard combat system have basically a two-level maintenance concept, "O"- and "D"-level; most avionics equipment has a three-level maintenance concept, "O"-, "I"-, and "D"-level, where "I"-level is exclusively performed by the AIMD.

"I"-level maintenance is as troublesome as that performed at the "O"-level, but it has a less immediate impact on  $A_0$ . The chief contributing factor is the lack of operational suitability of much of the ATE currently installed (i.e., poor reliability, poor maintainability, and incompatibility with most of the avionics components and modules so that complex interface devices must be used) and the limited availability and poor quality (diagnostic performance) of the test program sets. Inadequate training of ATE operators, maintainers, and software analysts is a distant second factor. All of the other factors are negligible in comparison to these two.

ANALYSIS OF CONTRIBUTING CAUSES. Each case example has a different story to tell. There is, however, a common thread which may explain why the Fleet has so much trouble meeting realistic readiness requirements in peacetime. While this assessment is based on a limited sample, and the specific rank order of

contributing factors may differ from case-to-case as well as over time, this common thread appears to be generic to the current weapon system acquisition and logistic support processes and, therefore, may be more informative in identifying root-causes vice symptoms of the problem.

The common thread consists of a series of assumptions made in weapon system acquisition and support -- assumptions which appear invalid and, in combination, result in a gap between maintenance skill requirements and the skills possessed by Navy technicians:

a. Design Concept. Combat system design concepts invariably emphasize minimum manning and skill level requirements. This is achieved through modular design and BIT. No contingency plans are made in case the concept turns out to be unrealistic. The process is success-driven; any problems are assumed to be subject to solution through engineering changes.

b. Contract. The contract between the government and the prime contractor specifies the design requirements. With respect to maintainability, if any quantitative requirements for testability are included, the measures used are arcane; i.e., they are ambiguous and open to different interpretations, they cannot be tested or evaluated, and they lack meaning in the operational environment. Nevertheless, the assumption is that the contract specifies precisely the requirement.

c. Design Engineering. In attempting to meet the numeric testability requirements, current design engineers customarily make three critical assumptions: (1) all faults are catastrophic, i.e., a fault is a fault; (2) only single faults occur; and (3) faults occur only within the electronic modules, not in interconnecting wires or connectors. None of these assumptions are valid.

d. Maintenance Engineering. Responsibility for logistics support analysis (LSA) is a maintenance engineering function, which may or may not be integrated with design engineering. In either case, the LSA is dependent upon the design engineer's specifications. Because the latter are not realistic, the LSA records are not either; nevertheless, they are assumed to identify all maintenance task requirements at each level of maintenance.

e. Job-Task Analysis. If an early analysis is conducted for developing training requirements, much of the "subject matter expert's" knowledge of the new system must come from the contract specifications. Unless gifted by a great deal of skepticism (acquired through experience), the subject matter expert's analysis will indicate that most, if not all, of the fault diagnostics are provided by BIT. The resulting job-task list, which eliminates most nonprocedural tasks, is assumed to identify the technician's job-task requirements. The same result is obtained when the analysis is deferred and based on completed LSA records.

f. Instructional Systems Development (ISD). The ISD model, as implemented by the Navy, is designed only for procedure training, not for development of cognitive skills. The model addresses only those behavioral tasks in the job-task list which yield to its methodology, systematically excluding any information that is not directly task-specific or cannot be taught in a stimulus-response training process. In spite of these fundamental limitations, the ISD model is perceived as an effective approach for developing training courses.

g. Training. The training plan and program of instruction are based on teaching that subset of identified tasks which can be most effectively taught in formal school within budgetary constraints, considering the following four factors: task-learning difficulty, importance of the task (frequency of performance or time spent performing), criticality of the task (consequences of inadequate performance; i.e., primarily personnel safety), and immediacy of task performance (task-delay tolerance). The assumption is that the rest will be learned (somehow) on the job. The present training philosophy does not provide for follow-on, career-level training.

h. Maintenance Demonstrations and Operational Testing. Maintenance demonstrations are conducted with predefined system failures. Operational testing is of limited duration. Neither is sufficient for assessing BIT performance or the completeness and validity of the job-task list. Even if BIT shortfalls are identified, approval for Service use is invariably granted (if the system's operational capability is satisfactory) in order to meet Fleet operational requirements. Navy technicians participating in operational tests are, normally, factory-trained, so that shortfalls in Navy technical training do not surface.

i. Fleet Experience. Once the system finally reaches the Fleet, technicians encounter problems troubleshooting with BIT such as:

- (1) false alarms,
- (2) erroneous fault-isolation indications,
- (3) a higher percentage than advertised not isolated at all,
- (4) high ambiguity of BIT indications,
- (5) excessive time required in using operator-interactive diagnostics.

Actually, the BIT is normally very accurate in what it is designed to do; the problem is that many failures (in excess of 50 percent according to most studies reviewed) do not meet the design assumptions. The BIT, however, cannot discriminate between failures it is designed to address and those it is not. Four additional problems serve to detract further from operational BIT performance. One is that the level of testability is designed to meet stated requirements using predicted failure modes and rates. To the extent actual



reliability behavior differs from the reliability engineering model, BIT performance (measured in terms of percentages of actual failures) is always less than designed. The second problem is that the gap between advertised and actual BIT performance increases over time; due to frequent removal/replacement of modules, the percentage of failures occurring in interfaces grows over time, and these are the failures normally not accounted for in BIT design. The third problem is caused by failures within the BIT hardware or software. Specifications are normally careful in requiring that BIT failures should not affect prime equipment operational status, but BIT failures are often not discernible as such to the technician. The result is that the equipment must be taken down for maintenance, even though BIT failures formally do not affect operational capabilities. When this happens several times, the technician loses confidence in the BIT. The fourth problem is that special diagnostic programs, requiring operator interaction for fault isolation, are often designed without regard to the Fleet environment, which puts a high premium on quick repairs of combat-essential equipment. In many cases, the testability features cannot be used in that environment because they take too much time, necessitating shortcuts by the technician.

j. Feedback. The Navy's maintenance data-collection system is not designed to identify the true causes of maintenance problems. What the data show is that there is a problem (large numbers of CASREPs, low reported FMC rate, and/or low computed  $A_0$ ) and that the Fleet is constantly short of spare parts. The assumption is that these surface manifestations reveal the cause of the problem as one of weak supply support. The feedback systems established to evaluate adequacy of training are not effective in identifying training deficiencies.

k. Corrective Action. Based on the available information, the emphasis by the Systems Commands or program (project) managers is understandably on getting funding for engineering changes to improve reliability and for increased spares. In some cases, where engineering studies (conducted by contractors as part of post-production support) identify failure diagnostic shortfalls, attempts are made to improve BIT. But, for practical reasons, such improvements are normally limited to software, deferring more costly hardware improvements to a later model.

The nature of the process is such that the root problem is not attacked. Particularly, equipping the technician to cope with BIT limitations by increasing the skill levels (paygrades) or revising the training or improving the job aids is not controlled by anyone. These issues are addressed again in Section IV in discussing what needs to be done.

#### FLEET ASSESSMENT

The Fleet has become increasingly concerned in recent years about the decreasing level of basic knowledge and skill proficiency of journeyman and apprentice-level technicians responsible for combat systems maintenance. This concern was expressed, for example, by the Commander in Chief, U.S. Atlantic

Fleet (CINCLANTFLT) to the technical training community.<sup>14</sup> In this message, CINCLANTFLT attributes skill deficiencies of journeyman technicians to poor retention, and those of apprentice-level technicians to shortfalls in formal school training, especially "A" Schools (curriculum content, method of instruction, or both). The Fleet expects apprentice-technicians, not novices, from the entry-level training pipeline; i.e., they must be capable of performing routine maintenance tasks under limited supervision. Yet, the message notes:

Today's apprentice-technicians are generally incapable of carrying out the basic tasks related to equipment maintenance. As a result, the senior petty officer is required to fulfill these basic tasks and outside assistance must be called in to accomplish journeyman petty officer tasks.

In order to make a general assessment of the Fleet's perception of the shortfalls of pipeline graduates, several informal interviews were conducted during the course of this study. During these interviews, the Fleet identified weaknesses of "A" School graduates in the following areas:

- a. safety procedures,
- b. basic electricity and electronics theory,
- c. use of basic tools,
- d. proper use of test equipment,
- e. troubleshooting techniques,
- f. printed circuit (PC) board repair,
- g. knowledge of ancillary equipment,
- h. proper use of technical documentation,
- i. supply procedures.

These shortfalls indicate that the instructional objectives established for the various schools do not match the skills and knowledge required by the Fleet. In turn, this suggests inadequate job-task analysis, inadequate specification of training needs, inadequate translation of training needs into instructional objectives, inadequate training design, inadequate training

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<sup>14</sup>CINCLANTFLT message to Chief of Naval Technical Training, Subject: Training of Technical Ratings for Fleet Maintenance; date time group 071410Z OCT 81.

implementation, or all of the above. Importantly, once mistakes have been made in the definition of training needs (as a result of improper job-task and skill analysis), any subsequent evaluation of the training program is, by definition, faulty by lack of the proper criterion.

**IMPACT ON THE FLEET.** The impact of these training shortfalls on the Fleet is severe. Short term, as highlighted in the above CINCLANTFLT message, the direct impact can be measured by such indicators as follows:

- a. Increased number of outstanding CASREPs in combat systems equipment.
- b. Significant increase in requests for technical assistance (MOTUs, Naval Sea Systems Command (NAVSEA) and Naval Electronic Systems Command (NAVELEX) field activities, and vendors).
- c. Significant increase in requests for system "grooms."
- d. Dramatic increase in damaged or abused general purpose electronic test equipment received at calibration facilities.
- e. Increased number of functional electronic components incorrectly classified by technicians as being faulty. For example, 70 percent of the PC boards turned into the Support and Test Equipment Engineering Program for repair are determined to be functioning correctly.

The increase in technical assistance required from the Fleet support community is estimated at 30 percent over the 1977 to 1981 time period, a period during which the actual number of surface combatants declined.<sup>15</sup>

Long term, the impact is even more serious: with senior petty officers doing most of the routine maintenance tasks and outsiders (technical assistance teams or embarked civilian technicians) doing the more complex corrective maintenance tasks, the whole concept of apprentice training through OJT suffers. Apprentice-technicians do not receive sufficient, guided, hands-on practice to develop maintenance skills; similarly, the skills of journeyman technicians do not increase but stagnate. The long-term impact, in other words, is one of declining organic skill proficiency in the Fleet -- a decline across the board in a period during which combat systems are known to become more complex and difficult to troubleshoot. As a consequence, further increases in the extent to which the Fleet must rely on nonorganic support will be unavoidable.

The available data suggest that the above indicators of poor maintenance performance are due more to formal school training shortfalls than other potential root-causes (e.g., operating tempo, low retention of journeyman

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<sup>15</sup>Unpublished data, Naval Sea Support Center, Atlantic (NAVSEACENLANT), Norfolk, VA.

technicians, operational environment). For example, based on the interviews with the Fleet, the following represents the consensus regarding the knowledge and skills possessed by graduates from the entry-level training pipeline (in the ratings responsible for electronics maintenance):

- a. Only five to ten percent are able to use common basic test equipment.
- b. Basic electronic theory is not understood by 95 percent.
- c. Most are able to run the built-in diagnostic checks associated with combat system preventive maintenance, but 85 percent have not the slightest idea what to do when a failure is detected and the automated diagnostics fail to isolate the failure to a single replaceable module.

Journeyman technicians (PO II or E-5) who perform the bulk of corrective maintenance also exhibit limited troubleshooting skills as evidenced by the high retest okay rate of modules replaced in the combat systems and evacuated to "I"- or "D"-level maintenance activities: about 30 to 50 percent of the modules -- 60 to 80 percent of PC boards (depending on combat system) -- are found ready for issue; i.e., were unnecessarily removed from the shipboard system.<sup>16</sup> These percentages are high considering that a significant proportion of the complex troubleshooting jobs is actually performed by so-called experts (technical assistance teams or embarked civilian technicians). Of course, these data must be interpreted with care: factors other than training may be the root-cause. The case studies indicate that equipment design characteristics and operational environment are as much to blame as inadequate training.

The Fleet, of course, cannot operate under these circumstances. The steps which have been taken to overcome or reduce organic skill deficiencies cover three broad areas: (1) establishment of an intensive "waterfront" training activity, (2) an institutionalized program of combat system grooms prior to deployment, and (3) embarkation of "super technicians" (military, Navy civilians, and contractor technicians) aboard deploying units.

The Fleet Training Commands and MOTUs have initiated functional skill courses in the deficient areas listed earlier. The original mission of MOTUs was, of course, to provide OJT in electronics maintenance. Now classes are run around the clock at the expense of the OJT mission.

Combat system grooms are accomplished by various equipment-oriented electronic groom teams, consisting of experienced military and contractor maintenance technicians. These teams perform maintenance tasks originally intended to be accomplished by organic (ship's force or air squadron)

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<sup>16</sup>CINCLANTFLT Message to Chief of Naval Technical Training, Subject: Training of Technical Ratings for Fleet Maintenance; date time group 071410Z, Oct 81.

maintenance personnel. Scheduled periodically by the Type Commander, the groom teams provide a direct workforce to the ship or squadron for correction of particular equipment deficiencies. The groom team's mission is to have the equipment in the highest operational readiness state possible. These programs are costly and manpower intensive. Originally designed as emergency programs, they have become permanent fixtures. The payoffs from these combat system grooms are considerable. For example, F-14 missile-firing exercises in the Caribbean were, in the past, plagued by problems first attributed to operator skill deficiencies. Once the combat system groom was instituted, it was found that the true problem was one of poorly aligned equipment: the missile hit rate currently achieved is triple that achieved before the groom was a formally scheduled requirement.<sup>17</sup>

The third area, embarkation of technicians supplementing organic manning of a battle group, is especially pronounced in the Pacific Fleet, not in the Atlantic Fleet. The explanation is the different operational environment: the former is deployed across large distances with little forward deployment of logistic support resources while the latter has considerable forward support available. Battle groups deployed with the Pacific Fleet have about 22 combat system technicians embarked to provide the technical skills which are otherwise lacking. This number is in addition to the 50 to 75 civilian technicians embarked aboard each carrier in support of the air wing.

Importantly, the success of these programs obscures the failure of the training pipeline to provide the Fleet with the apprentice-level technicians needed. A brief description of each Fleet's corrective-action programs follows.

**ATLANTIC FLEET PROGRAM.** The Type Commander, COMNAVSURFLANT, noted in recent years that the training readiness of combat system personnel was seriously lagging equipment readiness, based on the following observations:

- a. Limited ship's force involvement in combat system refurbishment and repair throughout the regular overhaul of a ship.
- b. Combat systems not fully tested or operational aboard ships completing regular overhaul or scheduled restricted availabilities.
- c. Ship's force inadequately trained to operate, test, or maintain combat systems.
- d. Unsatisfactory operational readiness training due to inadequate basic operator skills, degraded combat systems, and equipment casualties.
- e. Degraded operational readiness of deployed units due to combat system casualties involving excessive downtimes for maintenance.

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<sup>17</sup>COMNAVAIRLANT Interview, Norfolk, VA, October 1982.

The problem was attributed to two root-causes. First, the ship's force has a heavy workload during overhaul so that training receives a low priority and technical training is neglected altogether. Second, there is no single source document which defines the minimum standards of technical training required for combat systems technicians: equipment technical manuals, personnel qualification standards, personnel advancement requirements, and planned maintenance system maintenance requirements cards all address different aspects of the technicians' job and skill/knowledge requirements. In spite of this mountain of data, the Navy simply does not have a single, comprehensive document that provides a complete and realistic specification of the job-task requirements -- a lack which defeats efforts to conduct an effective job training program.

That was COMNAVSURFLANT's diagnosis of the true problem. Consequently, the Combat Systems Improvement Program (CSIP) was instituted in April 1982 to correct the problem. While CSIP covers a broad range of actions, the focus here is on the training aspects, the highest payoff area (according to COMNAVSURFLANT) in terms of expected improvements in combat systems operational readiness. In the training area, CSIP consists of two major initiatives: development of Combat System Training Requirements Manuals to identify training requirements, and establishment of Combat System Mobile Training Teams to provide supervised OJT programs to technicians aboard ships in the home ports. The manuals are being developed by specific ship class and are intended to identify minimum knowledge and skills required by rating and rate, including references to pertinent source documents. The plan is to evaluate these manuals during fiscal year 1983 (FY83). The Mobile Training Teams consist of senior combat system technicians from Group and Squadron staff located in a particular home port. These subject matter experts will conduct formalized training once the manuals are completed.

Each individual ship has a Ship Electronics Readiness Team (SERT) which is comprised of the assigned senior technicians responsible for each of the combat system components. The SERT was originally designed as a brain-storming group to help minimize equipment downtimes by cross-fertilization of maintenance and troubleshooting techniques. Although a good idea, the concept did not work on small combatants (destroyers and frigates) because the senior technicians on those platforms do not necessarily have much maintenance experience. Due to the way formal school training is currently structured (no formal school career training after first reenlistment), there is little or no opportunity for those technicians to acquire higher maintenance skills. The Mobile Training Team concept attempts to fill this void. In particular, the Combat System Mobile Training Team will train the SERT to conduct, monitor, and evaluate combat system component testing conducted by shipyard and vendor personnel, and to perform the Overall Combat Systems Operability Test. This test exercises all shipboard combat systems' components and interfaces, and provides a measure of overall combat system availability and operability in accordance with design specifications. The Mobile Training Team will also train apprentice-level technicians in the area of diagnostic readouts and in troubleshooting techniques which are required to correct any deficiencies found.

Quantitative Research on Retention Factors has been Limited. Past research has focused primarily on recruiting issues. Only very recently has DoD recognized that retention may be more of a problem than recruiting, and that policies adopted to alleviate recruiting shortfalls may have an adverse impact on retention (especially, the Variable Education Assistance Plan that replaced the GI-Bill in 1977). As a result, little quantitative data are available on factors that could be manipulated to increase retention. The Navy has, traditionally, assumed a leadership role, compared to the other Services, in examining the factors (attitudinal, biographic, and economic) influencing reenlistment decisions and the interactions among these factors. The Navy has introduced two well-designed programs (Human Resource Management Program; and Leadership, Management Education, and Training Program) to enhance motivation and retention. These programs receive management emphasis and attention. In addition, the Navy is making extensive use of the selective reenlistment bonus program for critical skills. Navy spending on bonus payments is already about 50 percent of the amount spent DoD-wide. In sum, the Navy is doing about all that can be reasonably expected in the area of retention.

Nonetheless, petty officer shortages have been a constant phenomenon in the Navy. The Navy's steady-state personnel retention requirement is approximately as follows: 45 percent first-term reenlistment, 60 percent second-term reenlistment, 95 percent third-term reenlistment and beyond.<sup>45</sup> These rates had never been achieved prior to FY82. In the late 1970s, the rates achieved were 37 to 40 percent for first-term reenlistments, 45 to 53 percent for second-term reenlistments, and 91 to 93 percent for subsequent reenlistments.<sup>46</sup> The result was a shortage in the petty officer ranks that will persist through the 1980s in spite of the improved retention results in FY82 and FY83. For example, the Navy's manpower projections for 1985 (projections made in mid-1982)<sup>47</sup> show the following fill of authorized billets by career personnel (beyond four years of service) in the combat system technician ratings:

- a. Aviation: 84% fill of E-5/E-6; 87% fill of E-7 through E-9.
- b. Nonaviation: 69% fill of E-5/E-6; 90% fill of E-7 through E-9.

One reason why these shortages are especially pronounced in the technical ratings is that they possess a much higher petty officer content (percent of billets authorized in the E-4 to E-9 grades) than the Navy-wide average. The latter is currently 62 percent (E-4 to E-9) or 43 percent (E-5 to E-9); for

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<sup>45</sup>Congressional Hearings on FY82 DoD Appropriations, Senate Armed Services Committee, February-March 1981.

<sup>46</sup>Ibid.

<sup>47</sup>Source data from Chief of Naval Operations (OP-112C), Projections based on Force Analysis Simulation Technique (FAST) run in mid-1982.

a. The much discussed decline in average Scholastic Aptitude Test (SAT) score (from 1963 to 1980, a decline of 11.3 percent on verbal reasoning, 7.2 percent on mathematical reasoning), camouflages a much more serious decline in above-average students (those scoring above 600 on the 200-800 scale), a serious increase in underachievers (those scoring below 400).<sup>41</sup>

b. Over 50 percent of high school seniors are grossly illiterate or semi-illiterate, unable to comprehend written material sufficiently to function in today's society.<sup>42</sup>

c. In recent years, the decline in above-average students has continued unabated due to an instructional focus on the underachievers. The long-term trend points to average mediocrity.

The results are observable in Navy recruit accessions as follows:

a. Over 30 percent of high school graduate accessions (46 percent of non-high school graduate accessions) have a reading grade level below 9.0, which is four grades below standard.<sup>43</sup> (Reading grade levels are standardized on the basis of 70 percent of students being able to read and comprehend 50 percent of reading material in the next grade; i.e., high school graduates are supposed to have a reading grade level of 13.0 based on that standard).

b. While recruit classification tends to keep most illiterates out of "A" Schools, a large percentage of students enrolled in "A" Schools report serious difficulty with reading course materials (36 percent) or understanding what they are supposed to read (56 percent).<sup>44</sup>

While the Navy has initiated several programs to counter these trends of functional illiteracy -- i.e., Academic Remedial Training and Job-Oriented Basic Skills -- there are limits to what can be done within available training budgets.

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<sup>41</sup>College Entrance Examination Board, Advisory Panel on the Scholastic Aptitude Test Score Decline, On Further Examination, New York, 1977.

<sup>42</sup>Barbara Lerner, "American Education: How Are We Doing?" The Public Interest, No. 69, Fall 1982.

<sup>43</sup>John J. Mathews, Lonnie D. Valentine, Jr., and Wayne S. Sellman, Prediction of Reading Grade Levels of Service Applicants from Armed Services Vocational Aptitude Battery (ASVAB), AFHRL-TR-78-82, Air Force Human Resources Laboratory, Brooks Air Force Base, TX, December 1978.

<sup>44</sup>Thomas G. Sticht, Lynn C. Fox, Robert H. Hanke, and Diane W. Zapf, Integrated Job Skills and Reading Skills Training System, NPRDC TR-77-41, Navy Personnel Research and Development Center, San Diego, CA, September 1977.



found by Dale and Gilroy).<sup>39</sup> Thus, a drop from 10.4 percent unemployment in 1982 to the five percent level in the early 1990s would reduce male HSDG enlistments in the Navy by roughly 23,500 from the 1982 base, everything else being equal (constant military/civilian pay ratio). As a result, the Navy would fall below the minimum Congressional standard of 65 percent HSDG accessions, and well below its own objective. A more meaningful measure of quality, however, is the percent of accessions (enlistment contracts) which are HSDG and score above average on the AFQT (MC I - IIIA). That has been, traditionally, about 50 percent of HSDG accessions, with the exception of FY82. The reason why this may be a more meaningful measure of quality is explained next.

Educational Attainment Has Lost Much of its Meaning as a Quality Indicator. The two standard indicators of quality used by DoD are high school diploma and AFQT percentile score; all quality standards are expressed in terms of these two indicators, but not in terms of the two combined (except for the bottom group: MC IV is eligible only with a high school diploma). Graduation from high school is an important indicator of suitability for military service. It is related to personality traits (achievement motivation and self-discipline) that are desirable in military service. Statistical analysis shows that first-term attrition of non-high school graduates is about double that of high school graduates; disciplinary problems are also more prevalent among non-high school graduates.<sup>40</sup> But as an indicator of educational achievement, high school graduation has lost much of its value due to the long-term decline in quality of education in public high schools. A few statistics follow:

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<sup>39</sup>A technical issue is that the dependent variable used (enlistment rate instead of number of enlistment contracts) implicitly assumes the elasticity of the eligible quality pool to be 1.0. Previous studies have found a much lower supply elasticity; i.e., the effective supply of high school graduates shows a less than 1-for-1 decline with a declining number of high school seniors. The argument is that only when the entire pool susceptible to enlistment is contacted effectively by recruiters, can enlistments be expected to decline proportionately with the eligible pool. To the extent this is true, Dale and Gilroy overestimate the unemployment effect. Because an increasing portion of public high schools is adopting the Armed Services Vocational Aptitude Battery (ASVAB) for counseling purposes, it is believed that the impact of this supply elasticity effect may be much less today than it was in the mid-1970s. It will become even less so in the future, with every recruiter in hot pursuit of every male high school graduate available (see previous observation).

<sup>40</sup>Caspar W. Weinberger (Chairman), Military Manpower Task Force Report to the President on the Status and Prospects of the All Volunteer Force, Washington, DC, p. II-3, October 1982.

The difficulty of sustaining the Navy's qualitative goal is illustrated by the recruiting results in FY82. This was a year with impressive recruiting results, helped along with a peak supply of 18 year olds, high youth unemployment, reduced recruiting quotas, and a substantial recruiting effort. Yet, the actual percent of HSDG non-prior-service accessions achieved was 74 percent vice the 82 percent goal. The number of upper-mental category (MC I - IIIA) male HSDG enlistment contracts, however, was 43,861, the first time in history that this group exceeded 50 percent of accessions.<sup>36</sup>

The Effect of Unemployment has been Underestimated in the Past. Previous studies show a bewildering range in estimates of the sensitivity of the number of quality accessions to changes in independent variables, both exogenous (pay, unemployment) and endogenous (marketing effort, numbers of recruiters).<sup>37</sup> The sensitivity (elasticity, in econometric jargon) to unemployment, however, appears to have been underestimated in most studies, due to inadequate data, improper statistical methods, or an improper model.<sup>38</sup> There is a consensus among the research community that one model cannot be applied indiscriminately to all accessions: high-quality recruits are supply-limited, low-quality are demand-limited; i.e., the two categories require different models. The recent results obtained by Dale and Gilroy show an unemployment elasticity of 0.94, relating the enlistment rate of male high school graduates to male teenage unemployment. (The rate equals the total enlistment contracts -- i.e., accessions plus delayed entry program -- divided by the male youth population of 16 to 19 year olds.) Converting to total unemployment rate and applying this to the Navy, results in an estimated drop of 6.8 percent (4,300) male, non-prior-service, HSDG enlistments per one percent drop in the national unemployment rate. This estimate of the unemployment effect is about triple that reported by many previous studies (with the exception of one which found an unemployment effect 2 1/2 times that

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<sup>36</sup>This information is based on LMI's review of actual recruiting data during FY82.

<sup>37</sup>For a recent comprehensive survey, see: Richard C. Morey and John M. McCann, "Armed Services Recruiting Research: Issues, Findings, and Needs," Naval Research Logistics Quarterly, Vol. 30, (1983), pp. 697-719.

<sup>38</sup>Charles Dale and Curtis Gilroy (Personnel Policy Research Group, U.S. Army Research Institute), "The Effects of the Business Cycle on the Size and Composition of the U.S. Army," Atlantic Economic Journal, Vol. 11, No. 1 (March 1983).

college; and with the overcapacity faced by colleges in the late 1980s, the percent going on to college can be expected to increase further. Propensity to enlist among college-bound high school graduates or those in college is much lower than for those who are undecided.

The third factor is the long-term trend in the civilian labor market. With the high youth unemployment of the early 1980s beginning to recede, the number of jobs in the national economy is projected to grow by 22 percent between 1982 and 1990 (Department of Labor projection, 1982), yet the work force (total U.S. population, 18 to 64 years of age) will grow only by ten percent.<sup>33</sup> The increasing scarcity of youthful workers (the 18 to 24 age group declines by 15 percent from 1982 through 1990) will ensure ample work opportunities for high school graduates, especially those of above average quality.

The combined result of these three factors is that current quality standards will probably not be sustainable. For example, the first two factors alone imply that seven out of ten uncommitted (noncollege-bound) male high school graduates must be enlisted in 1992 just to meet the 75 percent standard. This is nearly double the ratio in 1981, when four out of ten were required.<sup>34</sup> This implies at least a doubling of the recruiting effort and the necessity to contact every individual male high school graduate. The Center for Naval Analyses model of high school graduate enlistments projects a chronic shortfall in quality accessions for the Navy by 1989.<sup>35</sup> Even under the most favorable circumstances (military/civilian pay ratio remaining constant, no effects from declining unemployment rates), the model projects a shortfall of 16 to 26 percent in HSDG accessions (the extent of the shortfall depends on military pay) compared to the Navy's objective (which would be 59,900 based on a goal of 82 percent non-prior-service male accessions). The two other factors (more people college-bound and more civilian employment opportunities) would worsen this shortfall.

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<sup>33</sup>Bureau of the Census, Population Estimates and Projections, Series P-25, No. 922, October 1982.

<sup>34</sup>Richard W. Hunter and Gary R. Nelson, "Eight Years with the All-Volunteer Armed Forces." Paper included in Lt. Gen. Brent Scowcroft, USAF (Ret.), Editor. Military Service in the United States. The American Assembly, Columbia University, 1982.

<sup>35</sup>John A. Cirie, James J. Miller, and H. Wallace Sinaiko, "Department of Defense and Navy Personnel Supply Models," Proceedings of Workshop convened at request of Navy Secretariat, conducted by the Smithsonian Institute and the Office of Naval Research, May 1981.

19.5 percent (from 1982 to 1988) as compared to the Navy-wide growth in enlisted requirements of 8.6 percent.<sup>28</sup> This change in composition is even more pronounced in the Army. As a result, quality standards for new accessions have increased DoD-wide:

a. Mental Category (MC) IV (Armed Forces Qualification Test (AFQT) percentile 10 to 30) candidates without high school diplomas are ineligible.

b. High School Diploma Graduates (HSDG) scoring in the bottom quarter of MC IV (AFQT interval 10-15) are ineligible. (The Services set their own standards above this Congressionally mandated minimum; the Navy's cut-off is currently an AFQT percentile score of 17).

c. The maximum percentage of MC IV accessions is 20 percent (down from the 25 percent standard in FY82).

d. The threshold for the percentage of male non-prior-service HSDG accessions has been increased from 65 percent (current Congressional standard) to 75 percent (Defense Guidance 1985-1989). (The Services set their own goals based on annual reviews. The Navy Recruiting Command, in 1982, increased its objective from 76 to 82 percent HSDG).<sup>29</sup>

The second factor is the long-term change in the composition of supply (military eligible pool). The overall decline of the youth cohort has a proportionate effect on the number of high school graduates; i.e., a decline of 24.5 percent from FY82 to FY92, if the current dropout rate of 23 percent<sup>30</sup> remains constant (weighted average of 20 percent for whites, 36 percent for blacks, 40 percent for Hispanics).<sup>31</sup> But the youth cohort decline is concentrated in whites; black high school enrollments will actually show a small increase. Another trend is that an increasing proportion is college-bound. Traditionally, about 50 percent attend college; but a 1982 survey<sup>32</sup> shows that 56 percent of male high school graduates continue on to

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<sup>28</sup>Chief of Naval Operations (OP-112D), NAMPS run of 28 April 1982.

<sup>29</sup>CDR Donald L. Pilling (USN). "The Dwindling Muster," U.S. Naval Institute Proceedings, 7 June 1982.

<sup>30</sup>Bureau of Labor Statistics, Special Labor Force Reports; data as of March 1981.

<sup>31</sup>Caspar W. Weinberger (Chairman), Military Manpower Task Force Report to the President on the Status and Prospects of the All Volunteer Force, Washington, DC, October 1982.

<sup>32</sup>Jerald G. Bachman, American High School Seniors View the Military: 1976-1982, Institute for Social Research, University of Michigan, Ann Arbor, MI, November 1982.

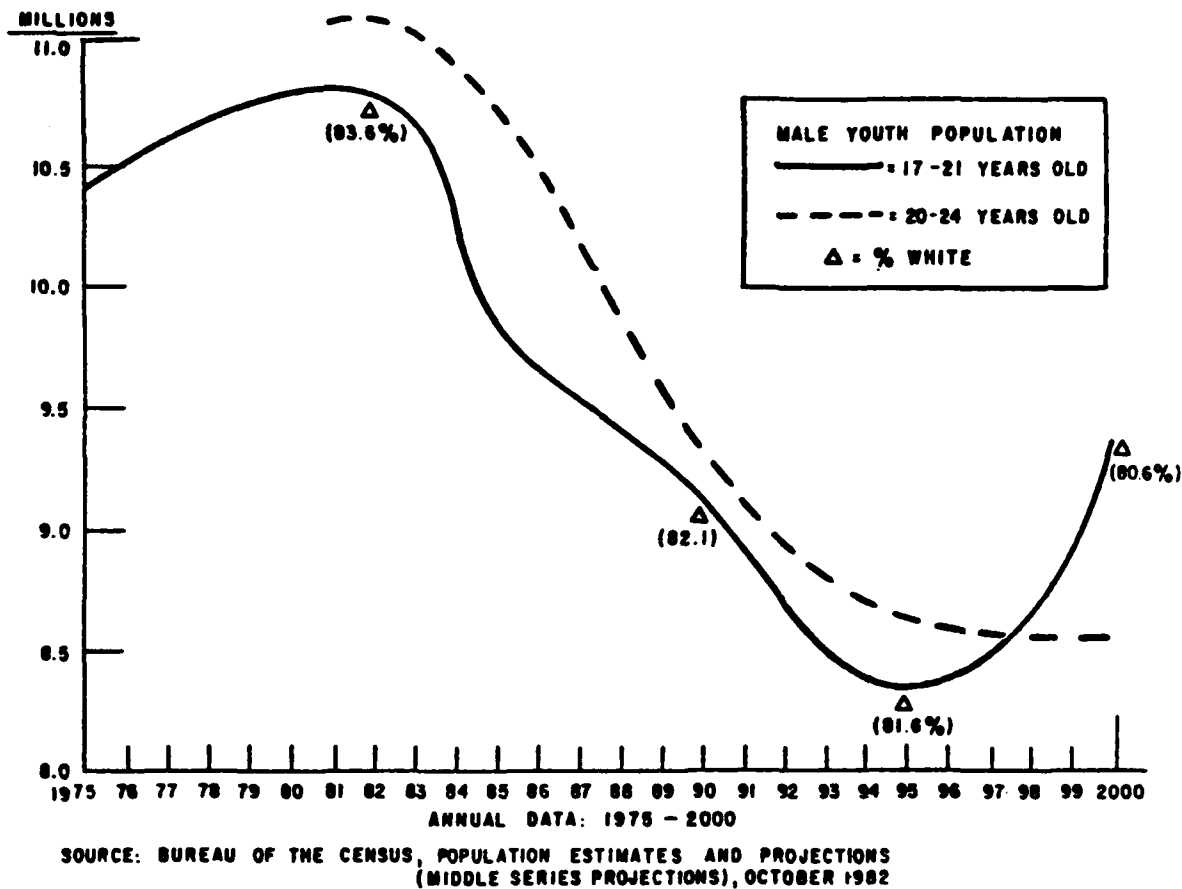


Figure 3. Trends in Male Youth Population.

the above ratio will have declined to 3.5 by 1990 and reach a low of 3.3 in 1992; i.e., one out of every three qualified males must be signed up.<sup>27</sup>

The Demand/Supply Relationship for High-Quality Accessions Will Become Tighter Yet. Three major factors are responsible for making the competition for high-quality youth very tight. First, the composition of military demands is changing. The growth of the Navy is concentrated in the highly technical ratings; for example, the combat system technicians are expected to grow by

<sup>27</sup>Richard W. Hunter and Gary R. Nelson, "Eight Years with the All-Volunteer Armed Forces." Paper included in Lt. Gen. Brent Scowcroft, USAF (Ret.), Editor. Military Service in the United States. The American Assembly, Columbia University, 1982.

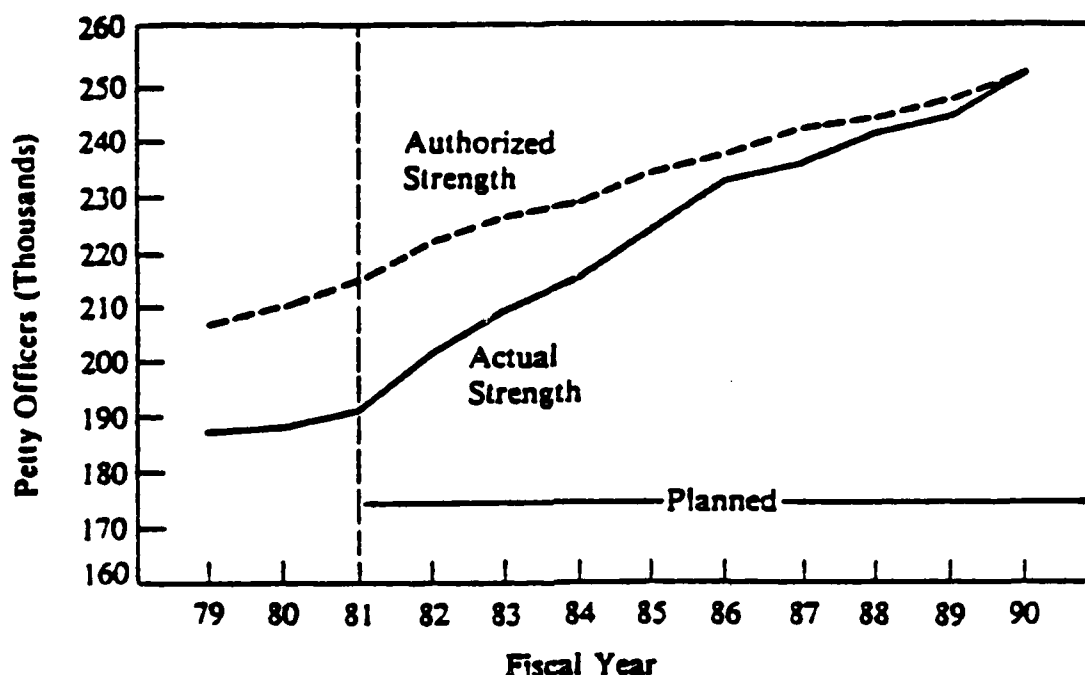


Figure 2. Planned Elimination of Petty Officer Shortages.

SOURCE: Caspar W. Weinberger (Chairman), Military Manpower Task Force Report to the President on the Status and Prospects of the All Volunteer Force, Washington, DC, October 1982.

The Demand/Supply Relationship Will Become Tight. The commonly used measure of tightness for military recruiting is the number of qualified, 18 year old males available per enlistment contract. In the 1950s and 1960s, this ratio hovered around 1.5 (i.e., the Services needed two out of every three qualified males), so that a military draft was necessary. With the post-Vietnam draw down and changing demographics, this ratio increased rapidly in the early 1970s, reaching a current level of about 4.5. This made the All-Volunteer Force possible. Even with the programmed DoD-wide accession requirements of 330,000 to 340,000 per year throughout the remainder of the 1980s<sup>26</sup> (a number which may turn out to be too low due to lower than planned retention),

<sup>26</sup>Caspar W. Weinberger (Chairman), Military Manpower Task Force Report to the President on the Status and Prospects of the All Volunteer Force, Washington, DC, October 1982.

Navy Manpower Plans Assume No Increase in Accessions. Formal plans are to accommodate the growth in manpower through increased retention so that non-prior-service accession requirements remain relatively stable throughout the remainder of the 1980s. Programmed non-prior-service (enlisted) accession requirements range from a high of 86,000 (FY85) to a low of 82,000 (FY88). (It was 98,000 in FY80 and 92,000 in FY81.)<sup>20</sup> Increased retention is also counted on to eliminate the existing petty officer shortage (see Figure 2). Favorable experience in the past two years, especially through lateral entry of prior-service personnel, agreed with this plan. For example, the petty officer shortage declined from 22,000 to 18,000 by the end of FY82.

Manpower Supply is Decreasing. The demographic trends are well-known. The market of primary interest to military recruiters, males in the age group of 17 to 21 years old, was 10.784 million in 1982 (year mid-point).<sup>21</sup> It will decline 15 percent by 1990, and 22.5 percent by 1995,<sup>22</sup> which is the trough for this age group (see Figure 3). Within this group, the prime recruiting cohort (males reaching 18 years of age) shows a drop of 24.5 percent from 1982 to 1992, the trough for 18 year olds. After 1995, male youths in the 17 to 21 years age bracket will slowly increase; this group will stay below the ten million level and, according to Bureau of the Census projections, will stabilize by the middle of the next century at a level 13.5 percent below that of 1982. While the pending decline still leaves a large number available, a significant portion does not count towards the supply of potential candidates for military service. The estimates of the percentage of the age group not qualifying for military service (based on current mandatory minimum physical, moral, and mental standards) range from 22 percent overall<sup>23</sup> to 27 percent for whites, 37 percent for blacks<sup>24</sup> to a weighted average of 34 percent projected for the late 1980s<sup>25</sup>.

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<sup>20</sup>Ibid.

<sup>21</sup>Bureau of the Census, Population Estimates and Projections, Series P-25, No. 922, October 1982.

<sup>22</sup>Ibid.

<sup>23</sup>Department of Defense, Soviet Military Power (Washington, DC: Government Printing Office, September 1981 (A 1983 update was published in Armed Forces Journal International, March 1983)).

<sup>24</sup>Thomas S. Gates (Chairman), The Report of the President's Commission on an All Volunteer Force, Washington, DC, February 1970.

<sup>25</sup>CDR Donald L. Pilling (USN). "The Dwindling Master," U.S. Naval Institute Proceedings (June 1982), pp. 35-39.

TABLE 4. NAVY RATINGS INVOLVING ELECTRONIC MAINTENANCE SKILLS

Rating	Occupational Title	Fleet/Shore <sup>1</sup> Ratio	Open to Women	Number of <sup>2</sup> Unique NECs
AQ	Aviation Fire Control Technician	40/60	Yes	37
AT	Aviation Electronics Technician	60/40	Yes	73
AX	Aviation Antisubmarine Warfare Technician	40/60	Yes	14
CTM	Cryptologic Technician, Maintenance	60/40	Yes	35
DS	Data Systems Technician	60/40	Yes	22
ET	Electronics Technician	60/40	Yes	78
EW	Electronics Warfare Technician	60/40	No	14
FTG	Fire Control Technician (Gun Fire Control)	60/40	Yes	59 (FT Total)
FTM	Fire Control Technician (Missile Fire Control)	60/40	No	
GMM	Gunner's Mate (Missiles) (Missile Fire Control)	60/40	No	16 (GM Total)
STG	Sonar Technician (Surface)	60/40	No	41 (ST Total)
STS	Sonar Technician (Submarine)	60/40	No	
TM	Torpedoman's Mate	60/40	Yes	14

<sup>1</sup>Approximate split of authorized billets between Fleet and shore establishment per Navy Enlisted Career Guide 1980-1981.

<sup>2</sup>NECs established for each source rating by NAVPERS 18068D, Navy Enlisted Manpower and Personnel Classifications and Occupational Standards, April 1980 issue.

NOTE: Excludes: MT (Missile Technician) and FTB (Ballistic Missile Fire Control Technician), both supporting strategic systems; and TD (Training Device Technician), being disestablished.



## SECTION III

## IMPACT OF FUTURE TRENDS

Two of the factors affecting maintenance performance, which the Navy can influence, but cannot completely control, are personnel availability (both in a quantitative and qualitative sense) and the future direction of technology as applied in combat systems. This study was focused, therefore, on projecting these two factors to the mid-1990s, and assessed the resulting implications in terms of maintenance skill requirements and maintenance performance.

## MANPOWER AND PERSONNEL

INTRODUCTION. Manpower and personnel, in combination, refer to the ability of each Service to meet and sustain its requirements (determined by force structure) with available personnel (determined by the inventory, attrition and retention rates, and extent to which new accession requirements can be met through recruiting), both in terms of quantity and quality. Because this is the single most critical issue for the continued success of the All-Volunteer Force, it receives a great deal of attention. Massive amounts of data are routinely collected and analyzed, both within and outside the Services, for use in manpower planning, personnel management, and policy decisions. Some of the data pertaining to the U.S. Navy was examined and is focused on the ratings responsible for non-strategic combat systems maintenance (see Table 4).

## OBSERVATIONS.

Manpower Requirements are Increasing. With the end of FY82 as a baseline and using last year's planning data for FY88, the increase in Navy manpower is as follows:

- a. Unconstrained Enlisted Requirements: 8.6% growth.<sup>18</sup>
- b. Programmed Active Duty Strength (officers and enlisted): 12.7% growth.<sup>19</sup>

For subsequent years, Navy manpower plans show an average growth of one percent per year into the 1990s.

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<sup>18</sup>Chief of Naval Operations (OP-112D), NAMPS run of 28 April 1982.

<sup>19</sup>Caspar W. Weinberger (Chairman), Military Manpower Task Force Report to the President on the Status and Prospects of the All Volunteer Force, Washington, DC, October 1982.

d. Leaving the problem unsolved is not cost-effective. First, the cost implications of poor maintenance performance are staggering, but not traceable as such, by current accounting systems. Second, the increased reliance on Fleet support to meet readiness requirements is at the expense of skill stagnation of Fleet technicians.

POSTSCRIPT

The assessment of combat systems maintenance performance, based on empirical and substantive data, is grim. It must be added that this assessment pertains to the generation of combat systems currently in the Fleet; i.e., designed in the 1960s or early 1970s when design for maintainability and testability received much less emphasis than it does today. The very recent changes in acquisition policies and the evolution of testability as a true engineering discipline (as will be discussed in Section IV) have potential for reducing the extent of the problem with the next generation of combat systems. The current systems, however, will remain with the Fleet well into the 1990s, so that the problem will not just disappear within the next few years. Furthermore, an overly optimistic expectation of improvements with the next generation in the 1990s may not be warranted as a result of the future trends described next. In other words, maintenance skill training is the most crucial issue today, and will remain so in the foreseeable future.

as assistance with equipment maintenance problems. Once the battle group arrives in Pearl Harbor, the units go into a repair mode. MOTU 5 personnel, supplemented by MOTU 1 technicians (homeported in Pearl Harbor), assist in accomplishing repairs. At the end of the 72-hour stay in Pearl Harbor, MOTU 5 personnel, to the extent they are not longer needed, return to San Diego. Normally, about 50 percent (11 technicians) stay with the battle group. The battle group continues its transit to Subic Bay, Philippine Islands (approximately four weeks). The MOTU 5 technicians continue to perform the same functions as on the first leg of the journey. Once in Subic Bay, units go again into a repair mode lasting five days. MOTU 5 personnel are now supplemented by personnel from MOTU 7 to assist ship's force in combat system repairs. Once again, MOTU 5 personnel no longer needed return to San Diego; some MOTU 5 technicians, however, stay with the battle group for the entire deployment (seven months) to compensate for shortfalls in on-board expertise.

This battle group technical support program was initiated in 1980 due to the low combat systems' A<sub>0</sub>. The reason the program continues today is the continued shortfall in the level of skills and knowledge of the technicians, causing a steadily increasing dependence on MOTU 5 for training and technical assistance. MOTU 5 is the largest Fleet support activity in the Navy.

**SUMMARY FLEET ASSESSMENT.** The two Fleet programs described above are strictly viewed as necessary "band-aid" programs. If technical training continues in its present form, however, the resulting void in technical proficiency will cause these programs to become permanent fixtures. In a peacetime Navy, where schedules are known in advance, these programs may flourish; in wartime, there are not enough assets to support the entire Fleet this way.

## CONCLUSIONS

The evidence presented in this chapter yields the following conclusions:

- a. Inadequate maintenance performance is a serious problem. It inhibits the Navy from achieving realistic readiness goals in peacetime and bodes ill for the Navy's ability to sustain wartime mission requirements.
- b. Inadequate maintenance performance is a systemic problem, influenced by a multitude of interrelated factors. Maintenance performance will improve through better maintenance training and aiding only if improvements are made in other factors such as job design, human factors engineering, training philosophy, design for maintainability, etc.
- c. The Navy is addressing the symptoms, not the causes, of the problem. The Systems Commands focus on reliability improvements and supply support. The Fleet is doing the best it can, steadily increasing its dependence on Fleet support from the shore establishment both for combat system maintenance (preventive as well as corrective) and practical job training. The Fleet's ability to continue doing so is, however, limited by Fleet support billets and funding; in wartime, it would be impossible.

In order to assess and monitor the contributions made by the Mobile Training Team, COMNAVSURFLANT plans to use two current combat system examinations as measures of effectiveness: the Combat Systems Post Overhaul Examination (conducted shortly after overhaul) and the Combat Systems Operational Readiness Examination (conducted upon completion of refresher training). Although training is not the only factor measured by these examinations, it is the most important aspect according to COMNAVSURFLANT.

PACIFIC FLEET PROGRAM. Commander, Naval Surface Force, U.S. Pacific Fleet (COMNAVSURFPAC), does not have a formalized program similar to the CSIP created by COMNAVSURFLANT. However, Logistics Command, Pacific (LOGPAC) provides a tremendous amount of technical training and support to West Coast units. LOGPAC is a Fleet support command peculiar to the Pacific Fleet; it represents a consolidation of diverse activities which, for the Atlantic Fleet, are dispersed among the Readiness Support Group, MOTUs, Systems Command field activities, and others. Whereas the CSIP is keyed to an individual ship's overhaul and post-overhaul cycle, the Pacific Fleet's program (which has no formal name) is keyed to the battle group deployment cycle. The primary thrust of this program is, again, technical training.

A deploying battle group is assembled approximately four to five months prior to deployment. As part of the predeployment work up, the battle group conducts a readiness exercise approximately three months prior to deployment. Just prior to the exercise, MOTU 5 (homeported in San Diego) provides the first step in the training process. Along with members of the deploying Group Commander's staff, MOTU 5 assembles the combat systems officers from individual units within the battle group and reviews the status of their combat systems' equipment and maintenance technician training. MOTU 5 then schedules and provides as much technical training assistance as feasible prior to commencement of the exercise. As a result, units go to sea with a higher readiness posture than in the past and, therefore, can participate more realistically in the exercise. All necessary training cannot be completed in the available time, however, so that units may not have the on-board expertise to repair combat system casualties occurring at sea during the exercise. In order to assist in this area, MOTU 5 provides six to eight of its technicians to the battle group for the duration of the exercise. The fields of expertise for these technicians are Naval Tactical Data System, communications (HF, UHF, and LINK), and radar (2D, 3D, and fire control). During the exercise, usually three to five weeks in duration, these technicians visit battle group elements that need assistance in accomplishing technical training or correcting equipment casualties.

Upon completion of the exercise, units begin preparing for deployment, usually with assistance from the Fleet support community, concentrating on repair and calibration of combat system equipments in order to deploy at the highest level of operational readiness attainable. When the battle group finally deploys, MOTU 5, by standard operating procedure, assigns approximately 22 combat systems maintenance technicians to make the transit with the battle group to Pearl Harbor, Hawaii, a period of two weeks. These technicians provide technical training to units in the battle group, as well

the combat system technician ratings as a group, this parameter is about 88 percent (E-4 or E-9) or 64 percent (E-5 to E-9).<sup>48</sup> As a result of the petty officer shortfall, the experience profile (years-in-service distribution) of personnel in each of these technical ratings is heavily biased; in 1982, the average months in service of personnel in these ratings ranged from a low of 66 to a high of 85 compared to the Navy-wide average of 67 months.<sup>49</sup> Most personnel (57 to 71 percent, depending on rating) have six or less years in service.<sup>50</sup> This profile of inexperience will become worse with the planned growth in these ratings at a rate more than double the Navy-wide rate.

**ASSESSMENT.** The situation is not hopeless. With appropriate recruiting efforts and use of available incentives, the Navy should be able to meet its accession requirements into the 1990s, if military pay comparability is maintained. Maintaining the modest quality standards currently in effect, let alone achieving current objectives, however, will be impossible without major changes in policy. Similarly, with respect to retention, if the unemployment rate comes down sufficiently and confidence is gained in civilian employment prospects, retention can be anticipated to decline to traditional levels. The Navy's manpower plan is fine as a goal; as a plan it appears to be unrealistic, unless major changes in policy are implemented to increase lateral entry of prior-service personnel and increase retention. Without those changes, a continued shortage in the senior enlisted grades (E-5 through E-9) in the combat system technician ratings can be anticipated, compensated in quantity (but not in quality) by an overfill in the junior grades.

**IMPLICATIONS FOR MAINTENANCE.** The net effect of the above trends is that less experienced personnel must carry more of the maintenance burden. Specifically, first-term technicians will be required to perform a much larger portion of corrective maintenance tasks than currently. Improvements in technical training and maintenance job aids will be essential to make this possible, unless maintenance skill requirements decline as a result of future combat system technology.

#### MAINTENANCE TRENDS OF CURRENT TECHNOLOGY

The maintainability characteristics and maintenance concepts of three "emerging" combat systems, one in each Navy community, were examined in order to identify changes from the current baseline (examples of currently operational equipment in the Fleet as summarized in Section II) and to assess future maintenance trends. Two of these systems, the AEGIS Weapon System and F/A-18A HORNET avionics, have already reached operational status; the third,

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<sup>48</sup>Defense Manpower Data Center, Requirements and Authorizations for FY82, Inventory as of 30 June 1982.

<sup>49</sup>Ibid.

<sup>50</sup>Ibid.

the Submarine Advanced Combat System (SUBACS), is still under development with a design freeze planned in 1989. The observations made are summarized here to illustrate some fundamental differences in future directions pursued in each community.

AEGIS. AEGIS sets a clear example for a much-needed trend; its inherent complexity is far above that of the comparable system currently deployed (Mk 86 GFCS), while its maintenance complexity is less. The built-in performance monitoring/fault localization (PM/FL) system, known as Operational Readiness Test System (ORTS), significantly reduces the uncertainty and ambiguity associated with corrective maintenance of the Mk 86 GFCS. Through reference codes displayed on the ORTS console display, the technician is either directed to the proper module replacement procedure (if the fault has been isolated by ORTS to a single module), or to the proper fault-isolation work package (to manually isolate the fault within a given ambiguity group). The needed technical data are retrieved through an automatic microfiche retrieval system, next to the ORTS console displays, and can be printed on the spot. AEGIS provides a de facto illustration of integrated diagnostics -- a concept which will be discussed later in this section. Factors that may have contributed to this successful implementation of automated/semi-automated maintenance diagnostics include the following:

- a. program management emphasis on availability,
- b. no cutting corners in maintainability,
- c. a long maturation program prior to Fleet introduction (prototypes have been used since 1973 for land-based testing, since 1975 for at-sea testing),
- d. professional engineering support to the program office, independent of the prime contractor,
- e. a closed-loop failure reporting, analysis, and corrective action system operated from 1973 to the present,
- f. verification of all "no-go" and "go" paths in the ORTS software (the latter is still in progress).

AEGIS appears to show that "it" can be done. Three observations must be added to temper unwarranted enthusiasm. One is that the ORTS design concept may have gone too far in its system-level orientation. As a result, the effectiveness of ORTS is dependent on the operational status of the AEGIS system. When the system degrades as a result of maintenance deferrals or inadequate maintenance, ORTS fault detection and isolation capabilities degrade too; when one or more subsystems are "down," ORTS is ineffective for the subsystems that are "up." For example, ORTS does not work on the Fire Control System unless the total weapon system (including Command and Decision System, Weapons Control System, SPY-1A Radar System) is "up." One lesson learned might be the need to address this issue in testability

specifications. Normally, such specifications are very careful in requiring that BIT failures must not affect the operational status or performance of the weapon system; but reverse requirements (i.e., that BIT performance must not be affected by graceful degradation of the weapon system or by having portions of the system "down") are never addressed, as far as can be determined.

The second observation pertains to the danger of drawing hasty conclusions from the favorable experience of the lead ship of the CG-47 Class during its first cruise. It is manned in accordance with authorizations, and all AEGIS technicians have received special training. Maintenance supervisors, while satisfied with ORTS capabilities, articulated their concern about what will happen to AEGIS once it is manned through the standard Navy personnel and training system. In this context, it may be useful to recall that the program manager's estimate of AEGIS manning requirements was for 1st and 2nd class petty officers in the DS rating, not the 2nd and 3rd class FTs currently authorized.

The third observation pertains to the level of supply support needed to sustain high  $A_0$ . Current methodologies for determining shipboard stockage of spares and repair parts are based on historic demands. Such a methodology can no longer provide adequate support for a complex system such as AEGIS: the high count of replaceable items and their individual high reliability combine to result in a very low probability of any particular item-type to fail within a specific time period, thereby disqualifying most items from being stocked aboard. There is a need to replace traditional demand-based stockage policies by a more sophisticated sparing-to-availability concept for highly complex electronics systems. (Section IV will return to that subject.)

F/A-18A HORNET AVIONICS. Maintainability and reliability were emphasized (including incentive awards) in the F-18 program. The Weapon Specification included the following BIT requirements:

- a. Initiated BIT. 98% fault detection; 99% fault isolation to WRA.
- b. Periodic BIT. 90% fault detection; 90% fault isolation to WRA.
- c. False Alarm Rate. Less than 1%.

Shortfalls in meeting these requirements were identified by Initial Operational Test and Evaluation (October 1980 - January 1981) and Bureau of Inspection and Survey trials (three BIT assessments from November 1981 - October 1982). Mature BIT assessment is currently in progress (October 1983 - September 1984). Due to changes in the rules for chargeability of failures and because of major BIT engineering changes (both hardware and software), it is difficult to get a fix on actual BIT performance in terms of the above measures. Based upon the analysis of two data sources, the best estimate of the BIT false alarm rate for the AN/APG-65 Radar is somewhere between 45 and

62 percent<sup>51</sup>. This means that, on the average, over 50 percent of the radar WRAs pulled from the aircraft are not faulty or cannot be determined to be faulty; i.e., NFR rate of 50 percent. This is a poor result, given the emphasis on maintainability, but not too different from any other current airborne radar. One lesson learned might be that the specifications were unrealistic or even inconsistent (high detection rates generally mean tight tolerances and, therefore, high false alarm rates); or, that further changes in BIT software are necessary (e.g., false alarms can be reduced by storing a BIT signal without triggering the BIT latch until the BIT has been rechecked several times confirming the failure indication); or, that avionics require "smart" BIT. The key lessons learned, however, are that testability specifications alone do not solve the problem and that the problem is only discovered in system integration; i.e., very late in the full-scale engineering development phase when time and funds are not available to solve unanticipated problems. This explains the need for a planned testability maturation program in the production phase. This is one aspect of the F-18 story.

Another aspect is the result of the comprehensive nature of the avionics BIT, the integrated system architecture and ATE compatibility design requirements. These factors drove the various avionics subcontractors (other than the radar developer) to include very effective BIT and testability characteristics in their designs. In most cases, failures are identified at the SRA level to provide a WRA fault-indication output to the mission computer, maintenance monitor panel and/or maintenance signal data recorder set, including identification of the culprit-SRA involved. This (unplanned) outcome has made possible a change in maintenance concept: performing on-aircraft fault isolation down to the SRA level for many of the nonradar avionics WRAs, using a "suitcase" test set, known as the Avionics Fault Tree Analyzer (AFTA); removal of the WRA and replacement of the defective SRA with a known, good SRA; and reinstallation of the WRA on the aircraft followed by a checkout via BIT. The concept eliminates the need for ATE to test those WRAs and permits reduced stockage of spare WRAs. About 75 percent of all avionic faults can be handled this way.

This concept has been adopted by the Royal Australian Air Force and the Canadian Air Force because of the substantial cost savings. The U.S. Navy has chosen not to adopt this concept. One reason frequently given is that using the aircraft as a test bench is a bad idea, but this would seem a poor argument:

a. "necessity to power-up the aircraft" (counter argument: the aircraft is powered-up anyway to re-run BIT for verification of fault indication)

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<sup>51</sup>Data from McDonnell Aircraft Company data bank (45% BIT false alarm rate) and the Navy's Maintenance and Material Management (3-M) data base (62% BIT false alarm rate), May 1983.



b. "unnecessary operating hours imposed on installed equipment other than the faulty WRA" (counter argument: not true in this case; the only equipment which needs to be turned on is the indicated faulty WRA, thanks to the novel power control design feature of the F-18)

c. "impact on turnaround time" (counter argument: if turnaround time is critical, the WRA can be replaced and its repair deferred to a shop or reinstalled and tested with AFTA when an aircraft becomes available).

Another reason given is: "need to reduce yellow gear on the flight deck" (AFTA, though only a small suitcase tester, is considered yellow gear). But the most frequently announced reason is that this concept does not conform to the Navy's standard maintenance concept for aeronautical equipment.

SUBMARINE ADVANCED COMBAT SYSTEM. SUBACS is in early development; design freeze is planned not earlier than FY89. The current maintenance concept is based essentially on eliminating at-sea maintenance, using a mixture of: functional and component redundancy, automatic reconfiguration, and graceful degradation, sacrificing the active sonar mode to keep the passive sonar mode operational. In this way, the plan is to provide a 70-day deployment with zero maintenance downtime for at least the passive mode.<sup>52</sup> The concept is to limit shipboard corrective maintenance tasks to removal/replacement of faulty modules isolated by the built-in PM/FL system. Repair of failures not isolated by the system will be deferred (except in emergencies). The plan is to reduce manning requirements, compared to those for the SSN 688 Class, by reducing watch station requirements (more automation), reducing maintenance workload (the maintenance concept moves most of the maintenance workload to shore-based assets), and combining different ratings into one composite rating.

Two observations can be made on the planned maintenance concept. First, the engineering effort required to provide a fault-tolerant system through automatic reconfiguration of the system, using standby equipment, is identical to that required for perfect PM/FL. If the latter is technically possible, then the use of technicians instead of standby equipment would be much cheaper. If it is not possible or does not work, the former (i.e., automatic reconfiguration) would not work either. As discussed later in this section, fault-tolerant design is not yet a mature discipline, but may become so by the late 1980s (see "Future Technology"). Second, in view of the much higher acquisition cost associated with the planned maintenance concept (if it is to be successful), the approach taken appears to be inspired more by the wish to eliminate the need for skilled technicians than by the objective of minimizing life-cycle costs. The same crew reduction anticipated with this maintenance concept might be achieved without eliminating shipboard technicians by changing traditional job design, splitting operator tasks from maintenance tasks and restructuring the ratings.

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<sup>52</sup>Naval Sea Systems Command, ILS Requirements Document for SUBACS, PMS 409, February 1982; Naval Sea Systems Command, SUBACS ILS Requirements, Concept Development Phase, PMS 409, March 1982.

If the proposed maintenance concept represents the way in which the Fleet wants to operate, so be it. The prime concern is that the up-front costs required for successful implementation of the planned concept may be underestimated or be underfunded, so that the Fleet ends up with additional problems.

**MAINTENANCE TRENDS.** The three examples summarized above may be compared as follows:

a. The AEGIS program tried to resolve the maintenance problem by providing a satisfying solution, while focusing on the ultimate goal of meeting very high  $A_0$  requirements. It was successful. Any future degradation will be due to the personnel and training system or inadequate supply support.

b. The F-18 program tried to solve the maintenance problem by providing an optimal solution, focusing on meeting detailed testability requirements. It appears to have failed in two respects. First, the radar does not and probably will not meet the stated requirements because the program was unrealistic with regard to the resources needed to achieve those requirements. Second, the remaining avionics possess testability features which permit a change in maintenance concept with much-reduced support costs, but this potential is not exploited because it conflicts with the traditional maintenance concept.

c. The SUBACS program tries to dissolve the maintenance problem by eliminating it from the "O"-level. The technology to accomplish that, however, is immature. The costs to do it successfully will be high, perhaps higher than anticipated and unaffordable.

#### FUTURE TECHNOLOGY

**INTRODUCTION.** The examination of future trends in technology, as applied in combat systems, is focused on one issue: whether or not future technology will reduce maintenance skill requirements compared to those required today, either by reducing maintenance task difficulty (maintenance complexity, see Section II) or by reducing or eliminating Fleet maintenance requirements. Maintenance skill requirements are defined in terms of a composite of cognitive abilities, training duration, and hands-on experience. Maintenance requirements are defined in terms of the extent and amount of maintenance (maintenance man-hours per operating hours or per week) allocated to the organizational level (surface/subsurface) or the organizational plus intermediate level (avionics) by maintenance concept.

This issue has been examined within the broader context of current U.S. defense strategy and weapon system acquisition philosophy which, in combination, result in increasing sophistication (inherent complexity, see Section II) of each next-generation combat system compared to its predecessor. Thus, stated another way, this analysis has examined the prospects for maintainability design and its ability to compensate for

increasing inherent complexity, thereby reducing maintenance complexity below that observed today.

The findings are summarized in the following subsections. Pointed out are current limitations in testing technology and factors which may delay major improvements including: limitations of computer-aided design (CAD), complexity of very large-scale integration (VLSI), and cost of fault-tolerant architecture. Due to uncertainties about technological advances in these areas, the assessment made cannot be a forecast, but is couched in doubt regarding the prospects for reducing maintenance complexity in the near future.

**CURRENT STATUS OF TESTING TECHNOLOGY.** Testing technology refers to the technology associated with design for testability, measurement of the testability characteristics of a design from engineering drawings, and evaluation of the testability achieved by prototype hardware. Testability is loosely defined as the ease, extent, and accuracy by which system performance can be verified and failures detected and isolated to a level of indenture in consonance with the maintenance concept. Lack of testability has been recognized in recent years as the single key design attribute responsible for maintenance support problems. Weapon systems fielded in the 1970s, including the case examples examined in the course of the present study, were characterized uniformly (i.e., DoD-wide) by serious testability shortfalls: they were presumed to possess a high degree of (semi)automated fault detection and isolation through BIT and maintenance diagnostic software (typical values in design specifications called for 90 or 95 percent fault isolation), but in the operational environment these design features did not perform as expected. Maintenance technicians, moreover, were not trained to cope with this testability shortfall; if a task and skill analysis was done at all, it was based on the advertised BIT performance so that the training objectives did not match actual job-task requirements. In some cases, testability shortfalls were reduced through engineering and software changes in the operational phase of a system's life cycle; in most cases they were not. Because of an ineffective feedback system, there was no appreciation of the causes of maintenance performance shortfalls, so that technical training courses were not revised. In other words, technicians were not equipped (neither by training nor by job aids) for their jobs, with the consequences that could be expected.

This situation ultimately led to the Industry/Joint Services Automatic Test Project initiated in 1977. This was a comprehensive, three-year study of management and technical issues related to automatic testing, both on-line (BIT) and off-line (ATE and test programs). The resulting final report provided a program for action in the form of 110 specific recommendations, integrated into 11 major areas. With respect to testability, rated the second most important area, the report summarized the problem as follows: "Testability, as a design discipline, is currently inadequate because there is no accepted method for measuring it and no mechanism for imposing and enforcing it during the equipment design phase." The report recommended that: (1) verifiable testability requirements be developed, (2) these requirements be imposed on the prime system/automatic test system design

process, and (3) measures be taken to ensure compliance.<sup>53</sup> Most of the recommendations are being followed up under the aegis of the Joint Logistic Commanders (JLC) Panel on Automatic Testing (established March 1978) whose study plan for an Automatic Testing Program was approved in October 1978. Of the 95 subtasks comprising that program, many are directly or indirectly concerned with testability. The program serves to coordinate and guide the testing technology efforts sponsored by the Services.

Testability has now emerged as a true subdiscipline of maintainability engineering. The significant research efforts in recent years have resulted in a body of knowledge regarding the specification and measurement of testability. Several guides have been published (Automatic Testing Acquisition Planning Guide, BIT Design Guide, Selection Guide for Digital Test Program Generation Systems, Reference Guide of ATE Information Systems, Sensor Handbooks), Service programs for future ATE have been coordinated, and a new military standard (MIL-STD) on testability is in preparation.<sup>54</sup> Training-course materials have been developed for industry (adopted by the National Security Industrial Association (NSIA)) and government personnel (incorporated in the Defense Systems Management College program manager course). In spite of these efforts, the impact on the design engineering community so far appears to be limited, which is possibly caused by the traditional chasm between design engineers and maintainability engineers. The notion of testability originated with the automated testing community; i.e., logistics support and maintainability engineering. Most R&D efforts to date have been limited to that same community. To bring this effort to fruition, the technology must be transferred, adopted, and institutionalized by the design engineering community for application in design. Further, the emerging technology requires much more R&D to evolve into a mature engineering discipline, applicable to current and next generations of electronics technology: VLSI, very high-speed integrated circuits (VHSIC), and wafer-scale integration. It appears that four major thrusts will be necessary to achieve successful implementation of design for testability.

First, a large educational effort will be required. Interviews with prime defense contractors indicate that current experience in testability design and evaluation is very limited.

Second, analytical tools must be developed to predict and monitor testability in the design phase. Only a handful of the prime contractors are reported to possess an effective capability (computer-based models) to measure testability at the system level; most of the software available today actually applies to modules (circuit boards) or integrated circuits as part of CAD

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<sup>53</sup>Industry/Joint Services Automatic Test Project, Final Report (June 1980).

<sup>54</sup>MIL-STD-XXX, "Testability Program for Electronic Systems and Equipments," August 1982 (Draft). Scheduled for approval in FY84.

systems (see "Design Automation"). The need for a more integrated process, both by function (CAD, system integration, failure mode and effects analysis, LSA, BIT) and by indenture-level (chip, board, assembly, subsystem, system), has frequently been noted, but does not currently exist. Frequently mentioned models which can be applied both as a testability assessment tool in design and as a diagnostic maintenance aid on the job, include LOGMOD, STAMP, and FIND.<sup>55</sup> But such models are just beginning to be considered as tools for testability design. (Past emphasis was on their use as maintenance job aids.) There is a great deal of confusion about the capabilities or limitations of these models.<sup>56</sup> Furthermore, such models would represent only part of a testability assessment system; other models are necessary for generating the test parameters. While a Testability Analysis Guide is in preparation under the auspices of the JLC Automatic Testing Program, much research remains to be done with regard to testability of embedded software and hardware-software integrated systems. For example, testability analysis has typically focused on identifying feedback loops and physically breaking those loops through redesign or modifying test points -- an effort which could be easily verified in the past through visual inspection of system or module block diagrams. With the increasing application of "embedded computer resources" in combat systems, an increasing portion of feedback loops are time-related "sneak paths" caused by software. Finding those "sneak paths" is impossible by traditional means and requires a sophisticated model; resolving those "sneak paths" requires micro-programming changes, not hardware changes. Sneak path analysis is currently more an art than a science. Similarly, the proposed military standard for testability is viewed with great skepticism by testability engineers (as opposed to those who have to administer testability

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<sup>55</sup>LOGMOD, developed in the early 1970s as proprietary software by DETEX Systems, Inc., is a logic model algorithm utilizing the maintenance dependency chart technique, which also underlies the format of the more effective troubleshooting aids. STAMP (System Testability and Maintenance Program), developed by ARINC Research Corporation, and FIND (Fault Isolation through Nodal Dependencies), developed by Hughes Aircraft Company, are more recent models with some similarities to LOGMOD. A recent independent survey by Northrop Corporation identified LOGMOD as the best testability assessment tool publicly available. A survey conducted by Lockheed California Company came to the same conclusion. Reportedly, the Naval Ocean Systems Center is planning to sponsor a comparative evaluation of these three models.

<sup>56</sup>An evaluation performed for the JLC Panel on Automatic Testing suggests that LOGMOD is not useful for analyzing digital systems. See: William L. Keiner, "The Assessment of LOGMOD as a Testability Design Tool," 31 December 1980. Actually, most of the LOGMOD applications to date are on digital or hybrid (sub)systems. LOGMOD can, and has been, applied to electronic (digital and analog) and non-electronic systems, including battle damage assessment.

programs); while it is a necessary first step, they do not see it as an effective approach to solve the testability problem.<sup>57</sup>

Third, the emphasis in weapon system acquisition must shift from design-to-unit-production-cost to life-cycle cost. While the latter is formal policy, it is accorded little more than lip service. Design for testability will increase the front-end cost as a result of more thorough engineering analysis requirements and additional cost for BIT hardware and software. It may also reduce system reliability due to increased complexity caused by more BIT circuitry (compared to poorly designed BIT, however, there may be no reduction in reliability).

Fourth, a new acquisition concept is necessary to guide implementation of design for testability, with the associated changes in current acquisition policies. This new concept is known as "integrated diagnostics," a concept adopted by the Air Staff in 1981 for implementation by the Air Force Systems Command and currently being examined for DoD-wide implementation by various JLC and NSIA committees.<sup>58</sup> In essence, the concept is that 100 percent diagnostics is required; must be quantitatively allocated to BIT, proceduralized aids, and the maintainer's cognition (training) based on early trade-off studies; must be measured and monitored throughout the development cycle for all levels of maintenance; must be matured through a planned maturation program in the production phase; and must be validated and verified in the production phase. This concept has not yet been adopted and institutionalized through DoD and Service regulations.

In sum, the current status of testing technology is immature. Much remains to be done to bring it to fruition. The OSD-IDA R&M Study (see Section I, footnote 3) arrived at a similar conclusion. The report describes the current status of testing technology and identifies R&D needs in the various testing technology areas. The study recommendations are quoted as follows:<sup>59</sup>

- a. Initiate a major weapon system design technology program, which injects testing technology into the design process.
- b. Invest in expanding the testing technology base to provide "off-the-shelf" proven alternatives for use in weapon system design.
- c. Institutionalize the transitioning and utilization of testing technology.
- d. Initiate actions to improve testing technology management.

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<sup>57</sup>John W. Cunningham, BITE, Inc., personal communication, 1983.

<sup>58</sup>Proceedings of Conference on Integrated Diagnostics, February 1983.

<sup>59</sup>IDA Document No. D-41, Testing Technology, April 1983 (Draft).

Another indication of the immature status of testing technology is provided by the current R&D program of the Rome Air Development Center (one of the major sponsors of testability research), which includes the following four projects:

- a. Prediction and analysis of testability attributes.
- b. Development of a practical engineering, mathematically tractable verification technique for accurate and economical test and demonstration of BIT.
- c. Development of practical design concepts to increase the efficiency, productivity, and cost-effectiveness of BIT through the application of artificial intelligence (AI) techniques ("Smart BIT").
- d. Development of design tools to implement the Integrated Diagnostics policy in an efficient and cost-effective manner.

DESIGN AUTOMATION. CAD has evolved as a design tool to assist the design engineer with many routine tasks. In the late 1950s, the focus was on automated logic diagrams, back-panel wiring with discrete wires, and electrical load checking. With the introduction of PC boards and increasing density of discrete components in the 1960s, the focus shifted toward circuit analysis and simulation techniques for discrete circuits. Integrated circuits (ICs) arrived by the early 1970s, so that computers became indispensable as record-keeping tools and means of design verification. By the mid-1970s, design tools evolved to automatically generate physical layout and interconnections of the components within an IC.

The present situation is characterized by numerous loosely coupled CAD programs, mostly incompatible due to different data formats, requiring manual intervention to move from one program to another. Much of the design process is still manual, with the designer creating specific circuit designs at the logic gate level, but using CAD tools for automated testing and simulation of circuitry, verification of physical and functional design, and production of final layouts for IC and complex PC board fabrication. With the introduction of VLSI, it has become apparent that the quagmire of stand-alone CAD tools must be replaced by an integrated design automation system. The consensus is that current tools are no longer adequate and are the constraining factor limiting the growth of IC complexity. Integrated design automation has become a "critical technology" to meet the needs of VLSI in the 1980s.<sup>60</sup>

The status and problems in design automation, especially in the area of design for testability, are best summarized by industry spokesmen:

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<sup>60</sup>Lawrence M. Rosenberg, "The Evolution of Design Automation to Meet the Challenges of VLSI," 17th Design Automation Conference Proceedings, June 1980.

a. Rosenberg (RCA): Our studies have shown that design for testability using currently understood techniques can be quite expensive; more so than their proponents acknowledge. In addition, conventional testability measures, such as "stuck-at" fault-coverage monitors (used by all known parallel and concurrent fault simulation programs) do not address the issue of pattern-sensitive faults. Nor do the scan techniques test for them. . . . I believe the development of cost-effective design for testability approaches and their supporting Design Automation tools remain a large challenge.<sup>61</sup>

b. Fitch (IBM): As system and component technologies continue their rapid rate of development, there is an increasingly higher probability that our ability to capitalize on them will be severely impacted by the lack of appropriate design system technology development. . . . The great progress made in the field (of Design Automation) over the past 10 years is miniscule compared to what we must accomplish in the next five years.<sup>62</sup>

c. Gwyn (Sandia National Laboratories): Substantial progress was made in implementing design aids during the 1970s; however, the development of new aids must be accelerated during the 1980s to support circuit design of VLSI complexity. New design aids will be required because of: (1) increased design complexity, (2) scarcity of design engineers, (3) need to reduce circuit design time and cost, and (4) increased emphasis in producing error-free manufacturable designs. . . . These design and manufacturing problems can be solved only by increasing the use of Design Automation and improving the design aids. . . . In the future, new aids will evolve and the emphasis will be on integrated design systems.<sup>63</sup>

d. Sapiro (American Microsystems, Inc.): VLSI design demands a hierarchical design approach with tools for each level of abstraction in the hierarchy. . . . We see the 1980s as broken up into two segments -- the early 1980s, when the work started on physical design tools in the late '70s will bear fruit, and the late '80s when a shift will occur away from physical design tools toward front-end tools to help the system design cope with greatly increased density and complexity. All these tools must be glued together by the much touted hierarchical design style. . . . These [front end design] tools, which will have the greatest impact on the system/circuit design process, are the most complex to develop. We see concentrated efforts starting in the 1980s but not completed until the 1990s.<sup>64</sup>

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<sup>61</sup>Ibid.

<sup>62</sup>Position paper included in the 17th Design Automation Conference Proceedings, June 1980.

<sup>63</sup>Ibid.

<sup>64</sup>Ibid.



e. Goel (IBM): We define Very Large Scale Logic (VLSL) to be that logic containing more than 10,000 gates. VLSL may not be common on the semiconductor chip of today but is found in abundance on second or higher level packages. Thorough testing of chips prior to packaging, combined with the availability of probe points on higher levels of packaging, have combined to temporarily obscure the testing problem for cards or boards with more than 10,000 gates. However, when VLSL becomes commonplace on chips, the chip testing problem will certainly become severe since a chip cannot be probed. Sizable increases in chip power dissipation may necessitate cooling methods which all but eliminate the feasibility of providing probe points on higher level packages. . . . Automatic test generation for VLSL will continue to rely on design for testability structures. The Level Sensitive Scan Design (LSSD) structure is an outstanding example of a design structure for testability. . . [But] with test generation costs of the order of minutes of CPU time for a 1,000 gate structure, we project a CPU time upwards of 1,000 hours for the 100,000 gate structure -- assuming super test pattern generation techniques and the deductive fault simulator. Parallel fault simulation is a technique which must be abandoned for large logic structures, considering that a 1 million fold increase in costs will be incurred in going from a 1,000 gate to the 100,000 gate logic structure. We hope that this paper will cause some rethinking about the frequently heard statement that test generation for combinational logic circuits is a solved problem.<sup>65</sup>

An independent review of the status of design automation in 18 companies and government laboratories, conducted in 1979, came to the following conclusions.<sup>66</sup>

a. Testing is one of the less mature but most active areas of Design Automation development.

b. Little effort is being devoted to formal design verification; rather, designs are checked in an ad hoc fashion by simulation, by building prototypes, or by employing the "first built" machine.

c. Most companies are either not ready to deal with VLSI design problems or are reluctant to discuss their present and planned efforts in VLSI. Register Transfer Level simulation, design verification, layout, design for testability, and test generation must be strengthened if future Design Automation Systems are to take advantage of new technologies.

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<sup>65</sup>Prabhakar Goel, "Test Generation Costs Analysis and Projections," 17th Design Automation Conference Proceedings, June 1980.

<sup>66</sup>Melvin A. Breuer, et al., "A Survey of the State of the Art of Design Automation," Computer, Vol. 14, No. 10 (October 1981), pp. 58-75.

Several universities (especially, Carnegie-Mellon University) and government laboratories (especially, Lawrence Livermore Laboratory) are active in the field of Design Automation. The Air Force Institute of Technology recently embarked on a five-year R&D program to upgrade its CAD tools into an integrated design automation system.<sup>67</sup>

In sum, the requirement to design and produce testable electronic components is widely recognized, but current tools are not adequate to cope with VLSI complexity. According to the judgment of the above experts, it would be 1990 at the earliest before such tools become available. In the meantime, the VHSIC program, as described next, has accelerated R&D on CAD tools and integrated design automation systems. Based on the progress reported to date and planned R&D efforts through FY87, it would appear that by the late 1980s design automation will have matured enough to cope with VLSI complexity.

VHSIC PROGRAM.<sup>68</sup> The VHSIC program is DoD's highest priority technology R&D program. The program was originally formulated by DoD in 1978 as a strategy to counter the lag of electronics applications in defense equipment behind commercial micro-electronics technology experienced throughout the 1970s. The reasons given for the program were to: (1) reverse the erosion of the U.S. electronic technology lead in the world, (2) increase the exploitation of IC technology advances, and (3) focus development efforts on military requirements. The VHSIC program differs from commercial VLSI developments by putting emphasis on:

- a. development of ICs for broad classes of military systems, including functions not needed in commercial applications,
- b. increased real-time system throughput, requiring higher chip complexity and higher clock rates,
- c. architectural concepts minimizing the need for design customization,
- d. reliability requirements in the military environment (temperature range, radiation exposure),
- e. exploitation of higher chip complexity for chip self-test (BIT) and fault-tolerant design.

The program structure and goals are summarized in Table 5. Recent revisions in the program were designed to emphasize VHSIC Phase 1 insertions

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<sup>67</sup>Harold W. Carter, "A Plan for Digital Systems Design Automation at the Air Force Institute of Technology," Planning Document (Dayton, Ohio: Air Force Institute of Technology, Wright-Patterson Air Force Base, November 1981).

<sup>68</sup>The VHSIC program description is taken from Larry W. Sumney, "VHSIC - A Status Report," IEEE Spectrum, pp. 34-39, December 1982.

way the contracts are written. While the Navy tailors its contract specifications to the developmental system using type specifications which involve standard general specifications, the extent of specificity and detail of human resource constraints in contract specifications ultimately is determined by policy and approved military standards and specifications. As indicated above none of the design guides so far has been accepted as a military standard; the only one available, MIL-STD-1472, is of little use beyond the traditional anthropometric measures of human factors. And current Navy policy leaves too much leeway to the program (project) manager.<sup>87</sup> To influence design in a more substantial way, design guides must be adopted as military standards which are invokable in contracts. And before this can happen, a consensus must evolve about what data in what format are necessary to relate skill and skill level to design attributes. Such a consensus, apparently, does not exist at the present time.

TESTABILITY. The above reasons explain why design for maintainability has not been very successful in the past, and may offer little prospect for improvements in the future unless the entire approach to influencing equipment design is changed. The notion among human factors specialists is that skill levels and skills can be defined, quantified, and presented to the design engineer as contractual constraints; and that just some more R&D is necessary to make that approach possible. Instead, a more pragmatic approach would be to focus on the one equipment design characteristic which determines maintenance task complexity that planned maintenance personnel can handle (a function of experience, training, and basic abilities) based on empirical evidence. That one equipment characteristic is testability, i.e., the ease, extent, and accuracy by which system performance can be verified and failures detected and isolated to a level of indenture in consonance with the maintenance concept. This is the approach adopted by the 1983 revision of MIL-STD-470.

The current status and prospects of testing technology (design for testability) is reviewed in Section III. Design for testability is crucial for achieving any substantial improvements in maintenance; in its absence, training and aiding improvements will be very costly and produce only marginal returns if measured in increased  $A_0$ . The Navy is on the record as recognizing that testability must be accorded top priority and funded

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<sup>87</sup>NAVMAT Instruction 3900.9A, "Human Factors in System Development," 1981 (Draft). This instruction exhibits a lack of detailed HFE standards, criteria, specifications, and guidance. A checklist of human factors information requirements in the acquisition process is provided by: D. Meister, Behavioral Inputs to the Weapon System Acquisition Process, NPRDC SR 83-21 (San Diego: Navy Personnel Research and Development Center, March 1983).

underutilization of man-machine technology in system acquisition. A similar assessment was made by the General Accounting Office (GAO) which estimated that over 50 percent of weapon system failures are human-induced (operator or maintainer) and concluded that more attention should be paid to human factors during the design process. It noted, however, that the new policy emphasis on human limitations in the design of systems may have a very limited impact because:

a. Human factor specifications, standards, and handbooks used in designing and developing systems and equipment do not adequately address human limitations.

b. There are no common methodologies and data sources for use by system designers in forecasting skill levels of future military personnel.

c. DoD testing policies and procedures do not tend to identify and resolve potential human-induced failures during the developmental stages of the acquisition process.<sup>85</sup>

NAVSEA has sponsored a HFE technology program since 1975, but implementation of the recommended process in new acquisition programs depends on available program funding.<sup>86</sup> The most straightforward design guide in the Navy relating design attributes to skill levels is the one previously referred to (see footnote 83).

DESIGN CONTRACTS. With the requisite acquisition policies in place, and information available to guide the design effort toward a system maintainable by Service technicians, the outcome may still be a system that is difficult to maintain. The reason for this is the design contract. Unless human resource constraints are explicitly included as design requirements (not just goals), there is little incentive for the design group to pay more than lip service to this aspect of design. It is difficult enough to meet the cost, performance, and schedule requirements which are invariably "hard" specifications. While the system program manager can influence the design effort through the preliminary and critical design review, any leverage ultimately depends on the

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<sup>85</sup>U.S. General Accounting Office, Effectiveness of U.S. Forces Can Be Increased Through Improved Weapon System Design, PSAD-81-17 (Washington, D.C.: Comptroller General of the United States, January 1981). It reiterated the same statement in: Guidelines for Assessing Whether Human Factors Were Considered in the Weapon Systems Acquisition Process, FPCD-82-5 (Washington, D.C.: U.S. General Accounting Office, December 1981).

<sup>86</sup>T. B. Malone, et al., Human Factors Engineering Technology for Ship Acquisition (Naval Sea Systems Command, October 1976). This was expanded subsequently to include aviation material: C. J. Baker, et al., Human Factors Engineering for Navy Major Weapon System Acquisition (Naval Air Development Center and Naval Sea Systems Command, July 1979).

System (NEPDIS), currently under development. A recent review of the literature on the use of human resource data to influence equipment design concluded that a solution to the problem is not clearly definable and the types of data required for communicating human resource information to design engineers not readily identifiable.<sup>81</sup>

The format normally used for presenting design-relevant human resource or human factors data to the design engineer is a design guide. Since publication of the first comprehensive guide (see footnote 74), literally hundreds have been published. None have been adopted as a military standard. The only existing standard is primarily concerned with anthropometric data, not with such concepts as skill and skill level and their relationship to design features.<sup>82</sup> A recent design guide for surface ship equipment, however, is focused especially on relationships between design attributes and skill levels (pay grades) and is probably as specific as one could expect, given the current state of knowledge.<sup>83</sup>

**HUMAN FACTORS ENGINEERING.** Human factors engineering (HFE) is broadly defined as the discipline concerned with the design and evaluation of the "man-machine interface" to ensure that it accommodates people's capabilities and limitations. HFE, as applied in the system acquisition process, is, by specification, supposed to encompass all elements of that interface: human engineering, biomedical aspects, personnel requirements, task and workload analysis, training, technical manuals and other performance aids, and test/evaluation.<sup>84</sup> While that specification has all the right words, there is little guidance how the human factors program requirements are to be accomplished. The only data reference in this specification is MIL-STD-1472, and the weight of that standard is on operability issues (design of displays, workspace, environment, safety), not maintainability (15 pages out of 200-page standard are concerned with maintainability, including two pages on test points, test equipment, and failure indicators). As a result, HFE has not been very effective in improving design for maintainability. The NRAC Study Group, previously referred to (see Section I), concluded that the existing military specification and standard are inadequate, thus contributing to the

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<sup>81</sup>Dennis Sullivan, System Design Characteristics and User Skills: A Literature Review, NPRDC TN 81-9 (San Diego: Navy Personnel Research and Development Center, March 1981).

<sup>82</sup>MIL-STD-1472, "Human Engineering Design Criteria for Military Systems, Equipment and Facilities," February 1968 (latest revision, May 1981).

<sup>83</sup>R. A. Dick and Marvin C. McCallum, Anacapa Sciences, Inc., Design Guide to Operator and Technician Requirements. NPRDC SR 83-14, 6 vols. (San Diego: Navy Personnel Research and Development Center, February 1983).

<sup>84</sup>MIL-H-46855, "Human Engineering Requirements for Military Systems, Equipment and Facilities," March 1968 (latest revision, January 1979).

supportability to the coequal of cost, performance, and schedule.<sup>78</sup> The second reason was that LSA typically was not conducted until the full-scale engineering development phase; i.e., much too late to influence design. The applicable specification was vague about the conduct of LSA in earlier phases of the acquisition cycle. Thus, LSA had become, in practice, a make-work activity of filling out reams of paper, instead of the design-analytic tool as had been intended.<sup>79</sup> Revisions of MIL-STD-1388 were initiated in 1981, emphasizing the need for front-end analysis and iteration of LSA from broad system-level analysis to detailed component-level analysis throughout the acquisition cycle. The revised standard was only recently approved and promulgated (April 1983). The third reason was that past policy focused on elapsed maintenance time (e.g., mean-time-to-repair, or some percentile of repair-time distribution) as the sole measure of maintainability. Outside the defense acquisition community, there is a consensus that this, by itself, is a poor criterion measure of maintainability: it is insensitive to design variables, downtime is contaminated with factors over which the maintainer has little control, etc.<sup>80</sup> There is, however, no consensus on what measures should be used instead. The recent revision of MIL-STD-470 ("Maintainability Program for Systems and Equipment," January 1983) adds testability as a measure of maintainability. This fundamental change may alleviate much of the problem.

**HUMAN RESOURCE DATA.** The lack of specificity of human resource data is another reason why design for maintainability is hard to achieve. Definitions of skills and skill levels are vague and inconsistent; available data are unclear and difficult to translate into engineering specifications; and there is a lack of concrete personnel skill data applicable to the design of Navy systems. The Navy Occupational Task Analysis Program data base appears inadequate for this purpose; this also appears to be the case for the more detailed data base, the Navy Enlisted Professional Development Information

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<sup>78</sup>DoD Directive 5000.1, "Major System Acquisitions," March 1980 (and subsequent revisions).

DoD Instruction 5000.2, "Major System Acquisition Procedures," March 1980 (and subsequent revisions).

DoD Directive 5000.39, "Acquisition and Management of Integrated Logistic Support for Systems and Equipment," January 1980 (superseding DoD Directive 4100.35).

DoD Directive 5000.40, "Reliability and Maintainability," July 1980.

<sup>79</sup>"The LSA shall be the single analytical logistic effort within the systems engineering process, and shall be responsive to acquisition program schedules and milestones." MIL-STD-1388, "Logistic Support Analysis," October 1973.

<sup>80</sup>Julien M. Christensen, "Summary Comments," Proceedings of Human Factors Design for Maintainers Conference (Warminster, Pennsylvania: Naval Air Development Center, March 1982).

in 1963.<sup>74</sup> By the early 1960s, maintainability engineering had evolved as a true engineering discipline: maintainability was defined in quantitative terms; methods for prediction and measurement were developed; and, for the first time, it began to be specified as a design requirement in the acquisition process.<sup>75</sup> The first systems-oriented textbook on maintainability, relating it to system effectiveness ( $A_0$ ) and ownership cost, was published in 1964.<sup>76</sup> And maintainability was recognized as the counterpart of reliability with both identified as key elements in the new concept of integrated logistics support.<sup>77</sup>

Thus, in the early 1960s, most of the machinery (policy, guidance, and knowledge) was in place to accommodate, if not encourage, design criteria for equipment maintainability considering the intended users. Yet, equipment design characteristics have remained one of the chief causes of maintenance support problems. The reasons for this lack of success in fielding better-maintainable equipment may be classified in four categories: (1) the acquisition process, (2) the inexactness of human resource data such as skill and skill level, (3) the focus of human factors engineering on operability vice maintainability, and (4) the way human resource constraints are specified in design contracts. Recent fundamental changes in acquisition policies, however, offer the potential of major improvements in design for maintainability.

**ACQUISITION PROCESS.** Three basic reasons explain why design engineers generally paid little attention to human design criteria for maintainability until DoD changed its acquisition policies in the late 1970s. One reason was that program cost, performance, and schedule were accorded top priority by formal policy, with maintainability or supportability a distant fourth. This was corrected with the 1980 revisions in acquisition policy, elevating

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<sup>74</sup>C. T. Morgan, et al., (eds.), Human Engineering Guide to Equipment Design (New York: McGraw-Hill, 1963). Revision of this guide began in 1965 and was completed in 1972 under the editorship of Harold P. Van Cott and Robert G. Kinkade, published by the U.S. Government Printing Office. Attempts to adopt this revised guide, one of the most referenced documents for this subject, as a military standard, have been unsuccessful.

<sup>75</sup>MIL-STD-778, "Maintainability Terms and Definitions," April 1964.  
 MIL-STD-470, "Maintainability Program Requirements," March 1966.  
 MIL-STD-471, "Maintainability Demonstration," February 1966.  
 MIL-HDBK-472, "Maintainability Prediction," May 1966.

<sup>76</sup>A. S. Goldman and T. B. Slattey, Maintainability: A Major Element of System Effectiveness (Huntington, New York: Robert E. Kruger Publishing Co., 1964).

<sup>77</sup>DoD Directive 4100.35, "Integrated Logistics Management System," June 1964.

1. Job Aids. The potential role of paper job aids in the performance of combat system maintenance is commonly overestimated: the operational environment at the organizational maintenance level (aboard deployed units) limits the acceptance and utilization of such aids because they tend to slow the work. The chief benefit of electronic maintenance aids lies in their potential flexibility so that the drawbacks of paper aids can be avoided. Electronic aids can be made to fit the job-site requirements (size, portability) and match the user's needs (directive task instructions or tutorial information). The Navy has been slow in recognizing the potential of such aids and in adopting them for operational use.

m. Training Equipment. Compared to operator trainers (especially flight simulators), experience with maintenance trainers is somewhat limited. There is a lack of institutional knowledge, procedures, and guidelines on how to develop design specifications for maintenance trainers such that positive transfer-of-training is guaranteed at least cost. From the limited experimental data available, it is known that maintenance trainers can be very cost-effective.<sup>73</sup> Most technical training provided today uses operational equipment, not maintenance training equipment. The result is ineffective hands-on training and excessive costs.

A brief discussion of these issues follows to provide the basis for the recommendations in Section V.

#### EQUIPMENT DESIGN

How to influence the design of new military equipment in order to ensure it will be supportable by the human resources that are available is an age-old issue. A brief review of what has evolved in this area suggests that little progress has been made over the past 20 years, at least until very recently. Improvements in the acquisition process, procedures, and guidelines for maintainability have been substantial indeed, but largely inadequate to keep abreast of "technology push" (increasing technological complexity of the equipment) and its impact on maintenance skill requirements.

Most of the groundwork in maintainability and human engineering was laid in the 1950s. In 1954, a Joint Services Steering Committee was convened to sponsor development of a ". . . guide in human engineering which the designer can use in the same manner as handbooks in other areas to assist in solving design problems as they arise. . . ." This guide was completed and published

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<sup>73</sup>J. Orlansky and J. String, Cost-Effectiveness of Maintenance Simulators for Military Training, IDA Paper P-1568, Institute for Defense Analysis, Arlington, VA, August 1981.



requirement of combat system maintenance technicians. This is not an indictment of ISD, as such, but the way it has been implemented by the Navy.

g. Proficiency Monitoring. Two steps are key in any instructional system, whether or not based on the ISD model. Those are task analysis (to identify training needs) and job performance monitoring (to provide feedback to the instructional system). Neither is done well in the Navy. Task analysis, if done in accordance with current ISD procedures, is limited to tasks which can be "proceduralized," ignoring cognitive tasks. Job performance may be monitored locally on a subjective basis, but the Navy lacks a standardized methodology. Lack of feedback inhibits identification of skill deficiencies which could be corrected through refresher training, remedial training, or revised training curricula. Questionnaires currently in use do not provide effective feedback.

h. Personnel Classification. Rating assignment eligibility is determined solely on the basis of ASVAB test scores, yet the ASVAB measures only a few of the individual abilities related to job performance potential. The absence of adequate tests inhibits both optimal utilization of the available talent pool and implementation of adaptive training to improve training effectiveness (reduce attrition).

i. Maintenance Data Systems. Maintenance information is inadequate at all echelons of equipment support. At the unit level, technicians lack the information which would help them do a better job (e.g., recent equipment maintenance history), and supervisors lack the information (e.g., jobs required and resources available) to schedule maintenance work efficiently. At the equipment-management level (Systems Commands and field activities), managers must rely on 3-M data which are not always accurate and not designed to identify causes of maintenance problems. The Navy lacks an aggressive data automation plan designed to provide information feedback to the technician, thus assuring self-interest in proper maintenance job reporting.

j. Technical Manuals. While the Navy has made substantial progress with improving technical manual acquisition and support through adopting a tailored contract requirements concept and automating distribution management, serious problems remain. The chief problems are incomplete, inaccurate, or out-of-date information so that technicians must rely on other sources. The Navy Technical Information Presentation System (NTIPS), and its predecessor R&D program were intended to eliminate those problems, but it has grown into a very ambitious project which has caused delays in applying automation to the generation, distribution, and control of technical information.

k. Supply Support. The Navy's stockage policy for spare parts is a demand-based policy; i.e., spares and repair parts are authorized for shipboard stockage only if they meet certain minimum demand criteria. With increasing system complexity (increased parts count), such a policy becomes increasingly suboptimal as the probability that any particular part will fail decreases. Switching to a sparing-to-availability methodology would increase  $A_0$  for the same investment in spares stockage or could reduce costs without reducing  $A_0$ .

## SECTION IV

## KEY ISSUES FOR MAINTENANCE IMPROVEMENT

## OVERVIEW

Inadequate maintenance performance is a systemic problem. Piecemeal actions, therefore, offer little potential for improvement. The time has come for a broad plan of action across functional specialties and disciplines to address the root-causes of the problem. The assessment of the problem is that such a plan should focus on the following key issues to be resolved through further R&D when necessary, or to be addressed by management action:

a. Equipment Design. Design characteristics have the largest potential impact on the problem, yet an effective process of influencing equipment design for maintainability is still lacking.

b. Job Design. The present rate, rating, and NEC structure exhibits excessive overspecialization, duplication, and a serious dichotomy between training for jobs and training for advancement. The structure is not supportive of current weapon systems, is inflexible, and cannot be supported by the personnel system. Additionally, the Navy lacks an effective process for job design.

c. Organization Design. Due to combat system integration, shipboard organization is no longer compatible with combat system architecture. This causes problems with divisional responsibilities for diagnosing failures at the system level and in subsystem interfaces.

d. Maintenance Philosophy. The current maintenance concepts for electronic equipment installed on board surface ships are based on a maintenance philosophy which is inconsistent with operational requirements and cannot be supported through the current supply system. The Navy has become aware of this and is in the process of evaluating alternative maintenance policies. Because of poor coordination, however, actions taken in other areas, such as ATE, are preempting the evaluation.

e. Training Philosophy. The current training philosophy for combat system technicians is based on front-end training. Not only is the current approach limited in effectiveness and efficiency, it is also demotivating for many trainees and, in principle, wasteful of scarce training resources.

f. Instructional System. Implementation of Instructional Systems Development (ISD) has resulted in impoverished training: course content lacks validity; presentation is hampered by inadequate training equipment for hands-on training; the pass/fail criterion is a phony "mastery" concept. Apparently, the Navy does not recognize that the adopted ISD procedures are designed only for proceduralized task instruction, not for development of cognitive skills like troubleshooting, which is the most critical job

c. Combat system maintenance concepts will continue in the same direction currently exhibited:

(1) Attack Submarines. Improvements in reliability through fault-tolerant design will permit meeting 60-day mission requirements with minimum maintenance. Most of the corrective maintenance skill requirements will be at the "I"-level, augmented by Direct Fleet Support. "O"-level skill requirements will depend on the extent to which the Navy is forced to take shortcuts in design or cuts in program funding. Keeping a small number of expert technicians aboard would reduce design complexity and lower acquisition costs.

(2) Surface Combatants. Improvements in maintenance diagnostics through system design for testability will permit continued reliance on a two-level maintenance concept without interfering with self-sufficiency. The concept may fail, however, if the Navy does not follow through with: (1) increased front-end investment to achieve the level of testability necessary to eliminate unnecessary removals, and (2) replacement of the present demand-supported stockage policy with one more supportive of availability/sustainability requirements. Corrective maintenance skill requirements will be distributed among "O"-level (fault isolation and module replacement), some "I"-level (screening for NFR modules and repairing selected modules), and "D"-level (module repair and rebuild of end items).

(3) Tactical Air. Technology will permit a reduction or elimination of "I"-level avionics repair and the associated ATE aboard the carrier. The exception, however, will be high-density VHSIC/VLSI boards, which, for reasons of affordability, may have to be repaired aboard the carrier. If the Navy revises its traditional maintenance concept accordingly, Fleet maintenance requirements will decline, with skill requirements distributed similarly to those for surface combatants.

d. Job-task requirements, both for operators and maintainers of combat systems, will increasingly demand cognitive skills. Tasks that can be proceduralized and taught as such will constitute an increasingly smaller portion. More attention to proper job design and a total change in training philosophy will be required if the Navy is to meet these requirements.

ASSESSMENT. History may repeat itself. In the late 1960s, BIT and automated maintenance diagnostics were adopted as the solution to prevalent personnel and training problems, but the needed testing technology was not available. The consequences became all too apparent in the mid-1970s. If the clock could be turned back, the testing technology currently available could be applied with great success to the systems developed in that past era. Some systems now entering the Fleet have been able to take advantage of advances in testing technology thanks to their long development times. Many systems have not.

Now, the presumption of many individuals is that the testability problem has been licked. But, it is often forgotten that, in the meantime, combat system technology has not stood still. The gap between today's testing technology and prime equipment technology currently on the drawing boards is as large as, if not larger, than it was in the late 1960s. The consequences in terms of maintenance performance and  $A_0$  of these systems, when deployed by the late 1980s, could be the same story all over again.

To avoid this result, the following steps are required:

- a. R&D efforts to advance testing technology, including the tools to apply it, must be accelerated to catch up with the next generation of weapon system technology.
- b. Technology insertion demonstration programs are necessary to develop, enhance, and verify the tools required to achieve testability.
- c. The rate of technology advances proposed for new weapon systems must be slowed down, pending closure of the testing technology gap. Because this is unrealistic, the alternative is to provide for a planned maturation program during the production/operation phase, keeping program resources (funding, people, support systems) together for as long as necessary to make the weapon system supportable.

#### SUMMARY

The projections of future trends in manpower and personnel, given the Navy's planned build-up, and in equipment maintenance requirements, given the direction of technology, may be summarized as follows:

- a. Requirements for experienced electronics technicians will increase, but the inventory of career technicians will exhibit an increasing deficit. Critical skill shortages will be unavoidable, unless the Navy implements drastic changes in personnel and manpower procurement policies.
- b. First-term personnel must be equipped to perform a portion of the corrective maintenance workload in order to compensate for petty officer shortages. Improvements in training and aiding are necessary to achieve this result.

Fault-tolerant design clearly offers significant potential, not only for improving system  $A_0$ , but also for reducing or eliminating "O"-level maintenance. This is, essentially, an expensive approach to solve the maintenance problem and, with the present state-of-the-art, not cost-effective except in special circumstances. With future advances in this technology, the cost-effectiveness ratio can be expected to change, so that this approach may become increasingly practical in the 1990s for mission-essential subsystems. It may even become a necessity by that time, if a breakthrough in VHSIC testing technology does not come to pass.

**ARTIFICIAL INTELLIGENCE.** The original focus of AI was on modeling human cognition in some limited domain. While knowledge representation remains the most active AI research area, many AI practitioners shifted their focus in the 1970s to knowledge engineering applications. Numerous "expert systems" (knowledge-based, rule-based, or model-based) and associated support systems (relational data base management, inference, and interface subsystems) have been developed during the 1970s, mostly for experimental purposes, but some for operational use. Applications of AI to system design or design for testability are, at the present time, totally experimental but are believed to have promising potential. For example, two applications reported in the literature are KBVLSI and CRITTER. The former is an experimental, knowledge-based system developed by Xerox and Stanford University to aid in VLSI designs; the latter, developed at Rutgers University, can be used to check the correctness and robustness of digital designs, including signal and timing margins, using heuristic reasoning. There are numerous other application programs under development. The OSD-IDA R&M Study recommended that AI techniques be applied to VLSI/VHSIC design for fault tolerance and testability, and that such an R&D project be incorporated in the VHSIC Phase 2 program.<sup>72</sup>

Recently, AI has received increased emphasis by DoD. It is included as a key technology area in the new "intelligent super computer" program to be launched shortly by Defense Advanced Research Projects Agency (DARPA), who projects a cost of \$1 billion during the remainder of the 1980s. This program, which encompasses a wide spectrum of technologies, is currently under review by a special task force of the Defense Science Board to recommend priorities. A final report of this review is scheduled for the first quarter of 1984.

Any assessment of the potential impact of AI on testability would be speculation. AI applications to maintenance aiding would appear to be more obvious and immediate. Section V will return to that subject.

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<sup>72</sup>IDA Document No. D-28, Artificial Intelligence Applications to Maintenance, April 1983 (Draft).

b. Failures can occur in dedicated spares but go undetected until the spare is required to substitute for a failed active component.

c. Latent faults tend to cause a continuous "flip-flopping" between active and spare components.

d. A failure in the small number of circuits responsible for reconfiguration is fatal.

A new concept, known as continuously reconfiguring, is designed to eliminate these shortcomings. The architecture consists of a pool of autonomous microprocessors, both active units and nondedicated spares, connected by a common set of data buses. Any processor is able to perform any task at any time, with task assignments continuously redistributed among all, using a concept of autonomous control. The concept is under development and evaluation by the Air Force Flight Dynamics Laboratory, but will require new bus standards (more flexible than MIL-STD-1553B) to become operational. Moreover, there is currently some doubt about the impact of this architecture on the effectiveness of fault detection.<sup>71</sup>

Apart from multiprocessor computer applications, fault-tolerant architecture appears to be in its infancy. R&D efforts required to make it possible include the following (as identified in the Air Force's PAVE PILLAR program, which is an integrated avionics architecture concept study):

- a. AI technology to discriminate true faults from false alarms,
- b. adjustable tolerances for fault isolation,
- c. improved CAD tools to integrate testability and functional requirements,
- d. new sensors and associated diagnostic techniques,
- e. testability analysis and marginal testing techniques for design verification,
- f. testing techniques for diagnosing cables and connectors,
- g. "Smart" BIT strategies and algorithms for determining accuracy and stability requirements for BIT,
- h. new high-speed bus architectures,
- i. exploration and evaluation of alternative fault-tolerant architectures (depending on amounts and types of chip-level BIT available from VHSIC) through simulation.

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<sup>71</sup>Richard A. Gunkel, Gunkel Consulting, personal communication, 1983.

maintenance skill requirements (due to the up-front emphasis on testability, with up to 20 percent of real estate on the chip reserved for self-test circuitry). Apart from the testability design problems discussed previously (Design Automation), it is believed that this expectation may come only partly true in the case of high-density boards for the simple reason of affordability, as explained next.

A very enlightening study of this topic was conducted at the Air Force Institute of Technology.<sup>70</sup> The study examined the various elements of life-cycle cost of an airborne synthetic aperture radar digital processor based on VHSIC technology. The study found that of all the variables influencing life-cycle cost, wafer size and on-line testability have the most profound impact. The finding with regard to wafer size is of interest because it would explain why some electronics companies put more emphasis on wafer-scale integration technology than on the philosophy pursued by the VHSIC program. The finding with regard to on-line testability could have a major impact on the maintenance concept for VHSIC technology insertion in avionics systems, such as planned for the F-18 and F-14. While the plan is to have a two-level maintenance concept ("O"-level replacing the VHSIC board based on BIT indications, and "D"-level repairing the board through chip replacement), the study concludes that a ten-fold reduction in life-cycle cost would be achieved by doing the repair on-line (i.e., aboard the aircraft without removing the board).

The interpretation of that study is that the Navy may need to reconsider its planned maintenance concepts for VHSIC technology. Even if the BIT performs perfectly, support costs may drive the Navy to a more forward-oriented support concept for complex VHSIC modules (comprising, say, 100 ICs); i.e., shipboard repair of those modules by chip replacement vice replacing the module with a spare and evacuating it to depot.

**FAULT-TOLERANT ARCHITECTURE.** Fault-tolerant architecture, not to be confused with design for "graceful degradation," is one basic approach to eliminating maintenance at the "O"-level. This approach has been standard practice at NASA for spacecraft. As previously indicated, it is also the approach planned for the SUBACS program. Successful implementation of the approach, however, relies on near-perfect BIT for automatic reconfiguration of the system. The approach has been successfully applied in multiprocessor systems, but the standard architecture used in the past (centralized control of reconfiguration and stand-by spares to be activated for specific computational tasks upon failure of specific active components) exhibited certain drawbacks:

- a. The time required to transfer tasks from a failed processor to a spare can cause transients in the output of that task.

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<sup>70</sup>Harold W. Carter, "A Preliminary Investigation of the Life Cycle Costs of a Digital Processor Using Very High Speed Integrated Circuits," Air Force Journal of Logistics (Fall 1981), pp. 9-17.

TABLE 5. VHSIC PROGRAM STRUCTURE

PHASE/DURATION	GOALS/PRODUCTS	BUDGET
PHASE 0 March - November 1980	Program definition including detailed concepts, design approach, and plans. Products include architecture and design approaches selected to implement chips with 1.25 micron and submicron size devices.  (Nine Contractors)	\$10.5M
PHASE 1 May 1981 - April 1984	Design, develop, and pilot-produce 1.25 micron chips with a $5 \times 10^6$ gate-Hz/cm <sup>2</sup> functional throughput rate. Develop subsystem brass-boards. Demonstrate feasibility of design tools and simulation aids. Develop submicron chip technology. Key features include BIT technology.  (Six Contractors)	\$ 167.8M
PHASE 2 1984 - Beyond	Demonstrate Phase 1 brassboards in operational systems (1.25 micron technology insertion). Develop technology for yield enhancement. Develop Integrated Design Automation System. Develop and pilot-produce submicron chips with $10^{11}$ gate-Hz/cm <sup>2</sup> functional throughput rate.	1984 - 1986: \$75M 1984 - 1988 Estimate: \$400M
PHASE 3 1980 - 1986	Develop technology supportive of Phases 1 & 2: architecture, lithography, design automation, materials, packaging techniques, fabrication, testing, standardization, and other problem areas.  (31 Contractors so far)	1980 - 1984: \$50M (59 contracts awarded) 1980 - 1986: \$60M

into existing operational systems or those under development, and to move more cautiously toward submicron goals.

The projected benefits from VHSIC technology insertion are lower life-cycle costs and increased systems performance, availability, and effectiveness. A preliminary investigation conducted by the OSD-IDA R&M Study clearly confirms this potential.<sup>69</sup> For example, the particular cases examined (paper studies) show mean time between failures improvements by factors ranging from 2.3 to 6.2, acquisition costs reduced by a factor of 3, and support costs reduced by a factor of 10. Specifically, with regard to maintenance, the expectation is that VHSIC technology insertion will lower maintenance requirements (due to much increased reliability) as well as

<sup>69</sup>IDA Document No. D-42, VHSIC Working Group Report, April 1983 (Draft).



accordingly.<sup>88</sup> The bottom line of the integrated diagnostics concept, as discussed in Section III, is that, for the first time, a precise estimate will be available of the "cognitive load" on the maintainer; or, vice versa, that this "cognitive load" can be addressed as a quantitative constraint in the design process. The associated measures have meaning for the design engineer, can be tested and validated, and can be evaluated through operational testing, if properly defined.

#### JOB DESIGN

The present personnel and billet structure by rate, rating, and NEC code, has evolved more in support of administrative needs than through a planned effort to optimize training and personnel utilization. The structure exhibits excessive overspecialization, proliferation of subspecialties, duplication, and a serious dichotomy between training for jobs and training for advancement. A Navy study from the mid-1970s summarizes the problems as follows:

a. The Study Group found no major problems in the availability of qualified people or the demands to be placed upon them in the future Navy. Where the main problem does lie, however, is in redesigning the Navy enlisted occupational classification system (NEOCS) so that it will maintain the supply of skilled people where they are needed. The Study Group defined the major problem areas of NEOCS as follows:

(1) The system does not adequately identify, classify, group, or structure skill requirements compatible with, or supportive of, existing weapon systems, existing logistics systems, and their respective subsystems.

(2) NEOCS does not provide the necessary flexibility in the transfer of skills to accommodate technological change.

(3) NEOCS promotes overlapping and duplicating classification of occupational fields.

(4) NEOCS cannot support a "One Navy" concept employing the cross-utilization of skills in different commands.

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<sup>88</sup>Vice Admiral Travers, Vice Chief of Naval Material, in his keynote address to the AUTOTESTCON '81, Orlando, Florida, October 1981. Rear Admiral Grich, Vice Commander NAVELEX, "The Navy Perspective of Testability," conference on Design for Testability, Arlington, Virginia, November 1981. Actually, the Navy's Testing Technology program dates back to 1977 when it was initiated by direction of the Assistant Secretary of the Navy for R&D in response to a study of Fleet problems with automatic testing (ATE Ad Hoc Working Group, "Report on Navy Issues Concerning Automatic Test, Monitoring, and Diagnostic Systems and Equipment," February 1976).

(5) As a system, NEOCS is degrading at an accelerating rate.<sup>89</sup>

The recommendations from this Study Group were never acted upon by the Navy. The same conclusions still apply to today's lack of proper job design for the technical specialties in the Navy. The NEOCS Study was probably the most significant personnel and training study conducted in recent years; but, ironically, the few cognizant personnel interviewed in the course of this study either did not know about the NEOCS study or implied that its recommendations had been implemented.

The reasons why the Navy decided not to follow-up on these recommendations are unknown. Perhaps, the recommended changes from the existing manpower, personnel, and training structure were too drastic for a tradition-prone organization, viz:

- a. Consolidation of all ratings into 23 occupational fields.
- b. Elimination of the linkage between skill levels and pay grades.
- c. Deletion of petty officer designation at the E-4 level.
- d. Elimination of all hardware-specific NECs.
- e. Restructuring of the NEC system to identify skill levels.
- f. Revision of training strategy by eliminating the front loading of training costs, introducing a distributed, multilevel training approach, and emphasizing supervised "hands-on" training at Type Commander (TYCOM) training activities.

Nevertheless, these are the types of fundamental changes necessary to resolve the maintenance skill proficiency problem within affordable cost constraints. Additional R&D may be required to refine the results of the NEOCS Study, but the issue is more one of management action than one requiring basic research.

After solving the issue of occupational structure, the next requirement is development and implementation of a more effective process of position analysis or design. There is currently no single document or data base which identifies the tasks, skills, and knowledge requirements of a job incumbent (occupant of a billet). Bits and pieces of the information are found in Personnel Qualification Standards (PQSs), Personnel Advancement Requirements (PARs), Technical Manuals (TMs), Maintenance Requirements Cards (MRCs) of the Planned Maintenance System (PMS), and Rate Training Manuals. Consolidating all this information into a single reference manual was one of the major efforts for CSIP, the program initiated by COMNAVSURFLANT in 1982 to improve

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<sup>89</sup>Chief of Naval Personnel, Navy Enlisted Occupational Classification System (NEOCS) Study, Vol. II (15 January 1974), pp. 85-86.

the proficiency of combat system technicians through diagnostic testing and remedial or refresher training (see Section II). A similar effort is currently underway at CNET. The Naval Enlisted Professional Development Information System (NEPDIS) effort is comprehensive and described elsewhere.<sup>90</sup> While it will provide the job-task data needed for position analysis, a process for designing positions in an integrated fashion with job aids and training does not currently exist. The variables in question are known from the literature, but attempts to improve upon position design often solve one set of problems at the expense of another set.<sup>91</sup> Further R&D is required to bring the state of knowledge in job design further along toward application. One basic aspect, for example, that has not received rigorous analysis is the trade-off between combining or not combining operator and maintainer tasks into the same job position and the associated implications for training requirements, skill development, job satisfaction, and proficiency.

#### ORGANIZATION DESIGN

Closely related to the issue of job design is that of organizational effectiveness. This term is normally associated with the theory of organizational development in behavioral or social sciences. Organizational development is very well addressed by the Navy's Human Resources Management Program which is contributing, indirectly, to improving job performance. This section is addressed at an entirely different issue, that of shipboard organizational structure and its potential impact on maintenance effectiveness.

Traditionally, weapon subsystems have been independent entities supported by rating-specific divisions within shipboard organizations. With the trend toward computer-based integration of subsystems into combat systems, a dichotomy evolved between system architecture and organizational structure, causing problems with assigning responsibilities for diagnosing system failures to the appropriate subsystem interfaces. The Bureau of Naval Personnel developed in the early 1970s the "combat system technician" concept to deal with this problem.<sup>92</sup> The concept was tested aboard a number of pilot ships by reorganizing billets concerned with electronics maintenance within the Operations and Weapons Departments into a single Combat System Department, including a System Test Officer billet and a Ship's Electronics

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<sup>90</sup>Thomas H. Ansbro, An Overview of the Naval Enlisted Professional Development Information System (NEPDIS), Technical Report No. 122 (Orlando, Florida: Training Analysis and Evaluation Group, April 1982).

<sup>91</sup>Theodore J. Post, "Job Design, Performance Aids, and Training," paper presented at The Human Factors Society Annual Meeting, October 1977.

<sup>92</sup>Bureau of Naval Personnel, Combat System Personnel Training and Management Plan (Washington, D.C.: Bureau of Naval Personnel, 1 November 1971).

Readiness Team (SERT) to which senior petty officers were assigned as collateral duty for system-level testing and casualty diagnosis. The experimental test had serious limitations (i.e., training was not changed, just the organizational structure) which resulted in the ambivalent finding that "... objective measures of electronics maintenance performance failed to demonstrate that improved maintenance resulted from implementing the combat system organizational structure onboard pilot ships." The conclusion from this evaluation effort was as follows:

The problem concerning electronics readiness of Navy combatant ships is not yet resolved. The centralized administration of electronics maintenance will assist in, but is not sufficient for, resolution of this problem. Factors beyond ship-level management of technical personnel contribute to the lack of electronics readiness of Navy ships.<sup>93</sup>

The current status of this effort is "in limbo." Only some pieces of the organizational combat system technician concept have been implemented. For example, most surface combatants have a SERT, formally or informally, but their function is limited to identifying skill deficiencies and training requirements to meet readiness inspections; they are not responsible, by standard operating procedure, for system-level diagnosis of casualties. The training aspects of the concept were never implemented. Clearly, additional R&D effort is necessary to bring the concept to fruitful implementation.

It is noteworthy that Naval aviation has been more successful in adapting its maintenance organization to the fundamental issue of system-level diagnosis; since the late 1960s, both the Squadron Manning Document and the Naval Aviation Maintenance Program (Office of the Chief of Naval Operations (OPNAV) Instruction 4790.2) identify a Troubleshooters Branch in the Line Division of the Organizational Level Maintenance Department. This Branch is manned by senior petty officers from the various ratings for system-level troubleshooting, for some aircraft on a full-time basis (e.g., F-14A), for other aircraft (e.g., S-3A) as additional duty during Flight Quarters (i.e., when aircraft are launched or recovered) by petty officers from the various organizational shops. There is a clear parallel between the Troubleshooters Branch in aviation maintenance and the SERT in ship or submarine combat system maintenance, but the latter was never fully implemented.

#### MAINTENANCE PHILOSOPHY

The maintenance concept of a weapon system or end item of equipment defines the conditions under which it is maintained, the tasks (what, when,

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<sup>93</sup>Lloyd S. Standlee and Del H. Sass, Combat System Personnel Training and Management Evaluation: Final Report, Technical Report TR 77-17 (San Diego: Navy Personnel Research and Development Center, February 1977). This report summarizes the results of 15 separate studies devoted to this topic.

and how) performed at each maintenance level, and the skill categories (rate/rating/NEC) to which the tasks are allocated. The maintenance concept and equipment design characteristics are closely related factors; they mutually influence each other to such an extent that the maintenance concept is often viewed as a design characteristic. Other factors, however, also influence the maintenance concept; these include the operational concept (in Navy terminology, the Plan for Use), established maintenance policy, and the existing maintenance structure. At the root of the latter factors is an overall, generic view of how maintenance is, or should be, performed: a factor referred to as maintenance philosophy. That, ultimately, drives maintenance policies or doctrine, the maintenance concepts espoused for new equipment, and consequently, the equipment design characteristics related to maintenance support. As a result, the maintenance philosophy has a pervasive influence on many maintenance-related factors, including job-task requirements and training.

To explain how changes in maintenance philosophy have contributed to poor maintenance performance, as evidenced by low  $A_0$ , it is necessary to go back to the early 1970s. At that time, the Navy reevaluated established maintenance policy in view of changes in electronics technology and shortages of resources (especially manpower) required to meet existing and projected maintenance support needs. The outcome was a revised, uniform maintenance policy for electronics equipment, eliminating on-equipment repairs from the "O"-level by means of modular design (permitting removal/replacement, vice repair of failed modules), moving module repairs to higher maintenance levels (favoring "D"-level over "I"-level on the basis of economics), and increasing the dependence on "I"-level support (establishing restricted availabilities for "I"-level maintenance in order to extend the period between major overhauls) (NAVMAT Instruction 4790.19, June 1973). This policy was subsequently firmly established in Navy maintenance doctrine (NAVMAT Instruction 4700.4B, "Levels of Equipment Maintenance," August 1974).

Adoption and implementation of this modular concept ignored two fundamental conditions to make it effective: (1) testability design to localize system failures to the removable modules, and (2) on-board stockage of spare modules. Neither condition was met. As a result, the first deficiency resulted in a high NFR rate which, in the absence of any screening capability at the "O"-level, depleted the supply system. That, in combination with the second deficiency, resulted in increasing CASREPs for parts. To counter the untoward impact on readiness, the Fleet developed the miniature/microminiature (2-M) electronic repair program. This program consisted of training courses for circuit board repair, installation of precision soldering equipment aboard selected surface combatants, and authorization to perform emergency repairs of circuit boards.<sup>94</sup> The program was strictly a

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<sup>94</sup>NAVSEA Instruction 4790.17, "Miniature/Microminiature (2-M) Electronic Repair Program," May 1980; and NAVMAT Instruction 4790.22A, "Miniature Electronic Repair Program," February 1981.

"band-aid"; was implemented without authorized parts, schematics of circuit boards, or test equipment; and, because of the uncertain influence on system integrity, resulted in as many problems as it solved.

By the early 1980s, the situation had become bad enough for the Fleet to confront the CNO and the Chief of Naval Material with requests to change the maintenance philosophy, authorizing the "O"-level to perform module repair in a more organized fashion (providing schematics and piece parts), and the "I"-level to screen all modules using ATE, returning good boards and repairing defective boards. The situation was summed up by CINCLANTFLT as follows:

To throw away a \$450 board because of a defective \$3.95 IC is foolish. To reduce combat capability of a \$100 million ship because the closest replacement module is undergoing repair at a depot is criminal, but both examples occur on a regular basis because of today's depot-only repair concept.<sup>95</sup>

Caught between peacetime cost-effectiveness considerations and the Fleet's demands for self-sufficiency, the Navy decided to study its modular philosophy once more. The result of this study consisted of identifying four alternatives:<sup>96</sup>

- a. Provide the Fleet with modular repair capability.
- b. Provide the Fleet with modular screening capability.
- c. Provide the Fleet with selective modular repair capability.
- d. Provide SIMAs with screening and repair capability.

It did not recommend one over the other.

Since no decisions have been made, NAVSEA is proceeding with two programs designed to test and evaluate the last two alternatives. Under the Support and Test Equipment Engineering Program (STEEP), pilot facilities have already been established at SIMAs in Norfolk and San Diego to test and repair circuit boards using ATE. A total of 68 STEEP sites are planned under this program:

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<sup>95</sup>Commander-in-Chief, U.S. Atlantic Fleet, Memorandum, Subject: Draft Navy Training Plan for Radar Display and Distribution Systems, November 1981.

<sup>96</sup>NAVMAAT Modular Philosophy Study Report (July 1981).

- a. AD/AR/AS: 28
- b. CV/CVT: 14
- c. LHA/LCC: 7
- d. MOTU: 10
- e. SIMA: 5
- f. SRF: 4

The second program underway is a pilot program of shipboard testing and repairing of selected, digital modules from the Mk 86 GFCS aboard selected ships of the DD-963 Class. This program was initiated in February 1981 at the direction of CNO. The test and evaluation plan was approved in September 1981, and an 18-month observation period began in August 1982 after installation of test equipment, technical documentation, piece-parts, 2-M repair station, and training courses. Based on a progress report reviewed, it appears that limited funding and a too-small sample of circuit board failures may threaten the validity of test results.<sup>97</sup> In any event, the program is to provide a cost-benefit analysis and assess the ramifications in training, documentation, support equipment, spares, and personnel requirements. It is scheduled for completion in FY84.

In sum, the current situation demonstrates a lack of consistency between policy and actions, and highlights a dire need for better coordination, as observed by a recent, informative study conducted at the Naval Postgraduate School:<sup>98</sup>

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<sup>97</sup>GFCS Mk 86 On Board Module Repair Pilot Program, Quarterly Status Report (February 1983).

<sup>98</sup>LT N. E. Brown, USN, Improving The Electronic Repair Capabilities in The Fleet," (M. S. Thesis, Naval Postgraduate School, March 1982).

a. Current NAVMAT maintenance policy is not consistent with CNO ship maintenance policy. As the latter is in accord with DoD maintenance policy, NAVMAT must change its policy.<sup>99</sup>

b. The evident trend toward increasing ship's force corrective maintenance capabilities will require central direction of maintenance policy, coordination of 2-M and ATE programs, improved supply support, improved training, and consideration of other factors than just cost in level-of-repair analyses.

#### TRAINING PHILOSOPHY

Navy technical training is front-loaded. Most formal technical training is given prior to any job experience, while little skill-enhancement training is available for career personnel (other than self-study training materials). Training durations for the 13 different ratings responsible for electronics maintenance vary by track, but extend to approximately one year for the longest tracks (not counting Recruit Training). The only other training that technicians might receive during their Navy career consists of additional "C" School courses when they are assigned to maintain equipment not covered in previous "C" School courses. (For the avionics ratings, skill progression training after "A" School is provided by the Fleet Readiness Squadron and Naval Air Maintenance Training Detachment (NAMTRADET), similar to, but not a "C" School. One key difference is that trainees in those ratings (AQ, AT, AX) receive "practical job training" (i.e., supervised OJT) on operational equipment in an environment resembling the operational environment; "C" Schools do not provide this).

The high cost and limited effectiveness of this approach to technical skill training has been a subject of concern for many years. First, the training is ineffective because most graduates do not possess the skills

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<sup>99</sup>OPNAV Instruction 4700.7F, "Maintenance of Ships," September 1981, includes corrective maintenance as an "O"-level responsibility: "Organizational (Shipboard) level maintenance is that corrective and preventive maintenance accomplished by the ship's crew. The individual ship shall be maintenance self-sufficient to the degree achievable within manpower and facility constraints." In contrast, NAVMAT Instruction 4700.4B limits "O"-level responsibility to: "... inspecting, servicing, lubricating, adjusting and replacing of parts, minor assemblies and sub-assemblies." DoD guidance on maintenance support consists of the following: DoD Directive 4151.1 states that military units should perform direct maintenance (where possible) and prescribes the role for contractor personnel; DoD Instruction 4151.12 assigns responsibility for developing maintenance support concepts to Maintenance Engineering; DoD Directive 4151.16 states that maintenance should be performed near the point of generation and oriented to weapon systems; and DoD directive 5000.39 encourages the use of innovative support concepts to improve system readiness/support costs.



required to develop job proficiency through on-the-job experience. Second, it is inefficient because the benefits to the Navy are not in consonance with the high, upfront investment. Contributing causes include high personnel turnover, a weak linkage between training content and job-task requirements, and a personnel utilization which results in losing most of the skills and knowledge acquired in training (i.e., during the first three to six months on their first duty station, school graduates are typically assigned to mess duty). Third, the training approach is wasteful since over 20 percent of high-aptitude students wash out in Basic Electricity and Electronics (BEE) School.<sup>100,101,102</sup> The Navy cannot afford losing these people. The cause of this high attrition rate is not a lack of student aptitude, but the inflexibility of the present computer-managed instruction (CMI) course which does not adapt teaching style to individual cognitive styles and abilities. Additionally, because a needs analysis was never done to determine BEE-course content, the course lacks any demonstrable relationship with the Navy technician's job.

For an outsider, it is very hard to understand how this approach to training came about. No one else, outside the U.S. Armed Services, trains this way. Our NATO allies -- specifically the British, Germans, and Dutch -- put more emphasis on upfront OJT to familiarize trainees with the equipment in the operational environment. They apply a multilevel, distributed-training concept (i.e., distributed over the individual's career), fitting the training to job-task requirements, as well as providing retention incentives. In many cases, factory training rounds off the training program for senior technicians in the career force. Why the U.S. Navy has not yet changed its training philosophy may be due to two persistent, common beliefs which had been exposed as myths many years ago:<sup>103</sup>

- a. Myth 7: The Military Services can take a high school graduate and turn him into a field service technician within a few months.
- b. Myth 9: On-the-job training is a good way to teach troubleshooting.

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<sup>100</sup>David C. Atwater and Norman M. Abrahams, Evaluation of Alternative ASVAB Composites for Selected Navy Technical Schools, NPRDC TR-80-15 (San Diego: Navy Personnel Research and Development Center, February 1980).

<sup>101</sup>J. Sachar, Macy Abrams, and Christine Buckley, Relating Performance in Basic Electricity and Electronics and "A" Schools, NPRDC TR-79-2 (San Diego: Navy Personnel Research and Development Center, October 1978).

<sup>102</sup>CINCLANTFLT Trip Report dated February 1982.

<sup>103</sup>Nicholas A. Bond, Jr., "Some Persistent Myths About Military Electronics Maintenance," Human Factors, Vol. 12, No. 3 (June 1970), pp. 241-252.

In essence, the Navy does not have a training "system" designed to ensure that technicians acquire the skills and knowledge required for proficient job performance along a career continuum. There is no adequate occupational data base (see "Job Design"). There is no career-development planning. And there is a sense of lack of direction as one recently retired CNET staff member observes:<sup>104</sup>

So we go blithely on our way, with "A" schools basing their curricula on one set of occupational data, some teaching basic skills, others teaching to specific equipment; "C" schools using the rate training manuals which use still another set of data and have no connection with what the "A" schools teach; the personnel qualification standards program plodding along on its own data base; and so on. With no system, there is nothing to manage in the true sense, creating confused sailors and unhappy fleet commanders.

Additionally, the presumption that Fleet training will fill the voids in formal school training, either through formal OJT or "F" Schools, is unrealistic because required training materials and other resources are not available. Fleet training also is hampered by the fact that, since the mid-1970s, no new PQSs have been written for maintenance tasks outside the Navy Air community. Only the avionics technicians receive the benefit of a short period of formal OJT. This was one of the reasons why the NEOCS Study recommended institutionalizing TYCOM training activities with formally specified (and resourced) training responsibilities for OJT, diagnostic testing of skill deficiencies, and refresher training programs.

In 1977, the NAVPERSRANDCEN attempted to fill this void by developing an integrated personnel systems concept showing the interdependencies among personnel, job aids, job design, career planning, training, technical data, and equipment design characteristics. This signalled the start of the Enlisted Personnel Individualized Career System (EPICS), an R&D project to develop a JPA-based integrated personnel system model, implement the model in a Fleet setting, and conduct a longitudinal test and evaluation program. The specific features of the EPICS model are:<sup>105</sup>

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<sup>104</sup>CAPT Worth Scanland, USN (Ret.), "Training Sailormen: Why Isn't It Working," Naval Institute Proceedings (October 1983), pp. 54-57.

<sup>105</sup>A more detailed description of EPICS is provided by: R. E. Blanchard and R. J. Smillie, Integrated Personnel Systems Approach: The Enlisted Personnel Individualized Career System (EPICS) Model, NPRDC TN 80-14 (San Diego: Navy Personnel Research and Development Center, May 1980).

NAVTRAEQUIPCEN MDA903-81-C-0166-1

- a. Place recruits directly from recruit training into a shipboard apprentice program and provide job indoctrination. Require EPICS sailors to mess cook, compartment clean, and to perform other facilities maintenance as scheduled part of the program.
- b. Defer and distribute shore-based technical training over a four-year enlistment and provide such training in two episodes: Equipment Technician Training at the 12th month and System Technician Training at the 24th month.
- c. Conduct job-design studies and define three skill levels for the first four-year enlistment, identified as Apprentice Technician, Equipment Technician, and System Technician.
- d. Develop fully proceduralized aids to meet all technical job requirements during the first year (Apprentice Technician), with partially proceduralized aids to meet job requirements during the second year (Equipment Technician). Develop advanced troubleshooting aids for use during remaining first-term enlistment as System Technician.
- e. Invest in individual shore-based training as a function of demonstrated interest, performance, level of shipboard adaptation, completion of all program and military prerequisites, and recommendation of commanding officer.
- f. Provide shipboard instruction by means of self-teaching exportable packages with narrative, summary, and programmed instruction including subject-scored module tests and supervisor-scored comprehensive tests.
- g. Develop technical competency through building blocks involving practical job experience, formal OJT, instructional modules provided for each skill level, and shore-based, resident school training.
- h. Provide a personnel career system with supporting organization, explicit advancement paths, integrated training episodes and job performance aids, specified time frames and prerequisites, assessment points, promotion points, and career decision points. Consider also such factors as new personnel assimilation into Fleet units, demotivation, turbulence and attrition contributors.

In October 1979, the Deputy Chief for Naval Operations (Manpower, Personnel, and Training) approved the project to proceed to pilot implementation for the NATO SEASPARROW Surface Missile System and to conduct a four-year longitudinal study to test and evaluate the cost and benefits of EPICS vis-a-vis conventional training. This decision received endorsement by the Fleet in 1980. The study, conducted by the NAVPERSRANDCEN, is being monitored by the EPICS Steering Group with membership from OPNAV (OP-01, OP-10, OP-11, OP-13, OP-03), Naval Military Personnel Command, CNET, Navy Recruiting Command, and NAVMAT (MAT 08D). Recruitment of EPICS sailors began in July 1980; shipboard data collection began September 1980 and will continue into FY85. The Fleet test and evaluation is scheduled for completion

September 1985; the cost-effectiveness analysis by September 1986; and publication of the Final Report, December 1986.

EPICS is, by far, the most important R&D project undertaken by the Navy to improve maintenance performance. It has far-reaching implications and is expected to demonstrate substantial benefits and cost savings over the conventional training approach. The interim reports are most favorable, and EPICS has been universally acclaimed as the model for all Services by experts who have spent their professional careers in addressing task performance problems.<sup>106</sup>

Further research will be required to ensure successful implementation of EPICS for all combat system technicians (and, possibly, other occupational groups not of interest to the present study). This effort relates to other topics discussed in this section: job design (revamping the occupational structure), instructional system development (course content), personnel system (need to develop individual career ladders and ensure that personnel return to training when scheduled), and reconsideration of some ideas espoused by the NEOCS Study (TYCOM Training Activities).

#### INSTRUCTIONAL SYSTEM

In the late 1950s, training technologies began to apply systems analysis techniques to training course development, resulting in training design manuals for use by laymen with little or no experience in training technology or educational psychology. According to one study, over one hundred such manuals were published between 1960 and 1975.<sup>107</sup> In the mid-1970s, DoD, through its Interservice Training Review Organization, adopted and prescribed, for use by all Military Departments, a standard, proceduralized approach, the Interservice Procedures for Instructional Systems Development, commonly referred to as ISD.<sup>108</sup> CNET adapted this approach to the needs of CNET formal schools and promulgated a condensed manual (Naval Education and Training (NAVEDTRA) 110, Procedures for Instructional Systems Development) in 1978 for the development of new, or revision of existing, instructional programs. Submarine training systems, however, are governed by NAVSEA OD45519.

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<sup>106</sup>NSIA/DoD, Proceedings of the Second Annual Conference on Personnel and Training Factors in Systems Effectiveness (San Antonio, Texas: May 1982).

<sup>107</sup>Melvin D. Montemerlo and Michael E. Tennyson, Instructional System Development: Conceptual Analysis and Comprehensive Bibliography, Technical Report IH-257 (Orlando, Florida: Naval Training Equipment Center, February 1976).

<sup>108</sup>R. K. Branson, et al., Interservice Procedures for Instructional Systems Development, TRADOC Pamphlet 350-30 and NAVEDTRA 106A, 4 Vols. (August 1975).

ISD is commonly perceived as a rational approach to job-relevant, task-oriented training. In reality, there are basic problems with the approach itself as well as its implementation:

a. The ISD manual is a guideline showing what must be done, with little guidance in how to do it. In the hands of novices, it is a dangerous tool as evidenced by the serious problems experienced DoD-wide with ISD implementation.<sup>109</sup>

b. The ISD model, as adopted and implemented by the Services, was designed exclusively for "proceduralized" tasks, not for cognitive tasks such as troubleshooting. Original plans to include such tasks in the final version were aborted when the preliminary version of ISD was adopted for use; only the Army is in the process of developing an "extended task-analysis procedure" for nonproceduralized tasks.<sup>110</sup>

c. The ISD approach uses behavioral objectives and criterion-referenced measures in training, but is based on a simplistic view of complex performance as a stimulus-response chain of simple, discrete steps. Performance is described in terms of external cues and feedback, involving measurable responses, steps to be performed according to prespecified sequences, and capable of being communicated in the form of written material.<sup>111</sup> The ISD model thus omits any task requirements which cannot be couched in these terms, including the "headwork" associated with integrating tasks in job performance.

d. Aside from these inherent limitations, the Navy's implementation of ISD, in practice, suffers from the following limitations:

(1) The guidelines for selecting the instructional setting in the ISD-analysis phase are designed to allocate training to resident schools only as a last resort. Application of the guide results in allocating training in priority order to OJT, on-board training with self-instruction materials, "F" Schools, or Resident ("A" or "C") Schools. Yet, self-instruction materials

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<sup>109</sup>R. Vineberg and J. N. Joyner, Instructional System Development in the Armed Services: Methodology and Application, Technical Report 80-1 (Alexandria, Virginia: Human Resources Research Organization, January 1980).

<sup>110</sup>Dr. Robert K. Branson, Director and Principal Investigator, Interservice Procedures for ISD, Center for Educational Technology, personal communication (Tallahassee: Florida State University, July 1983). The Army manual in question is TRADOC Pamphlet 351-4, Chapter 9.

<sup>111</sup>Gary A. Klein, Phenomenological Approach To Training, AFHRL-TR-77-42 (Dayton, Ohio: Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, August 1977).

have not been developed in the past. CNET only recently announced that production of on-board training packages has been initiated.<sup>112</sup>

(2) Criterion-referenced testing is a basic aspect of ISD. But the pass/fail criterion for most courses is getting 80 or 90 percent of the test items correct. Because training objectives are not stated in a hierarchy of importance or difficulty, tests sample among all objectives so that an 80 or 90 percent criterion may be achieved without meeting the most difficult or most important objectives. This is why this aspect of ISD implementation is referred to as a phony mastery concept.

(3) An inherent concept of the ISD model is the need for internal and external evaluation to control the quality (training effectiveness) of a training course. The two primary feedback channels for external evaluation are the CNET questionnaire distributed to supervisory Fleet personnel and the NAVMAT technical audit. Both appear limited in effectiveness. The NAVPERSRANDCEN spent several years developing and testing a more detailed, standardized approach to job performance monitoring, but this effort was aborted by the Navy. As a result, there is currently no meaningful feedback mechanisms for evaluating training.

(4) There is no linkage between PAR and the terminal objectives of ISD-based courses, other than by happenstance. There is no single, coordinated job-task analysis done in the Navy; everyone in need of job-task information goes their own way: training course developers, training equipment developers, technical manual writers, PQS and PAR developers, etc. The root-cause is that the single, integrated system, LSA, has never been implemented as conceived.

Concern about ISD and the way it has been implemented by the Navy is growing. The Fleet, as a whole, finds the training product -- i.e., the qualifications of school graduates -- unacceptable. At the top-levels in the Fleet, the root-cause is attributed to the emphasis on procedure training at the exclusion of cognitive training.<sup>113</sup> At the worker-level, teams responsible for ISD-syllabus development are deviating from the formal procedures in recognition of the voids in ISD and slipping cognitive detail back into the syllabus. But these attempts are uncoordinated, are subject to the experience of the team members, and are insufficient to divert the overall ISD thrust; they also become less substantial over time as ISD teams begin to

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<sup>112</sup>VADM James A. Sagerholm, USN, "CNET: Where We Are And Where We Are Going," U.S. Naval Institute Proceedings (October 1983), pp. 59-64.

<sup>113</sup>James J. Regan, former Technical Director NAVPERSRANDCEN, personal communication, June 1983.

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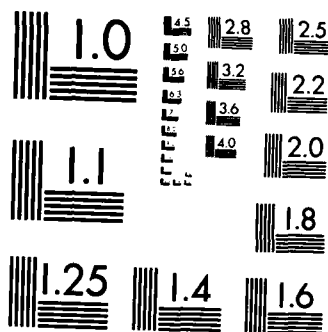
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include ISD-trained personnel who do not know better. And educators begin to wonder whether the elimination of cognitive training was a wise idea after all.<sup>114</sup>

This enumeration of critical observations on the implementation of ISD must not be interpreted as an indictment of the ISD concept; i.e., the need to base training curricula on a thorough task analysis, develop terminal and enabling objectives based on that analysis, determine the best mix of training presentation media, and establish a closed-loop feedback system to evaluate training effectiveness. Rather, the institutional shortcomings in implementing ISD are at fault, including the naive presumption that the current ISD manual is all that is needed. While training managers may believe that ISD solves their "training problem," ISD has served to highlight the inadequacy of current scientific knowledge about training. ISD, as currently institutionalized, is incomplete, and does not provide the answer as to what kind or level of cognitive training is required to ensure job proficiency. Further R&D is necessary to advance the state-of-the-art; the results must be incorporated into ISD to evolve the current inadequate process into one that ensures training content validity.

The amount and kind of theory required in technical writing has always been a matter of conjecture. An ISD-based course may or may not change the theory content of the course it is replacing. There are no objective data comparing course content before and after a course was "ISD'd." Thus, some of the Fleet observations reported above may be based on perception, not fact. Past studies indicate that the extent of theory in Navy technical-training courses is already limited, regardless of ISD. For example, a recent survey of course materials at 21 "A" Schools (excluding BEE) and 77 "C" and "F" Schools (with 12 of the 98 courses "ISD'd") shows the following:<sup>115</sup>

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<sup>114</sup>J. R. Brock, "Simulation in Maintenance Training: Now That I've Thrown Out the Bath Water, Where is the Dear Baby?", paper presented at American Educational Research Association, New York, 1977.

<sup>115</sup>William E. Montague and Wallace H. Wulfeck, II, Navy Personnel Research and Development Center, personal communication, June 1983 (report in press). The survey uses the Instructional Quality Inventory approach designed for evaluating instructional programs (see NPRDC SR 79-3, November 1978). This approach classifies each training objective, test item, or piece of instruction in accordance with a task/content matrix. Tasks are defined as: remember, use-unaided, or use-aided; content is defined in terms of five types: fact, concept, procedure, rule, and principle. Remembering (through recall or recognition) or using principles presumes understanding of cause-effect relationships and is, therefore, theory-based. Remembering or using rules also presumes some understanding as it pertains to a sequence of steps applicable across different situations or equipments.

- a. "A" Schools. Terminal objectives are primarily remembering facts and using procedures.
- b. "C"/"F" Schools. Terminal objectives are primarily using procedures.
- c. Average Theory Content. About 12 percent of the terminal objectives relate in some way to theory or understanding (five percent are principles, seven percent are rules).

Thus, assuming there is a direct relationship between syllabus hours and numbers of terminal objectives (an assumption which is not necessarily true), only five percent of the course content of current training syllabi, regardless of ISD, is devoted strictly to theory. Whether this is too much or too little depends on the training objective. If the training objective is to teach a first-term student to use the fully proceduralized manual on the job, it may be too much. If the objective is to teach him expert troubleshooting procedures, it may be too little, given that this is all the formal school training he would receive. Development of troubleshooting skills requires more than learning a few standard rules and applying them in free-play on operational equipment; it requires a thorough understanding of theory of operations, functional interdependencies, and symptom-cause relationships in order to form a "cognitive map" or model of the system to be maintained.<sup>116</sup> In the absence of a career-oriented training philosophy, training objectives do not differentiate between these different levels of job requirements so that some level of theory is invariably taught, but too much for the lowest and too little for the higher skill levels.

Lack of troubleshooting skills is the chief deficiency noted in graduates from formal school training throughout their first-enlistment term. They lack the foundation to develop this skill through experience on their own. The training establishment, however, insists it provides training in the particular skill. The explanation probably lies not with ISD, not with low-apptitude personnel or ability deficiencies, nor with inept instructors, but with the training approach. As far as it can be determined (based on interviews), the training consists of teaching the use of procedures (sequences of fixed steps) with the aid of a manual for a small number of pre-identified equipment malfunctions -- those that are easy, well-documented in the manual, and not necessarily representative of those encountered in the operational environment. In most cases, such practical troubleshooting training consists of instructor demonstrations on actual-equipment trainers, not student hands-on practice (by lack of simulators designed for the purpose). No one should be amazed that this does not lead to a proficient

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<sup>116</sup>Nicholas A. Bond and Douglas M. Towne, Troubleshooting Complex Equipment in the Military Services: Research and Prospects. Technical Report No. 92 (Redondo Beach: University of Southern California, Behavioral Technology Laboratories, December 1979).

troubleshooter. More importantly, this type of training approach may actually interfere with the development of troubleshooting proficiency later on.<sup>117</sup>

In sum, the DoD-wide implementation of ISD in 1975 was intended to improve the cost-effectiveness of resident school training in the Services by eliminating training not relevant to the job, standardizing the process for training syllabus development, and reducing training duration and support costs. This action was in response to a Congressional mandate in 1971, when Congress, for the first time, assumed authorization and appropriation responsibility for training as a separate line item in the DoD program and budget. This action, however, had the opposite effect. The ISD model adopted has fundamental limitations which are not recognized by the decision makers. The support costs are much higher than anticipated. While training durations have been reduced (not necessarily due to ISD itself), the net effect has been that costs have risen and effectiveness declined. The frustrations encountered with ISD implementation are very well expressed by a Navy officer responsible for the development and evaluation of the F-14 ISD syllabi:<sup>118</sup>

The Navy training establishment has committed the future of naval aviation to ISD. (This) approach to training has promised increased training effectiveness, greater standardization, reduced cost, reduced manpower, and greater flexibility and control. It has produced much less effective training because of its serious omissions; it has produced less standardization because of the high cost and lag time inherent in media update; it has dramatically increased training costs; it has made training dependent on complex and unreliable simulators; it has increased the manpower requirements; and it produces syllabi that are less flexible and less manageable than their predecessors. It has systematically, if unintentionally, destroyed the traditional foundations of naval aviation. The consequences for combat effectiveness, safety, and esprit de corps are only now becoming visible. The future implications are deeply disturbing. It is time for a complete reexamination of the direction of naval aviation

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<sup>117</sup>Gary A. Klein, Phenomenological Approach to Training, AFHRL-TR-77-42 (Dayton, Ohio: Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, August 1977).

<sup>118</sup>CDR Nicholas R. Criss, III, USN, "Aviation Training: A Systems Approach," U.S. Naval Institute Proceedings (October 1983), pp. 102-106. While his comments are, primarily, directed at flight-crew training, they pertain as well to maintenance training. His criticism of flight simulators is not so much an ISD issue as caused by the limitations of the F-14 training simulator.

training. It is time to forsake ISD for a true systems approach that encompasses not only behavioral tasks, but also the entire cognitive framework without which naval aviation cannot survive.

It is not suggested that ISD be abolished. Rather, the Navy should formulate an aggressive R&D program to fill the voids and develop needed improvements in the ISD process. Personnel tasked with applying ISD should receive the requisite training. Additionally, the process should be coordinated with a career-oriented, distributed training "system" to improve the linkage between job requirements and training. With regard to troubleshooting skills, there is an obvious need for a more comprehensive approach to teach what is commonly referred to as logical troubleshooting: understanding the theory of operations of an equipment family to acquire a mental model of failure symptom-cause relationships; learning the approach of hypothesis formation, selection, and testing; and acquiring the skill to apply that approach effectively, including proficient use of test equipment, across a broad range of prime equipment. Unfortunately, after 30 years of research, "educational experts" still do not agree on the most effective method for teaching troubleshooting (problem-solving) skills.<sup>119</sup> The R&D recommendations (Section V) are designed to help resolve this issue.

#### INDIVIDUAL PROFICIENCY ASSESSMENT

The Navy has an elaborate system for monitoring the "health" of its hardware (3-M system, CASREP system, Material Condition Reporting System). There is no system for monitoring the job proficiency of its maintenance technicians. (The personnel and training readiness indicators included in the UNITREP system refer exclusively to operator skills and the fill of authorized billets in critical rate/rating/NECs, not to the job proficiency of maintenance personnel.) This shows where the real priorities lie, even though personnel and training represent a large portion of the O&M Navy budget. Without a standardized method for proficiency assessment, evaluation of training effectiveness is impossible. This also inhibits identifying shortcomings in technical training and conflicts with the whole idea of ISD-based training. The current controversy between the Fleet and the training establishment is a clear illustration of the consequences. A more fundamental implication is that job proficiency may be perceived by technicians and their supervisors as a low-priority item: people normally behave in accordance with established evaluation systems, paying attention to what is measured or monitored.

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<sup>119</sup>Gary A. Klein, Improvement of Skills for Solving Ill-Defined Problems, AFHRL-TR-78-31 (Dayton: Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, March 1979).

In the past, the Navy has spent a large R&D effort, through the NAVPERSRANDCEN, developing a personnel proficiency assessment system (PPAS).<sup>120</sup> This effort came to a standstill, reportedly as a result of lack of interest by the Fleet, which viewed it as yet another administrative burden. In the meantime, however, the issue of maintenance skill deficiencies has gained increasing attention and visibility at the top echelons in the Fleet. The various maintenance-training improvement programs instituted by all Type Commanders to identify skill deficiencies and determine refresher, remedial, or skill-enhancement training requirements have already been described. These programs are under-resourced, uncoordinated, duplicative, and not always effective. The Navy would benefit from applying the technology gained with the PPAS R&D program to these maintenance-training improvement programs to arrive at a standardized, Navy-wide, performance-measurement system. It appears that the Fleet may be more receptive to such an idea than it was some years ago.

Institution of such a system appears to be crucial to the success of any attempts to improve maintenance performance. The resulting feedback is necessary to keep formal school training in tune with Fleet requirements. Only for strategic systems does the Navy conduct an operational program for testing the proficiency of technicians (this system is known as the personnel training evaluation program). Such a system, however, is not a luxury, but a necessity for all Navy technicians.

#### PERSONNEL

Among the personnel factors, personnel availability (fill of authorized Fleet billets by rate/rating/NEC) is the most important factor influencing maintenance performance. The factors influencing personnel enlistment and retention have been previously described and it has been shown that changes in personnel policies and manpower recruitment are necessary to improve personnel availability -- changes that will become increasingly essential with the planned Navy build-up. The focus here is on three related personnel issues: personnel classification, utilization, and management.

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<sup>120</sup>PPAS is described in numerous NAVPERSRANDCEN reports, including tests conducted for selected ratings. See, for example: Adolph V. Anderson, et al., A Personnel Readiness Training Program: Final Report, NPRDC TR 77-39 (San Diego: Navy Personnel Research and Development Center, August 1977); and T. Athnos, A Performance Proficiency Assessment System for Surface Sonar Technicians: Shipboard Gathering Procedures, NPRDC TR 80-16 (San Diego: Navy Personnel Research and Development Center, February 1980); and Andrew P. Chenzoff, Dennis L. Scott, and Reid P. Joyce, A Performance Proficiency Assessment System for Surface Sonar Technicians: Specifications for Simulated Troubleshooting Tests, NPRDC TN 81-19 (San Diego: Navy Personnel Research and Development Center, July 1981).

**PERSONNEL CLASSIFICATION.** Personnel are currently classified (assigned to rating-specific "A" Schools) on the basis of their ASVAB scores, individual preferences, recruiter sales techniques, and available school seats. The system implemented in June 1981 is known as CLASP (Classification and Assignment with PRIDE, where the latter stands for personalized recruiting for immediate and delayed enlistment). CLASP generates a recruit's enlistment options based on the best match of his mental group ranking and the complexity rankings of ratings for which school seats are available in a one-month window; the system also accommodates formal or unofficial cutting scores on area aptitude composites. Once the recruit decides, PRIDE automatically reserves a school seat for him.

The whole process very much depends on the reliability and validity of the ASVAB, a test with several limitations. Congress has repeatedly requested DoD to develop better test instruments more predictive of job performance (vice training performance) than the present ASVAB, with higher differential validity and higher reliability. The Defense Manpower Commission has made similar recommendations.<sup>121</sup> The Navy is the lead Service for the development of computerized adaptive testing (CAT) as one response to this Congressional mandate. It was therefore expected that the CAT project would entail introduction of other tests known to be more predictive of job performance. This is not the case. CAT is an individualized, interactive version of the same ASVAB tests. By zeroing in on the individual aptitude level, rather than the average level for which the conventional ASVAB is designed, CAT will improve somewhat the validity and reliability of test results at less cost (testing duration): the extent of guessing by test takers will be more uniformly distributed instead of being dominant at the lower aptitude levels; the test items in the data bank are carefully calibrated in terms of difficulty, discriminative power, and ease of guessing; and test time is expected to be reduced by 50 percent. CAT is scheduled for implementation in 1985, with the current ASVAB eliminated by 1989.

It is known that most of the individual's basic abilities which influence training and job performance, are not measured by the ASVAB. The extent of classification errors caused by the current, inadequate testing approach is unknown by lack of data (e.g., type 1: high ASVAB scores but low job-related ability scores; type 2: vice versa). What is known, is that the Navy is losing 20 percent of high-aptitude enrollments in BEE School (see footnotes 100, 101, 102) by its inability to adapt teaching style to individual, cognitive styles because the latter are unknown and not measured.

The ASVAB test requires approximately 2 1/2 hours to complete. Without extending that duration, CAT offers the potential for adding tests of cognitive abilities to improve the person-job match for combat system technicians. The Navy should examine the extent of current misclassification,

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<sup>121</sup>Defense Manpower Commission, Defense Manpower: The Keystone of National Security, Report to the President and the Congress, April 1976.

develop ability profiles for specific task clusters, expand classification standards and CAT test battery accordingly, and adapt teaching style to individual abilities.

**PERSONNEL UTILIZATION.** Two examples serve to demonstrate that the ways in which personnel are currently utilized are not conducive to technical skill development and growth. One is the use of school graduates for general duty details (mess cooking, etc.) during the first three to six months on their first duty station. During this period, much of what was learned in resident schools was forgotten because the training emphasis is on rote learning, not understanding. If the normal flow of nondesignated apprentices (non-"A" School eligibles) is insufficient to provide the necessary manpower for such general duty details, there is an easy way to increase the flow but avoid the loss of training investment in designated strikers: send every enlistee first to apprentice training, then to the Fleet for OJT, familiarization, and general duty; and return all "A" School eligibles to school after the first six months. This is more or less the first stage of the EPICS approach; the increase in Permanent Change of Station costs should be well worth the increase in training effectiveness.

The second example is that shipboard technicians receive little hands-on experience in the maintenance tasks for which they are responsible. Most of the time (roughly 75 percent) is spent on watch standing and other service diversions, not maintenance job performance. Under those circumstances, skill development on the job is slow, even for the most motivated persons. Without continuous attention by supervisors or Fleet training activities on the need for refresher training, self-study, and hands-on practice, skills may actually degrade over time. There is no easy answer to this problem. However, if there is no better way of designing the jobs, a formalized on-board training system for maintenance technicians would be essential to keep skills from degrading. As described earlier, such a training system does not presently exist. This circumstance also highlights the need for periodic diagnostic testing (proficiency assessment) to identify skill degradation and remedial/refresher training needs. In the absence of either, most technicians cannot be expected ever to achieve proficiency.

**PERSONNEL MANAGEMENT.** On the surface, the Navy appears to have a rigorous management system in place to ensure that: (1) personnel are assigned where needed, and (2) the best possible overall utilization of available personnel is attained. In reality, however, there are some problems which inhibit achieving these objectives:

a. The Navy Manning Plan (NMP) distributes available manpower assets by rate/rating across Navy-wide authorized billets so as to achieve an equal proportionate fill of authorizations in all units not accorded manning priority. A non-linear distribution logic, based on marginal utility rather than percentage fill, would result in a more effective utilization of available manpower.

b. The assignment decisions made by personnel detailers at the Naval Military Personnel Command are based on incomplete personnel data (only the primary and secondary NEC), incomplete billet data (the NMP is in terms of rate/rating so that the detailer must guess the NMP allocation among different NECs identified by OPNAV Form 1000/2), and are performed manually and sequentially. The use of an optimal assignment system would improve the person-to-billet match.

c. The data on OPNAV Form 1000/2 and the Enlisted Distribution Verification Reports (EDVRs) are inaccurate due to lack of discipline, inadequate training of administrative personnel, and confusing instructions/regulations. For example, a recent audit showed that close to 30 percent of the NECs listed on OPNAV Forms 1000/2 were wrong, and 36 percent of NECs shown on the EDVRs were wrong.<sup>122</sup>

Clearly, the Navy must improve personnel management; the steps required immediately follow from the above findings. On a more fundamental level, the Navy should recognize the basic conflict between its highly discriminate occupational structure (96 ratings, 1000 NECs) and the ability of its personnel system to support the level of discrimination. Special "communities" may escape that conflict through "closed-loop" detailing (as practiced in the submarine community). But that option cannot be applied Navy-wide for all ratings. We refer again to the NEOCS Study and the need to revamp the Navy's occupational structure. Pending such action, "closed-loop" detailing of combat system technicians might be the only answer.

#### MAINTENANCE DATA SYSTEMS

The 3-M system consists of two major subsystems, the Planned Maintenance System (PMS) and the Maintenance Data System (MDS). PMS is used for the planning, scheduling, and management of personnel and material to accomplish planned (preventive) maintenance. MDS is used for recording the expenditure of resources (personnel and material) associated with corrective maintenance and for identifying deferred maintenance. The 3-M system for Naval aviation is more detailed and more vigorously controlled than that for ships. The summary description that follows pertains to the 3-M system as implemented in the surface and subsurface communities.

Each ship's PMS is defined by Maintenance Index Pages (MIPs) and associated MRCs which specify for each equipment, the preventive maintenance actions required and their frequency; the tasks or steps associated with each action; the rate/rating/NEC required; and estimated man-hours. PMS is monitored by the Type Commanders and Systems Commands. Revisions to PMS, based on feedback from the Fleet, are promulgated through the Quarterly Force Revision (QFR) program, updating MIPs/ MRCs as required.

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<sup>122</sup>Naval Audit Service Capital Region, Review of Personnel Detailing Functions, Audit Report C37121, February 1982.



Data input into the MDS is by Maintenance Data Form (OPNAV Form 4790-2K, commonly referred to as the "2K" sheet). These forms document all maintenance performed or required beyond routine preventive maintenance defined by the PMS. The "2K" sheets thus cover:

a. Completed maintenance actions, including:

(1) All reportable corrective maintenance (not all equipment maintenance is reportable, but all combat system maintenance is).

(2) PMS actions for which the MRC specifies use of repair parts (all parts requisitions require "2K" documentation, which is one reason why all maintenance actions requiring parts issue by the supply room are documented, and many other maintenance actions are not).

(3) PMS actions requiring meter readings or tolerances to be reported.

(4) Any preventive maintenance other than PMS.

b. Deferred maintenance actions, including:

(1) Corrective maintenance not accomplished due to operational priorities or need for outside assistance.

c. Work requests for outside assistance.

All MDS data is accumulated in a central Navy data base by the Navy Maintenance Support Office. Each ship accumulates its own data base on deferred maintenance actions, known as the Current Ship Maintenance Project (CSMP). Maintenance inspections by the chain-of-command focus on the performance of PMS requirements (the CNO goal is that at least 75 percent be accomplished). The CSMP serves as a starting point for the development of work packages when ships go into overhaul.

Feeding and maintaining the above systems is a large administrative effort, but only a small part of the total shipboard administrative burden. The Navy initiated the Shipboard Non-Tactical ADP Program (SNAP) to alleviate this burden. The program is managed under the auspices of OPNAV Instruction 5320.16 and directed by the Fleet Non-Tactical ADP Policy Council. It consists of two major efforts:

a. SNAP I: Replacing the existing obsolete AN/UYK-5 computers aboard large ships and at shore facilities.

b. SNAP II: Providing smaller ships and selected shore activities with a standard ADP system compatible with SNAP I.

The hardware/software specifications developed by NAVSEA in accordance with the functional specification for SNAP II cover approximately 200 functions;<sup>123</sup> the majority (88 percent) is associated with supply and maintenance functions, primarily to serve the information needs of the shore establishment. Previous studies have recommended that people-related applications be accorded more emphasis;<sup>124</sup> one example is a personnel training management system.<sup>125</sup> But the present direction of the SNAP program is focused on automating what is currently done manually, eliminating manual files and manual generation of reports. Installations are planned for about 450 platforms, spread out over a period of six years, starting mid-1982.

The above background information serves to highlight one key issue: current maintenance data systems, manual or automated, serve primarily the information needs of the shore establishment; left out are the needs of the maintenance technician. Specifically, the technician is not provided with an up-to-date maintenance history of the equipment he is supporting; nor does the technician receive feedback on the components removed from the equipment for checkout and repair at higher echelons. The first type of data would help identify maintenance characteristics of the equipment and reduce NFR rate, mean-time-to-repair, and awaiting parts delays. The second type of data would help understand performance deficiencies (i.e., maldiagnosed faults) and reduce NFR rate.

The Navy must recognize this information void, re-think the current orientation of SNAP II, reconsider the potential advantages of distributed microprocessors vice SNAP II computers, and develop a data automation approach to serve the needs of the shipboard technician. Recent experience in the Air Force has shown that substantial improvements in maintenance performance can result from simple ADP applications for providing maintenance information to aircraft maintainers. An equally important payoff from serving the information needs of the technician is that there will be an incentive to provide accurate input data to such a system. There is no such incentive now; filling out the necessary 3-M forms is only additional work with no benefit for the technician. There is no need to elaborate on the repercussions in terms of data inaccuracies in the present 3-M data base.

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<sup>123</sup>NAVMAT, Integrated Functional Description for SNAP II, 30 March 1981.

<sup>124</sup>LT P. G. Smith, USN, SNAP II: Shipboard Micro Computer Applications in Personnel, Administration, and Training - A User's Perspective (M.S. Thesis, Monterey, California: Naval Postgraduate School, December 1981).

<sup>125</sup>LCDR John A. Dollard, USN, Computer-Based Shipboard Personnel Readiness and Training Management System: Subsystem Specifications, NPRDC SR 82-5 (San Diego: Navy Personnel Research and Development Center, October 1981).

## TECHNICAL MANUALS

An assessment of current problems in TM acquisition and support and an outline of needed improvements follow. (TMs, by our terminology, include hardcopy maintenance job aids; electronic maintenance aids are discussed separately.)

Management control of TM acquisition and support is exercised by centralized offices within NAVSEA for all nonaviation TMs, and within NAVAIR for all aviation TMs. Each is supported by a centralized field support activity responsible for post-acquisition management, including configuration management and distribution. These activities are the Naval Sea Data Support Activity and the Naval Air Technical Services Facility (NATSF), respectively. Both use automated management information systems; the Ships Technical Publication System (installed in 1981), and the NATSF Information Management System (NIMS, tested in 1983 and being installed now). In view of the gigantic inventory of TMs, these systems are crucial for post-acquisition management; e.g., tracing the impacts of alterations, tracking the status of engineering changes and deficiency reports received from the Fleet, and establishing TM update priorities. The recent implementation of these systems may alleviate some of the problems experienced in the past, such as the following:

- a. Close to one hundred military specifications are used in TM acquisition. While the Navy has implemented a modular specification system tailoring TM contract specifications to the associated equipment, lack of standardization (format, structure, sequence, illustrations, terminology, presentation technique) remains a problem, influencing TM acceptance and use by technicians.
- b. Over 50 percent of new TMs are not verified prior to distribution to the Fleet.<sup>126</sup> Such "preliminary" TMs cause confusion among the technicians as to their validity and deficiency reporting requirements.
- c. Deficiency reporting by TM users is incomplete: the process is focused on reporting errors, not voids; over 20 percent of technicians do not report TM deficiencies because the "system" is unresponsive.<sup>127</sup>
- d. Serious delays are encountered in updating TMs as a result of limited budgets. Approved changes are frequently deferred two to four years;

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<sup>126</sup>Office of the Inspector General, Department of Defense. Audit Report: Review of Technical Manuals (Report Number 83-128), 19 May 1983.

<sup>127</sup>The statistics are based on a survey of 177 electronics maintenance technicians, as documented in: NTIPP Fleet Survey of Technical Manual Users (Bethesda, Maryland: David W. Taylor Naval Ship Research and Development Center, January 1978).

many changes never make it before the associated equipment is replaced by a major upgrade (new model) or is retired from service (see footnote 126).

e. TMs are deemed inadequate by technicians:<sup>128</sup>

(1) Information is incomplete. Insufficient coverage is reported by 30 percent for equipment description, 50 percent for theory of operations, 44 percent for troubleshooting procedures, 80 percent for test equipment setup and use.

(2) Information is inaccurate. 30 percent believe theory of operations is inaccurate; 32 percent of technicians (51 percent of operators) report their TMs are out of date.

(3) Information is incomprehensible. 23 percent do not understand theory of operations; 90 percent of those using the Functionally Oriented Maintenance Manual (FOMM) format for troubleshooting do not understand it; 25 percent do not understand the illustrations/graphics in their TMs; 30 percent state they need more illustrations.

The consequences of inadequate TMs are significant. The average novice becomes very dependent on the supervisor or more experienced peers for developing skills through "show and tell"; the novice cannot get it from the manual. As long as those people are available to "hold his hand," there is no problem. When they are not available or have acquired poor maintenance habits themselves (as a result of inadequate school training and negative reinforcement), there is a problem. Furthermore, the overall result is a poor return on investment in TMs: novices cannot use them, journeyman technicians do not use them (they develop their own pocket guides or get them from contractors). This, in turn, contributes to a common perception that spending money on improving the quality of TMs is a waste: TM management line items in the O&M budget invariably suffer from a disproportionate share of budget cuts.

The above problems experienced with TMs in the past were not peculiar to the Navy. DoD-wide problems with TM management have been noted in several Inspector General and GAO reports. This resulted ultimately in a revision of DoD policy (DoD Instruction 4151.9, "DoD Technical Manual Program Management, February 1982), tightening the requirements for TMs in many respects including: technical accuracy and adequacy, completeness, comprehensibility, validation and verification, and configuration control with timely issuance of TM changes or revisions. It also reemphasized TM specifications and standards and the Army's continued lead role in standardization; and assigned the Navy to take the lead in "... R&D of advanced technology applicable to the development, presentation, use, storage, and retrieval of TM information."

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<sup>128</sup>Ibid.

a. Formulating the Mess. Capturing the essential systemic properties of the mess. Section II of this report (especially the "Summary of Case Studies") provides this information. It should be reviewed and discussed as a starting point in the process.

b. Ends Planning. Defining the objectives and goals to be pursued. If agreement is reached that the objective is "proficient maintenance performance enabling attainment of operational availability goals of installed combat systems by authorized personnel assets, while minimizing dependency on Fleet support resources and excess spares," then the gaps to be filled by the plan are identified by the information in Section II.

c. Means Planning. Selecting the ways of filling the gaps. They can take the form of policies, research projects, procedures, or management action. The crucial issues are discussed in Section IV. Some will require further research; some do not need further research -- just deciding and agreeing upon a course of action.

d. Resource Planning. Determining when, how much, and what type of resource (people, equipment, funds, information, knowledge) will be required by the means selected. If the resources required cannot be met, the previously formulated means must be revised and the cycle repeated.

e. Design of Implementation. Deciding who does what, where, and when, and how implementation is to be monitored and modified when necessary.

This approach appears obvious, but there are no indications that the Navy has ever addressed the maintenance performance problem in a systematic way. This may explain why previous attempts to deal with the problem have been largely unsuccessful. The problem, however, is not insurmountable. There is no doubt that the Navy can eliminate the problem, given sufficient management attention and priority. Now is the time to do so, because the problem has reached serious proportions, endangering the Navy's sustainability.

Such an approach may be useful in developing and executing a comprehensive Maintenance Improvement Plan to meet the following needs:

a. Provide top-level sponsorship and coordination of the two major R&D programs currently in test and evaluation: EPICS and NTIPS. Both are crucial for eliminating many factors which adversely impact maintenance. While both are sound in concept (multilevel, distributed training and technical data automation, respectively), tests will show whether the "frills" which have been added over time are necessary and effective. Implementation of these systems will involve radical changes in the Navy's traditional way of doing business with far-flung implications in many different functional areas. For this reason, implementation is bound to fail without aggressive, top-level sponsorship. Because the two systems evolved in isolation of one another, but have major overlaps, they are not coordinated. This must be corrected in the implementation planning for each.

## SECTION V

## RECOMMENDATIONS

The intent of this study was to identify R&D needs in the areas of maintenance training and aiding and to recommend specific R&D projects with a high payoff in terms of potential maintenance performance improvements. This section first touches upon the need for a much broader, systematic plan to effect maintenance improvements, and then focuses upon the specific R&D needs within the scope of that plan. Candidate R&D projects are listed in Appendix A.

## MAINTENANCE IMPROVEMENT PLAN

R&D programs in training and aiding technology must be coordinated within the much broader context of a systematic plan in order to reap the potential benefits from R&D investments. Better training equipment and/or job aids will pay off in improved maintenance performance only if the adverse maintenance impacts of other factors are eliminated. Some of those factors (e.g., weapon system design, maintenance policies, training philosophy, and instructional system development) have an overwhelming impact on maintenance performance; if left alone, they would negate the potential improvements offered by more effective training equipment or job aids. Other factors (e.g., personnel management, supply support) may carry less weight, but still would limit the potential payoffs from better training equipment or job aids.

The Navy currently lacks a systematic plan for focusing R&D effort or management action on the factors contributing to maintenance shortfalls. Development of such a plan requires a carefully structured process because the problem at hand is complex and systemic. An effective approach, under these circumstances, is provided by Ackoff's "design approach to mess management."<sup>148</sup> Ackoff defines this as an approach to dissolve a problem (changing the characteristics of the larger system containing the problem so as to remove the problem), in contrast to the clinical approach to resolve a problem (selecting a course of action yielding a satisfying outcome), or the research approach to solve a problem (obtain the best possible, optimizing outcome). The design approach synthesizes the clinical and research approaches but focuses on managing a mess (defined as a dynamic system of problems), not problem solving. It involves a structured planning process carried out participatively by all principals responsible for, or holding a stake in dissolving the mess. They are organized into small planning teams, managed to assure coordination of effort, and supported by planners and researchers, as needed. Ackoff defines the following five phases for this process, which are paraphrased for the purposes of the present case:

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<sup>148</sup>Russell A. Ackoff, "The Art and Science of Mess Management," Interfaces, Vol. II, No. 1 (February 1981).

mission availability (availability when needed in class hours), not average annual availability. Samples of current contractual requirements applicable to nonaviation training equipment suggest that the Navy needs to tighten the requirements.

These issues will be addressed again in the R&D recommendations in the next section.

#### SUMMARY

In summary, most of the key factors responsible for today's poor maintenance performance in the Navy are well-known and have been studied and analyzed in the past. The fact that the shortcomings identified in this section have so far not caused much more degradation in maintenance than our assessment indicates is a credit to the Fleet and its ability to somehow compensate or work around these shortcomings. Nevertheless, as discussed in Section II, the Fleet feels it has reached the limit; and as discussed in Section III, the situation is bound to get worse in the future, unless drastic improvements are made. To a large extent, the answers as to what changes are necessary are known. What appears to be lacking is an aggressive plan of action to develop and implement the necessary changes. The R&D efforts to move the Navy toward improvements on the material side (design for testability and integrated diagnostics) appear to be well orchestrated. Similar management action is necessary on the personnel and training side if the Navy is to solve successfully the problem of inadequate maintenance. The next section provides an outline of a systematic R&D plan in support of such action.

discussed at the Fourth Interservice/Industry Training Equipment Conference (Orlando, November 1982); and is planned as an interservice R&D effort.

g. User Involvement. The Fleet Project Team approach has traditionally been used to involve the ultimate users (instructors) in developing the specifications for new training equipment. Our survey showed that gaining instructor acceptance is possibly the most crucial factor determining utilization and effectiveness of training equipment. Acceptance is influenced by "perceived validity," a factor which is difficult to quantify, not always related to functional fidelity, and essentially based on instructor prejudice. Other factors influencing acceptance are: (1) responsibility for trainer maintenance, (2) method of trainer introduction, (3) ease of use by the instructor, and (4) extent of curriculum support. All studies on the issue of user acceptance agree on the necessity of user involvement in developing trainer design specifications. At the same time, experience has shown that instructors should not be allowed to exercise too much control.<sup>147</sup>

h. Fidelity. "Physical fidelity" has, in the past, often been confused with "functional fidelity" and/or "psychological fidelity." There is an increasing body of evidence that too much emphasis on physical fidelity may limit training-effectiveness, especially in the area of cognitive skills. Functional fidelity has been shown to be more important for training-effectiveness, while psychological fidelity has been shown to influence both instructor and trainee acceptance. Additional work is required to develop measures or specifications for these important attributes and to assess more precisely how each relates to transfer-of-training as a function of training objectives.

i. Logistic Support. Poor support of training equipment has influenced use: instructors tend to use the equipment for demonstrations vice student hands-on practice, and when the equipment is "down," it may remain unavailable for a long time. The Navy is in the process of transitioning to contractor support of all training equipment. If properly funded, this transition should tend to increase the use of training equipment as planned. Because past support costs are a poor indicator of future support needs (including configuration changes), the Navy needs to develop better estimating procedures to ensure that budget requests will reflect true support requirements. Furthermore, contractual support requirements must be specified in terms of

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<sup>147</sup>The troubleshooting training courseware for the A-7E HUD Test Set simulator was specified to a large extent by one instructor. By the time the simulator was delivered, a different instructor gave the course; the new instructor objected to the courseware as delivered. This was one of the lessons learned in the Simulated Avionics Maintenance Trainers program and ultimately resulted in a new procurement specification for front-end analysis: General Specification for Procurement of Maintenance Training Simulator Functional Requirements, NAVTRAEQUIPCEN N-712-357 (Orlando, Florida: Naval Training Equipment Center, January 1983).



c. Cost-Effectiveness. Because training-effectiveness is not properly assessed, cost-effectiveness is not either. To establish the case for simulation, hard data must be developed. Rigorous cost-effectiveness data are still lacking today.<sup>146</sup>

d. Media Mix. Bits and pieces of research data are available for relating training equipment design features and training objectives. Nevertheless, by lack of a coordinated research effort, the knowledge for determining the optimal mix of devices is not there. Previous authors (see footnote 95) have articulated the need for research to determine, the unique contribution each type of training device can make, the ways they can complement one another, the training methods which amplify the advantages of each, the types of training objectives most conducive to each, and the extent of hands-on practice required (in a "functional context" approach to learning) in order to minimize forgetting knowledge learned. Research in this area has been limited.

e. Acquisition Guide. In the present situation, the prime equipment program manager has every reason to decide on weapon system-peculiar training equipment. This may not always be the best use of limited training equipment funds for the Navy as a whole. In order to move toward more cost-effective decisions, the cost-benefits of alternative options must be articulated in an acquisition guideline which currently does not exist. The key questions to be addressed by such a guide are: (1) Is new training equipment required? (2) What type is most cost-effective, actual or simulated? (3) If simulated, what choice is best: general purpose, generalized, or equipment-replica? (4) What training features are important?

f. Standardization. Most equipments designed for use in training have certain features in common; i.e., there is an instructor station, one or more student stations, a general-purpose computer with courseware, and bits and pieces of operational equipment. It should be possible to reduce training equipment costs by several orders of magnitude by standardizing (form, fit, function) the components of such training systems. The modular concept for training simulators is a recent SIMSPO (the Air Force's Simulator Systems Program Office) initiative, addressing both hardware and software; was

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<sup>146</sup>The most authoritative account of the limitations of available cost-effectiveness studies of maintenance training simulators is provided by: J. Orlansky and J. String, Cost-Effectiveness of Maintenance Simulators for Military Training, IDA Paper P-1568 (Arlington, Virginia: Institute for Defense Analysis, August 1981). One of the few serious cost-effectiveness evaluations conducted to date is described in: Louis F. Cicchinelli, Kenneth R. Harmon, and Robert A. Keller, Relative Cost and Training Effectiveness of the 6883 F-111 Converter/Flight Control System Simulators as Compared to Actual Equipment, AFHRL TR-82-30 (San Antonio, Texas: Air Force Human Resources Laboratory, Brooks Air Force Base, December 1982). But, as its authors indicate, the latter study still ignores training adequacy.

but exhibiting poor training effectiveness and/or limited utilization.<sup>143</sup> It is unnecessary to elaborate on these issues. However, what is inhibiting the Navy from making much progress is the lack of institutional knowledge about training-effectiveness and cost-effectiveness of training devices or simulators, and the associated equipment design factors. One reason is a void in knowledge in spite of 30 years of research on training equipment. Another reason is the lack of follow-up and documentation of lessons learned with each training device that is installed.

Some of the critical issues that must be answered through additional R&D include the following:

a. Job-Task Analysis. Current procedures for job-task analysis are known to be inadequate for identifying the functional requirements for a training device.<sup>144</sup> A better procedure must be developed for this purpose.

b. Evaluation. The effectiveness of a new training device continues to be evaluated by comparing end-of-course performance tests of trainees trained with the new device and those trained conventionally on the actual equipment. The lack of validity of this type of evaluation has been addressed by numerous authors in the past.<sup>145</sup> The point is that some training objectives are better served through simulators; some require nothing more than a wall chart; and some may be trained best on actual equipment trainers. Another point is that end-of-course performance testing has limited validity and should be supplemented with operational field/fleet performance testing.

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<sup>143</sup>Naval Material Command, Training Equipment Management Study (December 1980).

<sup>144</sup>See, for example, the following references: William E. Montague, Is Simulation Fidelity the Question?, NPRDC TN 82-13 (San Diego: Navy Personnel Research and Development Center, April 1982); Nicholas A. Siecko, "Front End Analysis Lessons Learned from Maintenance Simulator Design," Proceedings of Conference on Front End Analysis for Simulator and Device Based Training (July 1981); and Bertram W. Cream, F. Thomas Eggemeier, and Gary A. Klein, "A Strategy for the Development of Training Devices," Human Factors (1977). The need for more basic research in this area was first pointed out by Glenn L. Bryan and James J. Regan, "Training System Design" (Chapter 13 in Harold P. Vancott and Robert G. Kinkade (eds.), Human Engineering Guide to Equipment Design (Washington, D.C.: U.S. Government Printing Office, 1972).

<sup>145</sup>See, for example, the following references: Melvin D. Montemerlo, "Maintenance Training Devices: Data and Directions," Proceedings of the 1977 Summer Computer Simulation Conference (Chicago: July 1977); and C. Dennis Fink and Edgar L. Shriver, Simulators for Maintenance Training: Some Issues, Problems, and Areas for Future Research, AFHRL TR-78-27 (Denver, Colorado: Air Force Human Resources Laboratory, Lowry Air Force Base, July 1978).

replace TMs; the latter will always be needed as a reference source -- paper, if properly protected, is still the most reliable information storage medium invented by man. Instead, cost-effectiveness of aids should be judged on the basis of reduction of OJT duration to achieve proficiency.

The PEAM (Personal Electronic Aid for Maintenance) R&D project is clearly headed in the right direction. Additional R&D effort is needed, it appears, in developing a better understanding of what differentiates an expert from a non-expert troubleshooter, and what tutorial software is needed to transform the latter into the former. Artificial intelligence has a lot to offer in this area, and will be addressed in the R&D recommendations in Section V.

#### TRAINING EQUIPMENT

The Navy's investment in training equipment is large (\$8 billion cumulative procurement cost of equipment as of 1982); most (85 percent) of the equipment is unmodified, operational equipment.<sup>140</sup> On a procurement cost basis, most is used for operator training; only five percent of the training device investment to date was spent on devices used for maintenance skill training.<sup>141</sup> But in recent years, the trend is shifting toward increased investment in training devices; over 50 percent of the device inventory in current use was procured in the last five years, and the cumulative procurement cost of installed devices is growing by 15 percent a year.<sup>142</sup> While the Navy is still spending three times more on operational equipment (\$300 million annually) than on devices (\$100 million annually), this ratio is projected to shift further in favor of the latter. This trend is attributed to the steep cost increase of operational equipment.

Previous Navy studies have identified the need for substantial changes or improvements in organization, management procedures and practices to counter the proliferation of weapon system-specific training equipment at huge cost

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<sup>140</sup>Naval Material Command, Training Equipment Management Study, December 1980.

<sup>141</sup>Naval Training Equipment Center, Financial Accounting and Inventory Record NAVTRAEQUIPCEN Cognizance Symbol 2"0", Special Report as of January 19, 1983. (The Navy classifies training equipment into two categories: (1) technical training equipment which is operational equipment under cognizance of a Systems Command, and (2) training devices which are any devices or aids used for training purposes and under the cognizance of the NAVTRAEQUIPCEN).

<sup>142</sup>Naval Training Equipment Center, Cognizance Symbol 2"0" Training Equipment-Device Accountability Program: Management Summary, 30 September 1981.

troubleshooting performance has received only very limited attention by training and aiding professionals.

f. Because such aids are fully prescriptive, they are not well accepted by users. And if forced to use them, users will try to take shortcuts which invariably lead them astray in the process.

g. For the same reasons, individuals who are forced to use such aids do not learn anything from using the aid. This absence of skill development on the job is probably the most heinous and self-defeating feature of the whole concept.

In sum, the concept of fully proceduralized troubleshooting aids was naive and did not consider the human implications; in practice, such aids can be applied to only a fraction of system failures and their accuracy is subject to the quality of configuration management, which is often poor. Yet the concept relies on totally accurate procedures. Verification of these procedures is very hard in the absence of a failure simulation or testability analysis model. For example, there are many instances in which a "top-down" logic is applied, whereby the procedure tells the technician to replace a failed module without first ascertaining whether failures or out-of-tolerance conditions are present elsewhere which may have caused the first module to fail. Replacement of the latter does not correct the cause and will result in the same failure symptoms again. Nevertheless, a maintenance demonstration or operational test may not surface such deficiencies in troubleshooting procedures.

**CRITICAL ISSUES.** Among the numerous requirements which an electronic job aid must meet to be operationally successful (small, portable, fast, reliable, etc.), the single most important requirement is flexibility. The software must be designed such that the user of the aid gets the information needed, no more, no less. The experienced technician needs a diagram and tolerance values of test points (he might, of course, prefer to have this in paper format, eliminating dependency on the aid); a less experienced technician may want to use the aid interactively, having it dictate what measures to make and feeding it his observations; a novice needs additional data on the system, nomenclature, locations, etc.

Traditionally, aids (paper or electronic medium) have been justified on the basis of obtaining some productivity from inexperienced personnel. And this attitude has influenced very much the naive notion of fully proceduralized troubleshooting aids. The most important objective of an aid should be to expedite skill development on the job through emphasizing learning while using the aid. The art of designing an effective aid lies in providing the apprentice-technician sufficient challenge and learning from task performance so that a level of proficiency is reached whereby the aid is no longer needed, except for reference data. This transitioning is key to the acceptance, utilization, and effectiveness of a troubleshooting aid in the real world. Thus, aids should not be justified on the basis of life-cycle cost comparisons with TMs. Such comparisons are irrelevant. Aids will never

which he must deduce what to do; and hybrid aids which combine the characteristics of prescriptive and deductive aids in various degrees. Physically, prescriptive aids provide sequences of steps or instructions, deductive aids provide graphics or diagrams.

Thus, aids come in many different forms. The increasing power of microcomputers has made aiding technology practical and cost-effective. But operational use of such aids by the Services is very limited at present. Some aids have been tested or demonstrated; most planned aiding application are still in R&D.

**LESSONS LEARNED.** One of the reasons for caution in the development and implementation of electronic job aids is that the experience with aids in paper format has not lived up to the claims or promises made by their proponents. Especially in the area of fully proceduralized troubleshooting aids, the experience has been dismal. The Navy has wisely preferred a deductive format (FOMM, MIL-M-24100) for aids supporting complex systems, but due to higher costs, such aids are still a minority. To avoid making the same mistakes with electronic job aids, it may be useful to recount why fully proceduralized troubleshooting aids in paper format failed. The following factors appear to be responsible:

a. Combat systems are complex; the acquisition process does not allow a complete failure modes and effects analysis to document all failures (symptoms and causes) which may occur in the operational environment. The aids, therefore, cannot be complete unless, and until, an automated testability analysis has become institutionalized in the acquisition process.

b. The operational environment is demanding; using a fully proceduralized aid requires excessive time and may not be successful, but the single operational criterion is minimizing system downtime. Such aids are, therefore, often impractical at the organizational maintenance level.

c. Engineering changes are frequent in combat systems; hundreds of engineering changes typically occur in the early operational years of a new combat system and by the time this stabilizes, a new model is typically fielded. The problem of keeping aids up to date is exacerbated by the volume of changes necessitated by fully proceduralized aids. Yet, the utility of such aids is totally dependent upon the accuracy and completeness of the information.

d. Failure modes and their relative frequencies are influenced by platform installation. That is, the same equipment behaves differently on different platforms. To be fully effective, proceduralized aids should differ among different platforms, but technical data, including aids, are equipment-specific, not platform-specific.

e. Failure detection and isolation is very much a probabilistic, not a deterministic process. Test points may exhibit marginal values which are insufficient to make a decision with certainty. The impact of uncertainty on

There is only one way to provide cost-effective supply support and that is through relating stockage requirements to weapon system availability, considering item costs, mission scenarios, item-to-mission essentiality, repair cycle requirements, and other parameters. So far, the Navy has not been successful in developing an appropriate model for this purpose, although sparing-to-availability models have been used in computing initial provisioning budgets for selected systems (e.g., AEGIS, SURTASS, and LAMPS Mk 3). The Ship Support Improvement Project has been working on an "A<sub>0</sub> Allocation Model," but it is still in the early stage of development. The need to replace traditional commodity orientation of the supply system by a weapon system orientation will become more urgent with the increasing complexity (parts counts and costs) and parts reliability of new weapon systems. The technology involved is well known.<sup>139</sup> Its implementation requires more detailed configuration and mission-essentiality data than provided in current equipment data files supporting COSAL and AVCAL computations. The Navy needs to proceed in this direction, starting with aircraft material and shipboard combat systems.

#### ELECTRONIC JOB AIDS

Electronic maintenance aids are loosely defined as any stand-alone devices (including associated software, data base, and input/output media) which aid the technician in performing maintenance tasks or improving maintenance performance. "Stand-alone" means it is not built into the prime equipment (i.e., BIT equipment), nor is it hooked up to the prime equipment (i.e., manual or ATE). It "aids" the technician by presenting information beyond that otherwise obtainable from an automated maintenance data system (i.e., maintenance log or history). The information presented depends upon the maintenance task involved and the sophistication of the software. The simplest type of aid duplicates the information presented in the TM. Such an aid, commonly referred to as an "electronic page turner," improves retrievability of the information (compared to the paper medium) and reduces the probability of human errors in lengthy troubleshooting procedures. If designed for interactive use by the technician, the aid will "step" the technician through the proper procedure. A more sophisticated aid may be designed to present heuristic procedures or strategies which have been developed by experts and are continuously adjusted based on failure experience. The most efficient aid for troubleshooting is based on an analytical model of the prime equipment, incorporating all failure symptom-cause relationships and identifying the minimum steps (or, the sequence of the easiest steps) required to isolate a failure. Another way of classifying aids is by type of information presentation: prescriptive aids which tell the technician exactly what to do; deductive aids showing the technician the maintenance dependency chains (functional symptom-cause relationships) from

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<sup>139</sup>T. J. O'Malley, The Aircraft Availability Model: Conceptual Framework and Mathematics, LMI Task AF201 (Washington, D.C.: Logistics Management Institute, June 1983).

(2) It ignores item costs, thereby inhibiting accommodation of cost constraints other than through awkward iterative procedures.

(3) It assumes a single Poisson distribution for the probability of item demands with no empirical justification found for this assumption.

d. The recent modification in the FLSIP model<sup>136</sup> (lowering the threshold on item demand rate from 0.25 to 0.10 demands per year to qualify for allowance as an insurance item and increasing the allowance for insurance items from 1 to 2 for item demand rates falling between 2.0 and 4.0 demands per year -- both changes for mission-essential items only) will reduce the probability of mission-degrading stock-outs, but a similar improvement could be achieved with a smaller increase in cost if a more sophisticated approach were applied by relating stockage criteria to weapon system availability.

e. The Repairables Integrated Model for Aviation Material (RIM-AIR), which has been proposed in an attempt to bring AVCAL policy in compliance with DoD policy and eliminate the inconsistency of current policy, is a step forward. As of March 1983, however, none of the RIM-AIR additives have actually been added to any AVCAL, and the model is subject to the following shortcomings:<sup>137</sup>

(1) In excluding turnaround times for beyond capability of maintenance items, it underestimates pipeline spares requirements.

(2) The manner in which the Poisson distribution is used for computing allowance quantities implicitly assumes an infinite repair capacity, thereby underestimating pipeline spares requirements. The actual repair process is nonhomogeneous.

(3) The established procedure of truncating recorded turnaround times reduces projected turnaround times to unrealistic values, again resulting in underestimating pipeline spares requirements.

(4) As a depth model, it must be supplemented with a rule for range; optimization must be used to determine both range and safety level for repairables as recommended in the RIM-AIR Study.<sup>138</sup>

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<sup>136</sup>CDR James L. Bigby, USN, Shipboard Parts Allowance Policy, CNR 12 (Alexandria, Virginia: Center for Naval Analyses, July 1981).

<sup>137</sup>Mark L. Mitchell, Retail Level Inventory Model for Naval Aviation Repairable Items (Monterey, California: Naval Postgraduate School, March 1983).

<sup>138</sup>RIM-AIR Study, Report 155 (Mechanicsburg, Pennsylvania: Navy Fleet Material Support Office, June 1983).

(4) The policy is not in compliance with applicable DoD policy.<sup>132</sup>

b. Supply support management is inadequate as indicated by the following:

(1) With a gross supply effectiveness goal of 65 percent (percent of total demands satisfied from on-board stock) for ship material, the actual value achieved is a Fleet-wide average for surface ships of 49 percent in calendar year 1979.<sup>133</sup>

(2) With an (implicit) allowance effectiveness goal of 76 percent (percent of demands that are for items included in the allowance list) for ship material, the actual value achieved ranges from 62 percent<sup>134</sup> to a three-year average of 40 percent.<sup>135</sup>

(3) In spite of attempts to reduce COSAL costs, only eight percent of on-board repair parts (Fleet-wide average) were used over a recent three-year period, with the remaining 92 percent of allowance line items unused (see Footnote 135).

(4) While these statistics reveal some of the shortcomings, more meaningful measures, such as the number or percent of mission-degrading stock-outs, are not monitored.

c. The Fleet Logistics Support Improvement Program (FLSIP) model used for generating COSALs is inadequate for the following reasons:

(1) It is designed to implement stated policy, thereby inhibiting relating resources to readiness.

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<sup>132</sup>DoD Directive 4140.44, "Supply Management of the Intermediate and Consumer Levels of Inventory," February 1978.

DoD Instruction 4140.45, "Standard Stockage Policy for Consumable Secondary Items at the Intermediate and Consumer Levels of Inventory," April 1978.

DoD Instruction 4140.46, "Standard Stockage Policy for Repairable Secondary Items at the Intermediate and Consumer Levels of Inventory," April 1978.

DoD Instruction 4140.47, "Secondary Item War Reserve Requirements Development," July 1979.

<sup>133</sup>CDR James L. Bigby, USN, Shipboard Parts Allowance Policy, CNR 12 (Alexandria, Virginia: Center for Naval Analyses, July 1981).

<sup>134</sup>Ibid.

<sup>135</sup>Samuel D. Judge and Palmer Luetjen, "Determination of Shipboard Repair Parts Level," Naval Engineers Journal (April 1979), pp. 37-43.



concluded in 1981.<sup>130</sup> As currently proposed, NTIPS embodies a very ambitious, "cradle to grave," technical information management system, encompassing the following subsystems: (1) technical information requirements (for job and training) specifications, (2) information generation (computer-based authoring) using LSA data and equipment source data as direct input, (3) mastering/replication (multimedia), (4) distribution, and (5) delivery (multimedia). All five subsystems are monitored by a control subsystem which includes configuration management and deficiency reports processing and disposition. The scope of NTIPS, in the view of many people, is too grand to have a chance of implementation. Yet, it appears to represent the right approach to solve the technical information problem. A great deal of effort will be required to get it implemented. Current plans call for implementation between 1986 and 1988, with full-scale operation in 1989. A limited test and evaluation of a prototype NTIPS is currently in progress.

#### SUPPLY SUPPORT

Documentation of the Navy's supply system, stockage criteria, supply effectiveness goals, and statistics on the supply achieved in the Fleet are beyond the scope of this report. The following comments serve to summarize the main shortcomings in Navy policy (OPNAV Instruction 4441.12A, "Supply Support of the Operating Forces," August 1973) and the procedures (models) used in constructing the Coordinated Shipboard Allowance List (COSAL) and the Aviation Consolidated Allowance List (AVCAL):

a. Current stockage policy is inadequate for four reasons:

(1) The stated measures of effectiveness governing the range of items stocked (gross and net supply effectiveness) do not relate to weapon system readiness/sustainability, the primary rationale for carrying shipboard stocks.

(2) The stated measure of effectiveness governing the depth of items stocked also does not distinguish between primary mission-essential and secondary mission-support items; i.e., the policy treats combat systems the same as laundry machines.

(3) The stated aeronautical material availability goals cannot be achieved with the specified stockage criteria stated in the same instruction as demonstrated by previous studies.<sup>131</sup>

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<sup>130</sup>NTIPS Office, Navy Technical Information Presentation System (NTIPS) Final Report (Draft) (Bethesda, Maryland: David W. Taylor Naval Ship Research and Development Center, January 1982).

<sup>131</sup>RIM-AIR Study, Report 155 (Mechanicsburg, Pennsylvania: Navy Fleet Material Support Office, June 1983).

If TM management is improved in accordance with stated policy, problems experienced in the past can be avoided. In the meantime, inadequacies of existing TMs must be eliminated. What needs to be done is clear. Requirements for verification of TMs should be satisfied, not waived. Funding priorities within the O&M's Navy budget for TM management should be increased to eliminate the backlog of TM revisions and updates. The following policy issues should be considered to improve the quality of TMs:

a. Adoption of a different management process, using maintenance channels (similar to the quarterly force revision process for the PMS) vice technical publications channels.

b. Adoption of a Navy version of the Air Force policy giving TMs the same sanctions as direct orders (such a policy obviously would require high quality TMs).

Resident training courses should be revised to alleviate the problems identified by the Fleet survey:

a. Devote more time to theory of operations. In current courses, time spent per TM section is fairly uniform. Yet, about 1 out of every 4 technicians report difficulties understanding theory of operations, while only 12 percent have difficulties with operating procedures.<sup>129</sup>

b. Add a training module on troubleshooting formats, especially the FOMM and the underlying concept of "maintenance dependencies."

c. Add training modules for all common test equipment that technicians will be using on the job. Detailed instructions on using common test equipment are, correctly, not included in prime equipment TMs, yet 80 to 90 percent of school graduates lack ability in test equipment use and expect to find procedural instructions in TMs.

The TM Policy Council needs to promulgate a standard specification of the minimum prerequisites a TM user will meet, delineating what type of information, at what level of detail, will be in the manual and what skills, knowledge, and reading comprehension will be possessed by the technician. Integration of training and technical documentation is not accorded more than lip service in the absence of such a specific quantitative standard.

Long term, the only way to cope with the explosive growth of technical data and the associated quality assurance and configuration control problems, is complete automation of the generation, distribution, and configuration control of technical information. That was the original thrust of the Navy's R&D effort to develop NTIPS. Over the years, the scope of NTIPS has grown to include the interfaces with related functional areas. The design phase was

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<sup>129</sup>Ibid.

b. Develop policy and responsibilities for the institution of a Navy-wide individual proficiency monitoring system for enlisted maintenance personnel. The lack of any objective measurement of individual job proficiency is one of the root-causes of the Navy's present predicament. It also explains the disjoint between the Fleet and the training establishment.

c. Expedite R&D in critical areas that are not receiving adequate emphasis in current R&D programs, with the following areas accorded top priority:

(1) ISD. Voids in task analysis and training know-how, inadequate manuals, and lack of training of personnel responsible for applying ISD, have resulted in serious training-curriculum deficiencies and a poor reputation of ISD. A major R&D program is needed to correct these shortfalls. Expanded task-analysis procedures must be developed for cognitive tasks. Procedural guidance must be improved. Computer-based aids to ISD must be developed. A professional-development program for ISD practitioners must be installed. And the whole process must be made consistent with the evolving trend to multilevel, distributed training.

(2) CAT. The CAT R&D program is designed to individualize service applicant testing for selection and classification purposes but without changes in the aptitude test battery currently used. The ASVAB, however, measures few of the abilities that are related to job-performance potential. The R&D program should be expanded to include available tests of cognitive abilities predictive of job performance.

d. Focus management attention, force decisions, and provide oversight over implementation actions regarding the following issues:

(1) Occupational Structure. Because the recommendations from the NEOCS study were never acted upon (see pages 71-72), it may be beneficial to reopen the NEOCS case, give it a full hearing, and decide on the best course for the Navy. The current occupational structure is unmanageable, inefficient, and out of date. These shortcomings also detract from needed improvements in other areas (job design, training).

(2) Maintenance Policy. Current policy for electronics equipment installed on surface combatants is ineffective. Modular repair capabilities must be authorized aboard ship. This capability must be engineered (test equipment, technical data, authorized parts, skills), not left out as an emergency "band-aid" as in the current 2-M program. The current policy will become effective only when testability has been improved and shipboard stockage policies revised.

(3) Integrated Diagnostics. Management action is required to implement the integrated diagnostics concept. Current policy (instructions) must be revised, guides must be promulgated, Navy input to new and revised military standards must be coordinated, and contract item specifications must be revised.

(4) Maintenance Data Automation. The thrust of the SNAP II program (relieving shipboard administrative burdens serving the interests of the shore establishment) and the associated physical equipment (stand-alone computers) must be reconsidered. Shipboard requirements would be better served by a distributed data processing capability with application programs designed to serve the needs of the ship, including maintenance information for the technicians.

(5) Support of Electronic Aids. Shipboard maintenance will, in the future, increasingly rely on electronic aids. Current plans are that the same technicians, who will use these aids to perform maintenance on prime equipment, will also maintain these aids. The soundness of this support concept is in doubt. A special rating (such as the TD rating which was recently disestablished by lack of sea billets) to support all shipboard electronic aids may be a better alternative. A policy for the support of electronic aids must be established now, while it is still early enough to influence the design characteristics of these aids.

e. Provide sponsorship and resources for the specific R&D recommendations in maintenance training and aiding technology specified in the remainder of this section:

- (1) Embedded maintenance training.
- (2) Embedded maintenance aids.
- (3) Job performance and training aids.
- (4) Maintenance training equipment.

A formal cost-benefit analysis has not been conducted in justification of these recommendations. It is believed that the Maintenance Improvement Plan could be executed at a small fraction of the true cost associated with poor maintenance -- a cost which is estimated to run into the billions if equipment redundancies, necessitated by poor maintenance, are included.

#### EMBEDDED MAINTENANCE TRAINING

Both the Defense Science Board's 1982 Summer Study and the Navy Training Improvement Program address the need to develop "embedded" or "strap-on" training capabilities for new weapon systems with embedded computer resources. The focus of past and current research efforts has been directed primarily at operator training capabilities.<sup>149</sup> One example of equipment

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<sup>149</sup>No information about current research projects on embedded training which may have been sponsored recently by the Navy or the Air Force was available. DARPA has no research program in embedded training, in spite of announcements to the opposite effect. The Army Research Institute (ARI) is sponsoring a research study on: "System Design Concepts to Support Embedded Training" (Request for Proposals, Commerce Business Daily, 11 August 1983). ARI could not provide further details on its research plans because the information is "procurement sensitive."

stimulation for training (not embedded training) is the FFG-7 Class Pierside Combat System Trainer. It is scheduled for delivery in early 1984 and will be used for shipboard combat system operator and team training. Evaluation of this trainer is intended, inter alia, to provide information on the most economical way for integrating this training capability within future combat systems. (In the case of the FFG-7 Class, embedding this capability within the existing combat system will not be economical.)

It does not appear that an embedded maintenance (as opposed to operator) training concept would be practical since embedded computer resources are sized for prime mission requirements; additional requirements for maintenance training (software for simulation and stimulation and courseware) would affect the reliability and maintainability characteristics of the prime equipment. Instead, a "strap-on" concept (hooking up a general purpose mini- or microcomputer to the prime equipment) would have significant potential. Prime contractors may already be developing much of the required software for the purpose of BIT design evaluation, though the software is not currently a contract deliverable item. Some past contracts (e.g., the F-15 in the Air Force) included a requirement for simulating system failures for assessing BIT performance as part of the formal maintenance demonstration and development test requirements. With the increasing emphasis on testability as a key maintainability characteristic, such simulation requirements can be expected to become a standard feature in future weapon system acquisition contracts. The reason is that this is the only way that BIT performance can be assessed adequately. The important point is that the same software (failure-simulation model) can be applied in a training mode to teach the technician the BIT indications on the prime equipment, the extent of false alarms and ambiguities, and the fault-isolation procedures required to find the simulated failure.

Needless to say, this would be the most cost-effective approach to troubleshooting training with a maximum transfer-of-training, and offering the potential of eliminating most of the actual equipment trainers from "C" Schools. (There would still be a need for part-task trainers at those school to train remove/replace actions, system knowledge, nomenclature, etc. Also, this shipboard troubleshooting training would, of course, be limited to those failures covered in BIT design; additional training may be required later to learn to cope with other failure modes, external influences such as damage, etc.) What needs to be done to bring this concept to fruition appears to be very limited:

- a. The prime-equipment contract must include a requirement for an interface adapter, permitting external computer-controlled stimulation of the prime equipment. A standard specification should be developed for such an adapter.
- b. The prime-equipment contract must include, as a contract deliverable, the failure-simulation model developed by the contractor in designing the BIT and measuring BIT performance.

c. Conventional computer-based courseware must be developed around the failure-simulation model to interface with the trainee-technician via a separate display.

It is recommended that this approach be examined by the Navy's engineering laboratories, not the NAVTRAEQUIPCEN or the NAVPERSRANDCEN. Consequently, this project, with the most immediate and highest payoff of the R&D recommendations, is not included in Appendix A.

#### EMBEDDED MAINTENANCE AIDS

There is a need for more attention to the technician's information requirements in designing built-in maintenance diagnostics. While much has been written on BIT design, testability requirements and how to measure it, and troubleshooting procedures, the way in which BIT information is to be displayed has been accorded little attention. There are no specifications or design guides, to our knowledge, that address this issue in a meaningful way. Thus, prime contractors are given much leeway in this respect, with the result that BIT indications sometimes leave a lot to be desired, apart from the issue of BIT performance itself. For example, one might conceive of a way to reduce the impact of misleading BIT indications (false alarms, erroneous fault isolations, or excessive ambiguity groups) by requiring the BIT also to display on request, those areas of the system it has tested to be good, and those areas that are marginal. Or, for airborne equipment, one might insist on a capability to eliminate BIT warnings resulting from intermittent failures. This study did not allow a detailed analysis of this issue, but it seems that this area needs more research.

It is recommended that the Navy's design for testability R&D program be expanded to address the subject of how BIT indications should be displayed or processed for maximum maintenance effectiveness. Again, this project concerns the prime equipment, not maintenance training equipment or stand-alone aids. It is, therefore, not included in Appendix A.

Another type of built-in aid is what is commonly referred to as display-aided maintenance; i.e., the job aid (telling the technician what to do or where to look in his manual) is built into the prime equipment, so to speak. (Physically, display-aided maintenance is invariably implemented on a separate computer, not part of the embedded computer resources supporting the tactical software for the very reason mentioned in the previous section. Because this separate computer is part of the weapon system, it is counted among the embedded computer resources, but there is a difference.) This approach will become more common in the future for large, integrated systems. Much of the job-aiding technology being developed (or, to be developed) with a view to stand-alone aids is directly applicable to such built-in aids; e.g., what information to display and how to display it. There is currently a lack of communication between the prime-equipment developers and the job-aiding technology developer. This limits reaping the full benefits from R&D investments in job-aiding technology. The approach for correcting this problem lies with the development of specifications and guides for job-aiding

software addressed in the next section and summarized as R&D Project 3 (Appendix A).

#### JOB PERFORMANCE AND TRAINING AIDS

In the area of job performance aids, additional research should be focused on answering the following two questions:

- a. How do technicians perform maintenance and what information (in what form, under which conditions, in what sequence) do they need to minimize maintenance errors and maximize maintenance effectiveness and efficiency?
- b. What distinguishes exactly an expert troubleshooter from an average technician?

A detailed investigation of the first question is necessary for the design of more effective aiding software. The second question needs to be examined more thoroughly than has been done in the past in order to acquire the knowledge necessary to design: (1) more effective training approaches for the development of troubleshooting skills, and (2) aiding software enhancements to maximize learning from using the aid. The experiments necessary to pursue these two questions are listed in Appendix A. Some care must be applied in selecting the systems used in these experiments. In practice this may not be a matter of choice, but depends on cooperation from the Fleet or Systems Command program (project) managers.

Electronic maintenance aids enhanced with tutorial software cannot cover all the training requirements. As this study indicates, there is a serious need for additional training in the Fleet. This training requirement, currently being met, in part, through local initiatives using workaround procedures, is bound to grow in the future as a result of increasing pressures to reduce front-end resident school training. Shipboard technical skill training, apart from OJT by supervisors, entirely depends on the printed medium and individual motivation. The quality of this type of nonresident school training would benefit enormously from a more disciplined approach, including a well-designed training delivery system for shipboard and "waterfront" use. It is recommended that the Navy initiate a major research program focused on meeting this need:

- a. Identify the technical training requirements in the Fleet.
- b. Resurrect the aborted PPAS program as a viable approach to individual skill-proficiency assessment, and continue its development and testing (it appears that the Fleet's attitude has changed in that the need for a more disciplined approach to proficiency testing and certification is increasingly being recognized).
- c. Design the most cost-effective training delivery system to meet Fleet training requirements, including administration of job proficiency tests

and conduct of remedial training at TYCOM training activities as well as shipboard skill-enhancement training.

d. Develop training modules based on "expert system" principles, using the information gained from the experiments recommended earlier.

e. Test and evaluate the prototype training modules (for selected skills, specifically troubleshooting, for selected systems) installed on prototypes of the selected training delivery system.

The R&D in job performance and training aids should be accorded highest priority in view of anticipated payoffs in improved maintenance performance. In recognition of the urgency of meeting Fleet training requirements, the Navy should set a formal target date in the late 1980s for a fully-implemented, operational training delivery system encompassing the task/skill/knowledge data base, proficiency tests, remedial courseware, interactive terminals for individualized learning (computer-aided instruction (CAI)), skill enhancement courseware, and training-enhanced electronic maintenance aids. The target date is important because by the late 1980s this type of system will not be a luxury, but a necessity as a result of the known personnel trends.

#### MAINTENANCE TRAINING EQUIPMENT

There are serious voids of knowledge in virtually all areas related to the acquisition and use of training equipment which is both training-effective (high transfer-of-training) and cost-effective. The need for more research in these areas was identified over ten years ago and much research has been done in the meantime; it is clear that the issues involved are complex. To maximize payoffs from available research budgets, it is recommended that the Navy pursue an interservice research program approach, coordinating its own efforts by the NAVTRAEQUIPCEN and the NAVPERSRANDCEN with those of the other Services, the Air Force Human Resources Laboratory (AFHRL) and the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), which focuses on the following:

a. Development of a new job-task analysis procedure for the exclusive purpose of identifying functional requirements for training devices.

b. Investigation of the relationships between fidelity (physical, functional, and psychological), training objectives, and transfer-of-training in the context of maintenance training equipment.

c. Development of a modular concept for training simulators, standardizing the various modules that constitute a trainer.

d. Development of a Training Equipment Acquisition Manual as a decision aid to assist in establishing training-device requirements for new weapon system acquisitions:

(1) Validation of the need for new trainers.



(2) Identification of the mix of trainers required (based on knowledge gained from (a) and (b) above).

(3) Determination of the functional characteristics required of each new trainer or software/hardware changes in existing trainers.

(4) Specification of standard procedures for acquiring the needed trainers (including solicitation, contract award, evaluation, and production).

e. Documentation of lessons learned from existing training devices and institution of a standard operating procedure for follow up of each new device. This documentation, in combination with a continuously updated register of the inventory of all maintenance training equipment (including their key characteristics), should be promulgated as an annex to the Acquisition Manual.

f. Development of a series of guides to help Fleet Project Team personnel do a better job:

(1) Job-Task Analysis Guide (based on "a." above).

(2) School Introduction Guide.

(3) Training Equipment Evaluation Guide.

g. Development, installation, and test of troubleshooting courseware in BEE School using video/computer-graphics, using the standard "Rouse package" (context-free and context-specific), supplemented with a third stage depicting general functional relationships of "typical" electronic systems. (Ensure that the software is designed to catch ineffective/inappropriate behaviors before they practiced and reinforced).

h. Examination of the wide variety of technology trainers currently used in BEE and "A" Schools in order to standardize on a small group for Navy-wide (not school-by-school) application, including: basic circuit trainers, special circuit trainers, servo-mechanism trainers, and digital logic trainers.

i. Development of design specifications for generalized training devices for use in "A" Schools, followed by acquisition and testing of prototypes. Most of the current equipment is either obsolete or ineffective. This effort should include one of each of the following:

(1) Generalized Transceiver Trainer.

(2) Generalized Radar Maintenance Trainer.

(3) Generalized Computer/Peripherals Maintenance Trainer.

(4) Generalized Fire Control Maintenance Trainer (i.e., restore funding of device 11D20).

(5) Generalized IFF Maintenance Trainer.

(6) Generalized Communications Maintenance Trainer.

(7) Generalized Sonar Maintenance Trainer (i.e., restore funding of device 14E21).

j. Development and installation of self-paced course modules in BEE School to teach setup and use of general-purpose test equipment (using CAI, not CMI).

The corresponding projects are listed in Appendix A. Neither the levels of research effort required for these projects, nor their relative importance or payoff are estimated. All would likely contribute to improved maintenance training. The other Services have ongoing research projects in some of these areas. Coordination among the Services clearly is required to avoid duplication of work.

#### MONITORING TECHNOLOGY IMPACTS

Finally, it is important to highlight one more issue: the need for some organization in the Navy to be responsible for closing the gap between what is taught in Navy "A" Schools (training content) and the maintenance skills required in the Fleet as a result of the technology employed. The two existing feedback mechanisms which are intended to close the gap (see page 84) are in place, however, the success has been somewhat limited. Consequently, that gap is still very large. For example, the BEE course content is, essentially, a programmed-instruction adaptation of a 1960s-era course for electronics hobbyists; apart from some basic electronics fundamentals, much of the course has little relationship to today's first-term technician skill requirements; and, as of 1983, no digital fundamentals are taught. An "A" School example is the revision of "A" School courses feeding "C" Schools for the Navy Tactical Data System (NTDS). This revision was initiated in 1983, though NTDS was first installed nearly 20 years ago. While it is true that, at any point in time, the technology employed in the Fleet may cover a span of some 20 years, the current gap between training course content and technology is more than is necessary or desirable.

Changes in combat system technology are rapid and the rate of change can be expected to accelerate in the future. The assessment of future technology impacts on maintenance skill and training requirements was very limited and considered only some very general trends. Nevertheless, the impact will be significant. Rather than allowing training to lag technology by some 20 years, the Navy should strive to stay abreast. It is recommended, therefore, that an office be created in Headquarters, Naval Material Command, responsible for monitoring technology trends, assessing the potential impacts on personnel, training, and skill requirements, and disseminating this

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information among those Navy decision makers responsible for these functional areas. The office, to be effective, should be represented as a permanent member on NAVMAT's Acquisition Review Group and Logistics Review Group.

SECTION VI

POSTSCRIPT

The focus of this study and the resulting R&D recommendations have addressed what needs to be done to improve the acceptance, utilization, and effectiveness of maintenance job aids and maintenance training equipment. Recommendations in other areas are limited to those which interact directly with this main theme. It is acknowledged that we have only scratched the surface in many related areas, and that much more R&D will be necessary to support a fully-effective Maintenance Improvement Plan.

## LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ACTS	- Adaptive Computer Training System
AD	- destroyer tenders
ADP	- automated data processing
AFHRL	- Air Force Human Resources Laboratory
AFQT	- Armed Forces Qualification Test
AFTA	- Avionics Fault Tree Analyzer
AI	- artificial intelligence
AIMD	- Aircraft Intermediate Maintenance Department
AMTESS	- Army Maintenance Training and Evaluation Simulation System
A <sub>o</sub>	- operational availability
AQ	- Aviation Fire Control Technician
AR	- repair ships
ARI	- Army Research Institute
AS	- submarine tenders
ASVAB	- Armed Services Vocational Aptitude Battery
AT	- Aviation Electronics Technician
ATE	- automated test equipment
AVCAL	- Aviation Consolidated Allowance List
AX	- Aviation Antisubmarine Warfare Technician
BEE	- Basic Electricity and Electronics
BIT	- built-in test
BITE	- built-in test equipment
CAD	- computer-aided design
CAI	- computer-aided instruction
CAPT	- Captain
CASREP	- Casualty Report
CAT	- computerized adaptive testing
CDR	- Commander
CINCLANTFLT	- Commander in Chief, U.S. Atlantic Fleet
CLASP	- Classification and Assignment with PRIDE
CMI	- computer-managed instruction
CNET	- Chief of Naval Education and Training
CNO	- Chief of Naval Operations
CNR	- Chief of Naval Research
COMNAVSURFLANT	- Commander, Naval Surface Force, U.S. Atlantic Fleet
COMNAVSURFPAC	- Commander, Naval Surface Force, U.S. Pacific Fleet
COSAL	- Coordinated Shipboard Allowance List
CPU	- central processing unit
CSIP	- Combat Systems Improvement Program
CSMP	- Current Ship Maintenance Project
CTM	- Cryptologic Technician, Maintenance
CV	- aircraft carrier
CVN	- aircraft carrier (nuclear)

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"D"	- depot
DARPA	- Defense Advanced Research Projects Agency
DoD	- Department of Defense
DS	- Data Systems Technician
DSARC	- Defense Systems Acquisition Review Council
DSB	- Defense Science Board
EDVR	- Enlisted Distribution Verification Report
EEMT	- Electronic Equipment Maintenance Trainer
EPICS	- Enlisted Personnel Individualized Career System
ET	- Electronics Technician
EW	- Electronics Warfare Technician
FCS	- Fire Control System
FIND	- Fault Isolation through Nodal Dependencies
FLSIP	- Fleet Logistics Support Improvement Program
FMC	- fully mission capable
FOMM	- Functionally Oriented Maintenance Manual
FPT	- Fleet Project Team
FSD	- full-scale development
FT	- Fire Control Technician
FTB	- Ballistic Missile Fire Control Technician
FTG	- Fire Control Technician (Gun Fire Control)
FTM	- Fire Control Technician (Missile Fire Control)
FY	- fiscal year
GAO	- General Accounting Office
GFCS	- Gun Fire Control System
GI	- soldier
GM	- Gunners' Mate
GMM	- Gunner's Mate (Missiles)
GMTS	- Generalized Maintenance Training Simulator
HF	- high frequency
HFE	- human factors engineering
HSDG	- High School Diploma Graduates
HUD	- head-up display
Hz	- hertz
"I"	- intermediate
IBM	- International Business Machines Corporation
IC	- integrated circuit
IDA	- Institute for Defense Analyses
IFF	- identification friend or foe
ILS	- integrated logistics support
ISD	- instructional systems development
JCS	- Joint Chiefs of Staff
JLC	- Joint Logistics Commanders
JPA	- Job Performance Aid

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LCC	- Amphibious Command Ships
LCDR	- Lieutenant Commander
LHA	- Amphibious Assault Ships
LMI	- Logistics Management Institute
LOGMOD	- logic model
LOGPAC	- Logistics Command, Pacific
LRU	- lowest replaceable unit (also line replaceable unit)
LSA	- logistics support analysis
LSSD	- Level Sensitive Scan Design
LT	- Lieutenant
M	- million
MADT	- mean administrative delay time
MC	- Mental Category or mission capable
MDS	- Maintenance Data System
MDT	- mean down time
MIL-HDBK	- military handbook
MIL-STD	- military standard
MIP	- Maintenance Index Page
Mk	- Mark
MLDT	- mean logistics delay time
MOTU	- Mobile Technical Unit
MRC	- Maintenance Requirements Card
M.S.	- Master of Science
MT	- Missile Technician
MTBM	- mean time between maintenance
MTTR	- mean-time-to-repair
N/A	- not applicable
NADC	- Naval Air Development Center
NAMTRADET	- Naval Air Maintenance Training Detachment
NASA	- National Aeronautics and Space Administration
NATO	- North Atlantic Treaty Organization
NATSF	- Naval Air Technical Services Facility
NAVAIR	- Naval Air Systems Command
NAVEDTRA	- Naval Education and Training
NAVELEX	- Naval Electronic Systems Command
NAVMAT	- Naval Material Command
NAVPERs	- Naval Personnel
NAVPERSRANDCEN	- Navy Personnel Research and Development Center
NAVSEA	- Naval Sea Systems Command
NAVTIIP	- Navy Training Improvement Program
NAVTRAEQUIPCEN	- Naval Training Equipment Center
NEC	- Naval Enlisted Classification
NEOCS	- Navy enlisted occupational classification system
NEPDIS	- Naval Enlisted Professional Development Information System
NFR	- no-fault removal
NIMS	- NATSF Information Management System
NMC	- not mission capable
NMCM	- not mission capable maintenance

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NMCS	- not mission capable supply
NMP	- Navy Manning Plan
NRAC	- Naval Research Advisory Committee
NSIA	- National Security Industrial Association
NTDS	- Naval Tactical Data System
NTIPP	- Navy Technical Information Presentation Program
NTIPS	- Navy Technical Information Presentation System
"O"	- organizational
OJT	- on-the-job training
O&M	- operating and maintenance
ONR	- Office of Naval Research
OPNAV	- Office of the Chief of Naval Operations
ORTS	- Operational Readiness Test System
OSD	- Office of the Secretary of Defense
PAR	- Personnel Advancement Requirement
PEAM	- Personal Electronic Aid for Maintenance
PMC	- partially mission capable
PM/FL	- performance monitoring/fault localization
PMS	- planned maintenance system
PO	- Petty Officer
PPAS	- personnel proficiency assessment system
PQS	- Personnel Qualification Standards
PRIDE	- personalized recruiting for immediate and delayed enlistment
R&D	- research and development
RADM	- Rear Admiral
R&M	- Reliability and Maintainability
RFT	- ready-for-training
RIM-AIR	- Repairables Integrated Model for Aviation Material
RM	- Radioman
SAT	- Scholastic Aptitude Test
SATCOM	- satellite communications
SECDEF	- Secretary of Defense
SERT	- Ship Electronics Readiness Team
SIMA	- shore intermediate maintenance activity
SIMSPO	- Simulator Systems Program Office
SNAP	- Shipboard Non-tactical ADP Program
SRA	- shop replaceable assembly
SRF	- Ship Repair Facility
ST	- Sonar Technician
STAMP	- System Testability and Maintainability Program
STEEP	- Support and Test Equipment Engineering Program
STG	- Sonar Technician (Surface)
STS	- Sonar Technician (Submarine)
SUBACS	- Submarine Advanced Combat System



**PROJECT 11: DEVELOPMENT OF SPECIFICATIONS FOR MAINTENANCE TRAINING EQUIPMENT  
(NON-SYSTEM SPECIFIC)**

**BACKGROUND.** Once the Navy has decided upon a training strategy and the implications for training simulators have been considered (Project 10), specifications must be developed for that equipment. Normal task analysis does not suffice for this purpose, even after revised procedures have been developed for training device specification (Project 7), because the training equipment is not tied to specific end-item tasks. Non-system-peculiar devices include technology trainers (simulating one or more sections of electronic equipment to illustrate operational or technological principles); generalized trainers (simulating the characteristics of a class or family of equipments to teach theory of operations, functional relationships, testing, measurements, and troubleshooting); and general-purpose trainers (which, through system-peculiar software and audiovisuals, can be made to simulate any specific system). This project addresses requirements for the first two categories.

**TASK DESCRIPTION.**

a. Review the requirements for technology trainers at the various schools. Define the commonalities among these requirements. Match the characteristics of current devices to these requirements. Identify what is obsolete and what is duplicative. Standardize on the smallest group of technology trainers possible for Navy-wide application:

- (1) Basic circuit trainers.
- (2) Special circuit trainers.
- (3) Servo-mechanism trainers.
- (4) Digital logic trainers.

b. Institutionalize a periodic review process of technology trainer requirements.

c. Develop design specifications for generalized trainers:

- (1) Transceiver trainer.
- (2) Radar maintenance trainer.
- (3) Computer/peripherals maintenance trainer.
- (4) Search radar/fire control maintenance trainer.
- (5) IFF maintenance trainer.

PROJECT 10: DEVELOPMENT OF A STANDARDIZED APPROACH TO TROUBLESHOOTING TRAINING

BACKGROUND. Past research suggests that there is substantial benefit in first training generic troubleshooting skills and then teaching troubleshooting, using 2-D simulators, on classes of equipment or specific equipment to address equipment-peculiar features. Versatility has been shown to be the most important aspect of troubleshooting skills in view of the continuous engineering changes or improvements of military equipment. This is why teaching troubleshooting skills on classes of equipments should receive more emphasis in lieu of troubleshooting specific equipments. To guide the development of the appropriate training equipment, an overall Navy-wide approach must be developed. Apparently, this has not been done. While we have definite ideas on this subject (see Project 5), this is based more on intuition than quantitative evaluation of alternatives.

TASK DESCRIPTION

a. Determine alternative options for developing troubleshooting skill proficiency of combat system technicians.

b. Evaluate the pros and cons of the alternatives, including acquisition and support cost estimates.

c. Decide what alternative is best on the basis of training-effectiveness and cost-effectiveness.

NOTES.

a. Training strategy is closely interlinked with this issue and that addressed in Project 9. The current training strategy would favor technology trainers in BEE School, generalized trainers in "A" Schools, and general-purpose trainers in "C" Schools. The implications of EPICS are that the first training phases are more equipment-oriented, so that the need for general-purpose trainers (with subsystem/system-peculiar software) is deferred to subsequent training phases, and generalized trainers may be eliminated altogether. Project 10 may thus influence the Navy's decision on training strategy, but is ultimately subject to the chosen strategy.

b. The negative results of a generic troubleshooting training experiment conducted in 1983 for BEE students (Technical Report NAVTRAEQUIPCEN 82-C-0119: Computer Assisted Instruction System Effectiveness on Troubleshooting Training, August 1983) suggests that context-free troubleshooting training must be done very early in the training track to be of any use. (The training package used was for generic troubleshooting training and is generally well-received by industry. This training was administered to students halfway through BEE School.) Context-specific troubleshooting training may be more effective at later points in the training track.

PROJECT 9: EMPIRICAL EXAMINATION OF THE MOST COST-EFFECTIVE AND TRAINING-EFFECTIVE MIX OF ACTUAL EQUIPMENT AND TRAINING SIMULATORS FOR MAINTENANCE TRAINING

BACKGROUND. While it is known that effective training requires a mix of actual equipment and training simulators, little empirical work has been done to determine the best mix. Another potential question focuses on the most effective sequence in which the equipment is to be used in a training pipeline. The optimal mix is influenced by the type of tasks involved. To determine training time allocation among actual-equipment trainers and simulators, more empirical work is necessary.

TASK DESCRIPTION.

- a. Review research findings from the literature.
- b. Conduct systematic experiments to assess the impacts of different mixes of actual and simulated training equipment.
- c. Document findings.

NOTES.

- a. To our knowledge, no work in this area is planned by AFHRL.
- b. ARI is conducting work in this area with outside contractor support (George Mason University).

**PROJECT 8: EMPIRICAL EXAMINATION OF THE RELATIONSHIPS BETWEEN TRAINING EQUIPMENT DESIGN FEATURES, TRANSFER-OF-TRAINING, AND TRAINING OBJECTIVES**

**BACKGROUND.** Past research on the relationships between training device "fidelity" and transfer-of-training has been largely academic because the interaction with training objective (type of tasks trained) was ignored. For example, it is now recognized that cognitive training (e.g., troubleshooting) benefits from low physical fidelity though high functional fidelity, while manipulative tasks such as removing/replacing assemblies are best learned on the actual equipment or a close replica thereof (whole or part-task trainer). In the latter case, the need for a high physical fidelity device vice actual equipment is justified on the basis of cost savings and the fact that actual equipment is not designed for student abuse so that instructors are reluctant to use it for hands-on training (instead, the hands-on lab work advertised in the curriculum is more a hands-on demonstration conducted by the instructor). A third dimension, psychological fidelity, is frequently referred to, but what it is, how it can be measured, and how it influences transfer-of-training, is not clear. Another factor not very well covered in past research is training strategy -- a factor which probably has the largest influence on the relationship between training simulator design and training effectiveness. Training strategy determines whether the training objective is generic versus equipment-specific training, whole versus part-task training, free play versus "aided" training, and lock-step versus self-paced training. Finally, little is known about the interactions, if any, of individual abilities. Much empirical work remains to be done to assess the interactions of all these factors with the traditional fidelity/training effectiveness relationship.

**TASK DESCRIPTION.**

- a. Review and consolidate previous research on this subject.
- b. Conduct systematic experiments to assess those interactions about which insufficient knowledge is available.
- c. Document results.

**NOTES.**

- a. ARI is planning a comprehensive data base of previous research findings.
- b. AFHRL is conducting a series of experiments on this subject.

PROJECT 7: DEVELOPMENT OF EXPANDED TASK ANALYSIS PROCEDURES

BACKGROUND. There is a growing consensus among researchers that present ISD procedures are not suitable for deriving training device specifications. A different procedure must be developed for this purpose, but there is no consensus on how to do this.

TASK DESCRIPTION.

- a. Review the existing literature on this topic and the status of research in the other Services.
- b. Identify the specific shortcomings of current ISD procedures.
- c. Develop revised procedures to overcome these shortcomings.
- d. Coordinate with the other Services to promulgate a tri-Service standard for expanded task analysis procedures required to:
  - (1) Fill the voids in current ISD guides and procedures.
  - (2) Meet the specific needs for training device specifications.

NOTES.

- a. ARI is planning work in this direction.

PROJECT 6: TEST AND EVALUATION OF PROTOTYPE FLEET TRAINING DELIVERY SYSTEM

BACKGROUND. Following development and approval of the overall concept, commercial hardware should be procured and software developed to test and evaluate the prototype system.

TASK DESCRIPTION.

- a. Procure and install prototype hardware suitable for the job aiding software (Project 3), troubleshooting tutorial software (Project 4), and other courseware developed in accordance with the plan (Project 5).
- b. Conduct longitudinal test and evaluation of the system, refining or revising components of the system accordingly.

NOTES.

- a. Unless the Navy commits itself in advance to conduct this type of operational testing in accordance with an approved plan of action and milestones, all previous recommended research projects would have little practical use or payoff.

## PROJECT 5: DEVELOPMENT OF A FLEET TRAINING DELIVERY SYSTEM CONCEPT

**BACKGROUND.** The Navy currently has no coordinated plan whether and how to support Fleet technical training requirements. ISD-based training course curricula are developed with the knowledge that most technical training is not provided at Resident Schools. Yet, development of on-board training packages has not occurred in the past, and the opportunities for OJT are limited. TYCOM training initiatives are strained by training resources. Identification of skill deficiencies and refresher training or skill-enhancement training requirements is currently not a well-managed process. The Navy needs an overall concept or plan for meeting these Fleet training requirements (individual maintenance skills) in the most cost-effective way.

**TASK DESCRIPTION.**

- a. Proceed with NEPDIS to develop a comprehensive data base for task/skill/knowledge requirements.
- b. Review with TYCOMs the current Fleet training effort, training requirements, and procedures for skill appraisal and certification.
- c. Identify the training delivery system requirements:
  - (1) Student load.
  - (2) Training modules.
  - (3) Proficiency testing.

(Enhanced job aids will ensure proficiency only for frequently occurring tasks).
- d. Develop a cost-effective concept to meet this need using available technology.

**NOTES.**

- a. The training strategy espoused by this study eliminates all actual equipment from Resident Schools, replacing it with technology trainers in BEE School (Project 11), generalized simulators in "A" Schools (Project 11), and general-purpose simulators (such as the GMTS) and part-task trainers in "C" Schools. TYCOM training activities, under the recommended strategy, would have operational equipment for practical job training. Thus, this project should consider the availability of operational equipment (or, "TTE") supplementing the training delivery system.
- b. The Navy has experience with various media suitable for this system, except for interactive video disc technology in which ARI has invested considerable efforts. Technological overkill should be guarded against, however; the GMTS experience shows that microfiche can be applied very well in troubleshooting training. Video disc, however, is needed for motion dynamics.

PROJECT 4: DEVELOPMENT OF EXPERT TROUBLESHOOTING TUTORIAL SOFTWARE (EQUIPMENT SPECIFIC)

BACKGROUND. Experience has shown that the application of AI principles is effective in teaching troubleshooting skills. What is currently not known is the best mix between "feed-forward" and "feed-back" in teaching these skills. Nor is it known how this tutorial information should be modified ("faded") as a function of the student's progress or how to mix "product" vice "process" knowledge of results. What is known is that, in the instruction mode, the tutorial information must be more extensive than in the job aiding mode. Empirical validation is necessary to resolve these issues in developing effective tutorial software.

TASK DESCRIPTION.

- a. Develop and test prototype software for a small set of equipments and systems of graded complexity. Assess the impacts of systematic changes in: the mix of feed-back and feed-forward information; the extent of fading; and the type of information (process vs. result).
- b. Analyze and document empirical results.
- c. Revise the draft specification for tutorial troubleshooting software (Project 3) accordingly.

REFERENCE.

Rasmussen, Jens, and Rouse, William B. (eds). "Human Detection and Diagnosis of System Failures," Proceedings of NATO Symposium, August 1980. New York: Plenum Press, 1981.

NOTES.

- a. The Navy already has a system, the Generalized Maintenance Training Simulator (GMTS), with equipment-specific software for the AN/WSC-3, AN/SPA-66, and Fleet Communications System. This system could be used in support of Project 4 instead of starting from scratch. One question that must be considered is whether current GMTS software faithfully reflects the uncertainties of test measurement validity encountered in the real world (i.e., marginal values, neither yes nor no). ARI's ACTS, reportedly, is designed to handle that aspect of diagnostic activity very well.



PROJECT 3: DEVELOPMENT OF SPECIFICATIONS AND GUIDES FOR JOB AIDING SOFTWARE

BACKGROUND. The previous two projects are not recommended for their own sake, but as prerequisite efforts in developing effective job aiding software, tutorial enhancements to that software in order to transition novices to experts as soon as possible, and effective troubleshooting training software. To institutionalize this approach, guidelines and specifications are necessary in support of acquisition of this software. Such data are currently not available.

TASK DESCRIPTION.

- a. Following completion of Projects 1 and 2, develop draft specifications and guidelines for job aiding software and tutorial software for use in job aids and maintenance training curricula.
- b. Validate the specifications through pilot applications (see Project 4).
- c. Coordinate with the other Services and promulgate a military specification for use in contracts.

NOTES.

a. ONR and DARPA have sponsored considerable research in Artificial Intelligence (AI) and novice versus expert behavior in problem solving but, it appears that this project does not duplicate anything done in the past.

b. NAVPERSRANDCEN has embarked on a research program to utilize AI concepts for presenting technical information to technicians but a project like the one described here is not included in that program.

c. Current AI-based training systems, such as ARI's Adaptive Computer Training System (ACTS), employ a theoretical model of expert performance based on maximizing "expected utility" from each troubleshooting step. There is some question as to how realistic that concept is.

d. AFHRL has no known research planned in this area.

e. Past research in this area, according to ARI, suggests the following:

(1) Technicians tend to have difficulty verbalizing why they are doing what they are doing; it may be necessary to add video and query the technician after each session.

(2) The first step, prior to experimentation, should include a detailed analysis of existing technical documentation to develop a conceptual model (cognitive and psychomotor demands) of the target system.

(3) The on-line protocols developed in each session can be used for improving this conceptual model and ultimately for task analysis validation and training.

PROJECT 2: ANALYSIS OF EXPERT TROUBLESHOOTING STRATEGIES AND BEHAVIOR

BACKGROUND. Past research has indicated that experts rely on a mental model of the functional interrelationships within a system; that they possess specific cognitive abilities (e.g., problem sensitivity, information ordering, flexibility of closure, spatial orientation, visualization, selective attention, and attention to detail) which non-experts may not possess; that they utilize the information gained from test measurements much better than non-experts do, especially measurements that identify sections of the equipment as "good"; and that they are able to utilize built-in testability features more productively than non-experts do. More specific details on what makes an expert need to be learned to apply this knowledge for expediting the transition from non-expert to expert troubleshooting performance.

TASK DESCRIPTION.

a. Interview subjects (experts and novices) to assess their knowledge of selected systems and the procedures they profess to follow in diagnosing failures. Tape record each interview.

b. Conduct a series of experiments, observing how the experts troubleshoot and isolate system failures. Encourage subjects to think aloud, articulating why they do what they do. Tape record each session.

c. The number of experiments (or the size of the experiment if all variables are manipulated in one experiment) depends on the scope and validity desired:

(1) Individual differences of expert technician subjects.

(2) Different types of equipment.

d. Conduct identical experiments with the control group of novice troubleshooters.

e. Anchor the expert performance in each experiment by means of a testability analysis model (LOGMOD) identifying the minimum steps required for fault isolation.

f. Analyze and document results, identifying:

(1) How good the experts are.

(2) What specific factors explain their performance (cognitive abilities, experience, knowledge).

(3) What the key differences are between experts and novices.

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b. While current R&D programs (PEAM, NTIPP, Hybrid JPAs) are designed to address this issue in some form, a more rigorous examination is deemed necessary to achieve the full potential of aiding technology.

c. It appears that, neither ARI nor AFHRL have a project of this type in their research programs.

APPENDIX A

CANDIDATE RESEARCH AND DEVELOPMENT PROJECTS

PROJECT 1: ANALYSIS OF TECHNICAL INFORMATION NEEDS IN MAINTENANCE TASK PERFORMANCE

BACKGROUND. The effectiveness of a job aid is determined by many factors. One factor is the extent to which the technical information provided by the aid matches the information needs of the technician in terms of content, format, detail, sequence, chunk (amount of information per frame), and type (fact, concept, rule, procedure, or principle). There is only limited knowledge about these specific needs and, especially, how they vary with different conditions (equipment, type of task, operational environment, experience level, individual differences). This void in knowledge must be eliminated.

TASK DESCRIPTION.

a. Conduct a series of experiments observing subjects performing maintenance. Subjects have no Technical Manuals (TMs), tools, or test equipment. Experts are present to respond to questions by subjects, including requests for specific information, tools, and test equipment. Observers document what goes on, using tape recorders.

b. The number of experiments (or the size of the experiment if all variables are manipulated in the same experiment) is determined by the following factors:

(1) Individual differences (contrasting cognitive abilities of subjects).

(2) Different equipment (different levels of complexity).

(3) Task coverage.

(4) Maintenance levels ("O" and "I").

(5) Experience levels (e.g., less than one year, two years, four years). (To increase the insights gained from the project, the same experiments could be conducted on equipment other than combat systems).

c. Analyze and document the specific information needs identified as a function of experience level and individual differences.

NOTES.

a. The limited success of JPAs is attributed to the lack of knowledge this project is intended to provide.

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TD	- Training Device Technician
TM	- technical manual or Torpedoman's Mate
TRADOC	- U.S. Training and Doctrine Command
TTE	- technical training equipment
TYCOM	- Type Commander
UHF	- ultra-high frequency
UNITREP	- unit status and identify report
U.S.	- United States
USDRE	- Under Secretary of Defense for Research and Engineering
USN	- United States Navy
VADM	- Vice Admiral
VHSIC	- very high-speed integrated circuit
VLSI	- very large-scale integration
VLSL	- very large-scale logic
WRA	- weapon replaceable assembly
2-M	- miniature/microminiature
3-M	- Maintenance and Material Management

- (6) Advanced communications maintenance trainer.
- (7) Sonar maintenance trainer.

REFERENCES.

Parker, E. L. Generalized Training Devices for Avionic Systems Maintenance.  
Santa Barbara, California: Anacapa Sciences, August 1974.

Parker, E. L. Applications and Design Characteristics of Generalized Training Devices. Santa Barbara, California: Anacapa Sciences, March 1971.

PROJECT 12: CONDUCT OF COST-EFFECTIVENESS STUDIES OF MAINTENANCE TRAINING EQUIPMENT

BACKGROUND. The lack of adequate cost-effectiveness studies of maintenance training simulators has been pointed out by several observers. While studies confirm that simulators are cheaper than actual equipment and students trained on simulators perform equally as well as those trained on actual equipment, the limitations of such studies are obvious. To demonstrate convincingly the cost-effectiveness of training simulators, longitudinal studies must be performed, taking into account a number of other aspects as well; e.g., mix of equipment used in the training pipeline, training strategy, skill retention. These studies could be combined with some previously referred to (Projects 8 and 9) in assessing training-effectiveness of alternative training strategies.

TASK DESCRIPTION.

- a. Consolidate the findings from past evaluation studies.
- b. Identify the shortcomings of these evaluations.
- c. Develop a comprehensive evaluation plan.
- d. Conduct experimental studies.
- e. Document findings.

REFERENCES.

Orlansky, J., and String, J. Cost-Effectiveness of Maintenance Simulators for Military Training. Arlington, Virginia: Institute for Defense Analyses, August 1981.

NOTES.

a. AFHRL is conducting work in this area, but the results will be subject to similar limitations as those of past studies (see: Louis F. Cicchinelli et al., Relative Cost and Training Effectiveness of the 6833 Converter/Flight Control System Simulators As Compared To Actual Equipment (Brooks Air Force Base, Texas: Air Force Human Resources Laboratory, December 1982)).

b. ARI is planning to conduct studies in this area under the AMTESS program.

c. The Navy's current evaluation of the EENT is subject to the same limitations as indicated for AFHRL's work.

d. According to some observers, the utility of this project may be limited because the rate of change of technology is too rapid to obtain meaningful results.



PROJECT 13: DEVELOPMENT OF TRAINING EQUIPMENT ACQUISITION MANUAL AND POLICY

BACKGROUND. The Navy lacks a standard, uniform procedure for the acquisition of training equipment. There is no effective review process to determine if training requirements resulting from a new weapon system acquisition program could be met by training equipment in the existing inventory. Rather, it is assumed that every new prime system requires one or more new trainers. Additionally, the potential suitability of a new trainer to meet the training requirements of more than one new system is not considered. Furthermore, the trainer design characteristics are more influenced by contractor proposals than by a rigorous, independent assessment of the functional requirements for a new trainer. To improve the situation and achieve more training effectiveness from training device investments, current policies must be tightened in one respect (procedure and process) and loosened in another (planned test and evaluation of first-article trainers treat them as prime equipment with much unnecessary detail and administrative burden). More importantly, prime equipment program (project) managers must be given the decision aids they are currently lacking.

TASK DESCRIPTION.

- a. Expand the training device data base to include data elements permitting retrieval of device information keyed to a taxonomy of devices by type, tasks simulated, and utilization.
- b. Consolidate empirical and case history information on current devices into a training device design guidelines manual.
- c. Consolidate the results of previous R&D (Projects 7-11) and the above tasks into a Training Equipment Acquisition Manual in a format suitable for addressing the key issues in acquisition:
  - (1) Validation of the need for a new trainer.
  - (2) Identification of the mix of trainer types required.
  - (3) Specification of the functional characteristics required.

NOTES.

- a. ARI is embarked on a five-year program that is ultimately to result in a decision support system for training equipment acquisition decisions. This R&D program appears to be well-designed and is very comprehensive.
- b. AFHRL's past efforts in this area have resulted in preliminary manuals; see, for example, AFHRL-TP-81-51, Maintenance Training Simulator Design and Acquisition: Handbook of ISD Procedures for Design and Documentation, February 1982. AFHRL plans to complete its work in this area by the end of the current fiscal year with issuance of a set of introductory handbooks for ISD teams and acquisition managers.

PROJECT 14: DEVELOPMENT OF FLEET PROJECT TEAM GUIDE

BACKGROUND. Responsibilities of the Fleet Project Team (FPT) are specified by OPNAV Instruction 1551.7B (April 1977). The FPT acts as the user representative and subject matter expert in training device acquisition. Its specific duties include:

- a. Provide guidance to the developer.
- b. Develop training syllabus in which the device will be used.
- c. Assist developer in specifying acceptance criteria.
- d. Identifying trainer deficiencies requiring correction before ready-for-training (RFT) approval.

The FPT guide spells out, in more detail, the functions of the FPT and the milestones or activities associated with device acquisition. It also makes clear that the FPT role is advisory only, subject to invitation or request to comment on the various acquisition requirements (military characteristics, design reviews, ILS plans, inspections and tests) by the developer (NAVTRAEQUIPCEN) who has technical and contractual authority. In view of personnel turnover and the lengthy acquisition cycle of complex trainers, the effectiveness of the FPT could be increased by providing them with more detailed aids. One area in which the FPT can be instrumental is to promote user acceptance, but that area is not addressed in the current FPT guide. In all other areas, the guide tells what is to be done, not how it should be done.

TASK DESCRIPTION.

- a. Consolidate findings from previous studies on the issue of user acceptance.
- b. Develop a School Introduction Guide outlining how user acceptance can be gained through early interface with instructor personnel, proper introduction of the device, and timely availability of the training syllabus.
- c. Develop a Training Device Evaluation Guide.

REFERENCES.

- Mackie, Robert R., et al., Factors Leading to the Acceptance or Rejection of Training Devices. Goleta, California: Human Factors Research, Inc., August 1972.
- Wylie, Dennis C., and Mackie, Robert R. Factors Influencing Organizational Acceptance of Technological Change in Training. Goleta, California: Human Factors Research, Inc., October 1982.

NOTES.

a. ARI's R&D program includes a work unit on training device effectiveness evaluation to result in guidelines for conducting empirical evaluation, a handbook, and a computer-based decision aid.

PROJECT 15: STANDARDIZATION OF INSTRUCTOR AND STUDENT STATIONS

BACKGROUND. The benefits of modular design and standardization of common modules have been demonstrated in many cases and represent the chief lesson learned from past experience with ATE in the Department of Defense. The same concept can be applied to maintenance training simulators because they have some modules in common, regardless of application: the instructor station and student station. Significant acquisition cost savings can be achieved by developing standards for these modules and prescribing these standards for new maintenance trainers, whenever feasible, so that they do not have to be redesigned for every peculiar maintenance trainer. Savings in support costs will also be significant as a result of standard spares and repair parts, lower stockage costs, and standard manuals.

TASK DESCRIPTION.

- a. Develop a detailed taxonomy of maintenance training equipment, including types and attributes.
- b. Conduct a commonality analysis.
- c. Identify the functional requirements of instructor and student stations.
- d. Develop specifications and design guidelines.
- e. Coordinate with the other Services to promulgate a military standard.

NOTES.

- a. The Air Force program office for simulators (SIMSPO) has this subject in its program and is supposed to take the lead in this effort. Coordination with SIMSPO would be well-advised.

APPENDIX B

DEFENSE SCIENCE BOARD 1982 SUMMER STUDY  
ON TRAINING AND TRAINING TECHNOLOGY

INTRODUCTION

The Defense Science Board (DSB) 1982 Summer Study addressed for the third time in seven years the topic of training and training technology. Reasons advanced for this renewed focus were the lack of action by the Department of Defense (DoD) on previous training recommendations (1976 DSB), the shrinking manpower pool, limited supply of high mental category accessions, rapid turnover of personnel, increasing technological complexity of equipment, and increasing ratios of equipment to personnel. The training and training technology panel was chaired by Admiral Isaac C. Kidd, Jr., USN (Ret.) and comprised four subpanels: organization and acquisition of training, training technology, manpower requirements and skill development, and operational training.

The panel's findings, conclusions, and recommendations are summarized in this appendix for reference purposes. This summary is based on the panel's final briefing charts as distributed by the Under Secretary of Defense for Research and Engineering (USDRE).

FRAME OF REFERENCE

The panel focused its effort on the following key questions:

- a. How effective is current training?
- b. How is training effectiveness measured?
- c. What are the cost-benefit trade-offs between simulators and other training aids versus actual equipment for training?
- d. What technologies exist that would improve the training of operator and maintenance personnel?
- e. How much improvement is possible and what areas of training could benefit most by adopting new approaches?
- f. What actions are necessary to improve implementation and utilization of advances in training technology?

With respect to the first four questions, the panel found that current training is marginally effective; training effectiveness is measured subjectively and poorly; cost data and performance data necessary for cost-benefit trade-offs are very limited (but in the few cases they are available, simulators cost 20 to 60 percent less to acquire than actual

equipment, and are equally effective as measured by student achievement); new technologies applicable to training are available and include computer-based simulation, stimulation, communication, data collection, reduction, and retrieval as well as new means of computer input and output.

With regard to the fifth question, the panel assessed present equipment and personnel performance at 40 percent of optimal potential and estimated this could be improved to 70 percent with proper application of training technology and planned reliability/maintainability improvements in weapon systems. The training areas to benefit most from new technology were found to be individual advanced skill training (both operators and maintainers) and team or unit training. The sixth question was answered negatively; the panel found a continued lack of coordination between "people people," "hardware people," and "training people" due to a lack of guidance from the top. Addressing the final question, the panel estimated that expenditures for training have fallen out of balance with those for prime equipment. While present training is expensive (individual training at service schools costs \$12.8 billion a year with 20 percent of military personnel involved in training as students, instructors or school support; the additional costs involved in unit training and advanced training not in schools is unquantifiable), the panel found that increased spending for high-technology training methods and equipment holds the promise of quick return on investment by improving personnel ability to use and maintain military equipment. It estimated that an additional \$2.6 billion a year could be used effectively for improved training technology, including devices, software, and courseware.

## CONCLUSIONS

The panel's conclusions, organized by subpanel, are summarized in Table B-1. Not included are those conclusions pertaining to operational and unit training since this study is focused on individual maintenance skills.

## ISSUES AND RECOMMENDATIONS

The panel's recommendations were briefed by a subpanel. Only those issues and associated recommendations applicable to maintenance training are listed here, quoted verbatim from the briefing report.

### MANPOWER REQUIREMENTS AND SKILL TRAINING

ISSUE #1: Demographic projections and "technology creep" indicate manpower problems.

#### Recommendations:

- a. Use technology to reduce failure rate and simplify operator/maintainer tasks (Project Office, 2% of system FSD cost).
- b. Explore self-motivating arcade-like devices to increase performance level of recruits (R&D agencies, three years at \$250K/system/year).

c. Require use of contemporary methodology such as HARDMAN to match hardware to people (Project Office, \$3M/system).

ISSUE #2: Educational deficits can result in serious under-utilization of the recruit's talent.

Recommendations:

a. Develop technology to match instruction to ways recruits learn best (Service Schools, five years at \$5M/year).

b. Use innovative ways to provide necessary English language skills (Service Schools, \$5M/year).

c. Use technology such as video storage in school and field to teach students about equipment they will be using (R&D agencies, five years at \$10M/year).

d. Use transportable devices in the field to broaden understanding for career growth at leadership (R&D agencies, five years at \$5M/year).

ISSUE #3: Benefit of CAI and new technology for field refresher and other training are limited by slow introduction into the training base.

Recommendations:

a. Innovative ways to make trainers accept technology changes such as CAI and learn to use them (Chiefs of Staff, cost to be included in demo projects).

b. Accelerate introduction of CAI into the "schoolhouse" to allow transportability of this training to the field (Service Schools, five years at \$46M/year).

c. Build CAI into training package of all new operational systems (Project Office, 0.5%-10% of system cost).

ISSUE #4: Adequate data not yet assembled to determine cost-effectiveness of training methods and devices.

Recommendations:

a. Undertake demonstration projects and provide high technology testbeds for training and performance measurement (R&D agencies, five years at \$16M/year).

b. Direct where possible embedded training and performance measurement be built into new systems (Material Command, \$1M or 2% of system cost).

c. Develop and adopt quantitative performance measures (R&D agencies, Training Commands, five years at \$12M/year).

d. Establish a repository for all training data (OSD Field Agency, five years at \$250K/year).

#### TRAINING TECHNOLOGY

ISSUE #1: Advanced software techniques exist which promise gains in software/courseware production efficiency, but they are not yet applied.

##### Recommendations:

###### (Short Term)

a. Encourage use of common courseware modules and "user friendly" interfaces (AI based).

b. Direct future CAI acquisitions to specify transportable software including operating system (Joint Services, \$ negligible).

###### (Long Term)

a. Direct Machine Intelligence R&D efforts in automatic programming, information extraction, expert systems, and "good teacher" models reducing courseware production cost (DoD agencies, \$12M/FY84-89).

ISSUE #2: Weapon systems, based on digital technology, can be used to provide more effective training and performance measurement.

##### Recommendations:

a. Embedded training: new weapons systems should include means of providing simulated targets and environmental conditions (DSARC & Material Development, 10% of weapon system development).

b. Develop and incorporate performance measurement capabilities in new weapons systems (Material Development agencies and R&D labs, \$5M/year for three years to develop methodology; negligible unit costs for implementation).

ISSUE #3: Satellite communications capacity exists which may be used for remote training, maintenance, technical manual updating, and maintenance teleconferencing.

##### Recommendations:

a. Develop cost-effective ground stations with hardcopy and video recording capability (Joint Services, \$20M).



b. Pursue technologies related to data compression (USDRE, \$5M).

c. Establish a group from the training commands to explore satellite capability (USDRE, \$ negligible).

ISSUE #4: Critical training technologies need additional emphasis and focus by USDRE.

Recommendations:

a. USDRE assign responsibilities within DARPA and Services for emphasis on key technologies -- such as:

- (1) Voice recognition and synthesis.
- (2) Voice forwarding and speech storage.
- (3) Interactive display technology (soft and hard)
- (4) Personal microprocessor training aids.

b. Use advanced training devices as testbed for application of VHSIC.

c. Establish "brainstorming" sessions with industry to develop new ideas.

ORGANIZATION AND ACQUISITION

ISSUE #1: The need for proper training management and training technology mandates that OSD establish the proper environment to support the training initiatives of the Services and JCS.

Recommendation:

a. Establish an OSD steering committee for training matters (SECDEF, \$ negligible).

ISSUE #2: A single proponent within each Service is required to ensure proper emphasis and consideration of new training technologies and/or devices.

Recommendation:

a. SECDEF direction to the Services to provide a single proponent within each Service for consideration of new training technologies and devices (SECDEF, Service Heads, \$ negligible).

ISSUE #3: The history, tradition, and organization of Service labs often appears to establish research priorities. An example is the minimal emphasis on training technology.

Recommendation:

a. Direct the Services through their directors of laboratories to formulate a program to increase the priority for training technology (USDRE, allocate within current \$s).

ISSUE #4: The time required for weapon system data to stabilize in the development process often tends to cause training device development to start late.

Recommendations:

a. Initiate training device development earlier in the weapon system acquisition cycle (USDRE/Service Heads).

b. Consider providing relief in acquisition process for training devices (USDRE, Service Heads, can decrease annual DoD training costs by 5%).

SUMMARY

The recommendations of the DSB, as summarized in its Final Report, are shown in Table B-2.

TABLE B-1. SUMMARY OF DSB CONCLUSIONS<sup>1</sup>

#### MANPOWER REQUIREMENTS AND SKILL TRAINING

- Recruit quality and quantity goals met in FY81; FY82 will be even better, but...
- Future shortages may be anticipated
  - declining manpower pool, changing demographic mix, expanding economy
  - increasing skill requirements.
- Training technology offers significant and exciting solutions to some of the challenges.
- More and better data are needed to guide future applications.

#### TRAINING TECHNOLOGY

- Microprocessor based, interactive video disk systems have revolutionized the instructional industry.
- DoD need not fund the entire technology, but only its special needs.
- Software, including courseware development, is the dominant cost factor for computer-based instructional systems.
- Potential exists for improved training and performance measurement using embedded simulation and stimulation.
- New technologies such as VHSIC, advanced storage techniques, voice synthesis and recognition will produce improvements.

#### ORGANIZATION AND ACQUISITION

- OSD not tuned to Services training management and training technology needs; nor are the Joint Chiefs.
- Control and management of 6.1-6.4 training technology funds are fragmented within most of the Services. This fragmentation causes inadequate emphasis and/or acceptance of new training technologies.
- Currently available data on individual/collective performance is not sufficient to support effective management of training resources (system and non-system).
- Training devices often seriously lag the introduction of the weapon system.
- Service laboratories direct very little effort to the potential improvements in training through the application of contemporary technologies.

<sup>1</sup>Excludes conclusions on operational training and unit training.

TABLE B-2. SUMMARY OF DSB RECOMMENDATIONS

Area <sup>1</sup>	Specific Actions Required
A	<ol style="list-style-type: none"> <li>1. Establish an OSD Steering Committee for Training and Training Technology. Focus is to be on policy review and coordination of initiatives to produce more effective training through use of existing and new technology.</li> <li>2. Establish a Defense Training Data and Analysis Center for all training-related data.</li> <li>3. Revise acquisition process to: (a) ease procurement specifications and standards commensurate with training device use and (b) acquire training requirements data earlier in weapons system development cycle.</li> <li>4. Increase use of analytical methods to: (a) assess/project impact of manpower skills/performance of recruits to meet system needs, do not pool on new weapons systems and (b) identify where training may increase skills/performance of recruits to meet system needs, do not wait for more analysis/assessment. There are enough data to proceed now.</li> <li>5. Direct the Military Departments to increase funding and management emphasis on research and development of training technology, its application and its payoff.</li> <li>6. Direct the Military Departments to provide a single point of contact for propensity and coordination of training and training technology.</li> </ol>
B	<ol style="list-style-type: none"> <li>1. Provide the Reserve Components with up-to-date training technology and equipment. Support training to meet the unique needs of the Reserve Component training objectives, schedules, and environment.</li> <li>2. Support the funding of research, development and applications of technologies for unit training.</li> <li>3. Support research, development and use of war games that provide intelligent adversaries and realistic conditions to promote effective combat leadership training.</li> <li>4. Upgrade ranges; increase number/size of ranges based on requirements for operational training and testing of current/programmed weapons.</li> <li>5. Accelerate use of computer-based instructional methods (including CAI and CMI) in the schoolhouse and on the job via portable aids and/or embedded training systems.</li> <li>6. Use transportable devices in the field to broaden understanding and general-skill knowledge for career growth and leadership.</li> </ol>
C	<ol style="list-style-type: none"> <li>1. Establish (a) a research and development program on performance measures to develop criteria, methodology and equipment for use at all levels of training and (b) demonstration projects for new training technology to collect data on performance and cost effectiveness.</li> <li>2. Increase exploration and use of current/advanced technology devices (e.g., arcade-like games) to motivate and teach functional skills.</li> <li>3. Increase support/funding for research, development and use of the following technologies; voice recognition, interactive display, personal aids and VHSIC.</li> <li>4. Develop and incorporate embedded training and performance measurement/recording capabilities for new weapon and support systems.</li> <li>5. Direct future acquisition of training equipment to use transportable software and to be "user friendly" in meeting instructional needs.</li> </ol>

<sup>1</sup>A = Organization and Management; B = Planning and Application; C = Technology.

SOURCE: "Defense Science Board Summer Study on Training and Training Technology," Final Report, November 1982.

APPENDIX C

SECRETARY OF DEFENSE MEMORANDUM APPROVING DSB RECOMMENDATIONS



THE SECRETARY OF DEFENSE  
WASHINGTON, THE DISTRICT OF COLUMBIA

25 FEB 1983

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS

SUBJECT: Defense Science Board (DSB) Summer Study on Training and Training Technology

I have approved the recommendations made by the Defense Science Board to improve training by application of technology. The report and approved implementation plan are attached. I have asked the Under Secretary of Defense for Research and Engineering (USDRE) to take the lead in initiating the actions called for in the plan. I have also asked the Assistant Secretary of Defense for Manpower, Reserve Affairs and Logistics (ASD/MRA&L) to assist in this effort. I am confident that the implementation of the DSB recommendations will improve our readiness significantly.

There are four areas that, in my view, demand special consideration and the following specific guidance.

1. The DoD must increase its funding and management emphasis on the development of training technology and the use of this technology to address training problems. We must take advantage of current technology and press the research of emerging technologies to develop ways to make training more efficient and effective. To support this effort, it will be necessary to develop performance measures and criteria for use in determining performance levels and cost effectiveness of alternative training methodologies.

2. Each Service should accelerate efforts to apply technology to meet the training needs of the Reserve Components. This investment has the potential for very high payoff and merits a high priority. I ask that MRA&L coordinate this effort.

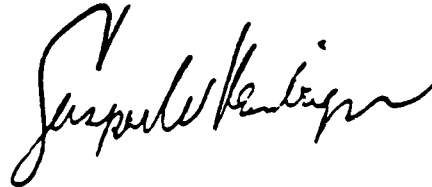
3. There is an urgent requirement to upgrade our land, sea and air ranges to make them as compatible as possible with the needs of the systems being tested and fielded. Since there are clear limits to real estate and air space, the capabilities of existing ranges must be expanded and made more versatile. Each Service should review range requirements and budget funds to upgrade range capabilities to include realistic threat simulation and instrumentation for total operator/system performance evaluation.

## APPENDIX C

2

4. A major continuing weakness of the overall training system is the absence of high-level perspective and proponentcy for training technology. This is true, with some exceptions, in both OSD and the Services. I expect that each of you will create an advocate for training and training technology within your own secretariat. General Vessey has offered to take the lead in establishing an OSD Steering Committee for training and training technology. I endorse this initiative and direct the Committee to consolidate advocacy consideration within OSD on matters related to the effective exploitation of training technology.

I trust that you are as impressed as I am with the quality of the DSB study and will support all of its recommendations. I am requesting the OSD Steering Committee include in its charter a process to review the implementation status of these recommendations as well as other actions taken to strengthen training.



Attachment

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APPENDIX D

NAVY TRAINING IMPROVEMENT PROGRAM

The Navy Training Improvement Program (NAV TIP) is a recent initiative which may be traced to Chief of Naval Education and Training's (CNET) concern about the cost-effectiveness of training, the Defense Service Board's 1982 Summer Study in Training and Training Technology (see Appendix B), the Under Secretary of Defense for Research and Engineering's (USDRE) memorandum for the Secretaries of the Military Departments (4 April 1983) assigning responsibilities for the actions recommended by the Defense Service Board as approved by the Secretary of Defense (see Appendix C), and the Chief of Naval Research (CNR) who advocated that more emphasis be put on transferring training research and development (R&D) results into application. The NAV TIP Steering Committee function is part of CNET's Training R&D Policy Board.

The objective of NAV TIP is twofold:

- a. Improving training through the immediate application/implementation of technology (e.g., through evaluation of R&D product demonstrations).
- b. Modifying and/or augmenting research programs to improve training technology with payoff in the near future.

The first Steering Committee meeting was held in May 1983. Work group meetings have been conducted through the summer to develop and finalize a Plan of Action and Milestones composed of two parts responsive to the two objectives. The first part includes demonstrations/evaluations in the areas of computer-based instruction, automated curriculum development, and job performance aids. (The first two coordinated by CNET, the third by the NAVTRAEQUIPCEN.) The second part is a five-year R&D plan, coordinated by the Office of Naval Research (ONR). For the whole plan, OP-01B7 (formerly OP-115) serves as executive secretary. The program was planned to take effect October 1983, but has been deferred.

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Office of Naval Research  
Code 422 (Dr. M. Tolcott)  
800 North Quincy Street  
Arlington, VA 22217

Office of Naval Research  
Code 422TT (Dr. S. Chipman)  
800 North Quincy Street  
Arlington, VA 22217

Office of Naval Research  
ONT 0722 (Dr. S. Collyer)  
800 North Quincy Street  
Arlington, VA 22217

Office of Naval  
Acquisition Support  
ONAS 041 (Mr. M. Aptner)  
Washington, DC 20360

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Naval Air Station  
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Naval Air Station  
Pensacola, FL 32508

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Naval Air Station  
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Chief of Naval Technical Training  
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