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HUMAN RELIABILITY RESEARCH

C. Beek, et al

Operations Research Incorporated
Silver Springs, Maryland

September 1967

EQUIPMENT RELIABILITY

SUPPORT ELEMENT RELIABILITY

SYSTEM RELIABILITY

Prepared for

New Developments Research Branch
Personnel Research Division
Bureau of Naval Personnel
Contract No. Nonr 4451(00)

September 1967

Prepared by

Gabriel Markisohn,

Kenneth Haynam

Program Director

Charles R. Beek

Director, Management Systems

Dr. Donald S. Orkand

Operations Research Incorporated

Silver Spring, Maryland

Technical Report 430

Report No. PRR-67-2

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ACKNOWLEDGMENTS

The human reliability research program described in this report was carried out under the direction of the Personnel Research Division (Pers A3) of the Bureau of Naval Personnel. The program was initiated under the direction of Capt. L. A. Wilder and was continued and concluded under Capt. R. G. Black, Director of the Personnel Research Division.

The performance of this program would not have been possible without the continued guidance and interest of the New Developments Research Branch, headed by Mr. A. A. Sjoholm and acting head Mr. V. Camp. Of particular significance was the assistance received from Mr. W. L. Hopkins, who provided technical direction throughout the program as Scientific Officer. Direct monitoring was carried out by Mr. Robert Seiler and Mr. Peyton G. Walker.

The assistance received from numerous individuals in the Personnel Research Division proved invaluable. Their knowledge of Naval systems and the agencies associated with these systems greatly enhanced the research effort.

In addition, ORI wishes to acknowledge the generous cooperation extended by all Naval personnel who were contacted, particularly during the first phase of the program. The names of all individuals contacted during the research program appear elsewhere in this report. Their assistance was instrumental in bringing this effort to its successful completion.

SUMMARY

PROBLEM

1. In the past decade more and more attention has been focused on the role of the human element weapon systems. The contribution of this personnel element to system reliability and effectiveness and the degradation in system performance because of human error have been subjects of numerous studies and research programs. These studies have substantiated the fact that a significant percentage of system unreliability is caused by human error.

2. These findings validate the urgency for quantifying human performance and developing new techniques for the prediction and analysis of human reliability as a part of system effectiveness. It is virtually impossible to test the human element in the laboratory under controlled environment and to use the results for predicting human performance under actual conditions. Consequently, data must be obtained from the field during the operational and maintenance phases of weapon systems. This need for field data poses a major problem in that data on human performance collected to date are of little consequence; more significantly, no vehicle exists for their collection.

3. As a result, the problem of the data gap must be overcome before new techniques for human reliability analysis can be developed. New methods for acquiring the necessary data will have to be investigated, and an extensive Navy-wide and preferably DOD-wide effort will have to

be initiated to establish a meaningful data base. The establishment of such a data base will require considerable time. There is a definite need to develop, at least on an interim basis, techniques for human reliability analysis that do not depend on direct human-performance data. Rather, these techniques must be designed so that by mathematical and/or statistical means human reliability can be inferred from existing equipment performance data.

BACKGROUND AND REQUIREMENT

4. The recognition of the need to develop new tools and techniques for human reliability analysis has become widespread throughout the Navy, as manifested by the issuance of SECNAVINST 3900.36 dated 27 January 1966. The purpose of this document is to "establish policy for the guidance of efforts to increase the reliability of naval material and to assign responsibility for its achievement." The Chief of Naval Personnel is assigned the responsibility to:

> "1. Coordinate with the Chief of Naval Material and the technical bureaus and offices to develop and implement reliability educational programs for military personnel assigned to technical, contracting and quality assurance billets and assigned to the supervision of these activities.
>
> 2. Develop techniques, methods, and knowledge in the field of human reliability.
>
> 3. Participate in the human factors analysis for reliability in each Navy system as appropriate."

5. In response to this directive, the New Developments Branch of the Personnel Research Division under the Chief of Naval Personnel initiated this research. The objectives of the ORI study were the following:

a. Creation of methodologies for using data presently available in existing Navy failure reporting systems for human reliability analysis.

b. Development of indirect approaches to human reliability that are not dependent on direct data on human performance but can be derived from equipment data.

c. Recommendations for further research efforts in the quantification of human performance and in human reliability analysis.

APPROACH

6. The initial efforts of the study were to establish the objectives for the work and to establish sound definitions of human reliability terminology which could serve as the framework for the remainder of the study. These definitions are:

a. Human Error - Any action of the human element of a system that is inconsistent with a predetermined behavioral pattern established in the system specifications and in the resulting system design.

b. System Failure - Any system performance that does not meet the requirements established by design specifications and documentation. Such failures fall into two categories: (a) total system failure, in which there is a complete breakdown in performance, and (b) system degradation failure, in which the system fails to perform at its specified level of performance over a period of time.

c. Human Reliability - Probability that human error will not cause a system failure or malfunction.

The scope of the research is limited to human reliability as related to the operational and maintenance phases of the weapon systems life cycle.

7. Navy failure reporting systems were systematically surveyed to determine the relevance of their data to human reliability analysis, to evaluate the accuracy of such data, and to ascertain other pertinent characteristics such as range of hardware covered and amount of data available. At the completion of each survey, the usefulness of the data for human reliability analysis was objectively evaluated. The following systems were surveyed:

a. Electronic Equipment Failure/Replacement Report (EFRR) System

b. Casualty Reporting System (CASREPT)

c. Fleet Ballistic Missile Weapon System - TFR Program

d. Surface Missile System and Air-Launch Missile System Performance and Failure Reporting

e. Air-Launch Guided Missile Systems Performance Data Reporting Program

f. Surface Missile System Equipment Status Log

g. Material Maintenance Management (3-M) System

h. Fleet ASW Data Analysis Program (FADAP)

8. The effort dealing with the indirect approaches consisted of the development of two mathematical techniques neither of which relies on the direct reporting of human-initiated failures and malfunctions.

9. The first approach is termed the Elementary Reliability Unit Parameter Technique (ERUPT). By grouping the components of a weapon system into Elementary Reliability Units, ERUs (the lowest levels at which maintenance is performed), this approach provides a means of inferring human performance parameters from available equipment reliability and maintenance data. In the preliminary stages of development during this study, ORI quantified two measures of human performance during maintenance as part of a model expressing weapon system readiness. These two parameters were:

a. The probability that a failure is detected and repaired during maintenance

b. The probability that maintenance does not induce failure.

The model consists essentially of equations and computational routines for deriving system measures of effectiveness from failure and maintenance parameters.

10. The second indirect approach uses multivariate correlation analysis techniques to relate certain personnel characteristics of individuals operating and maintaining the equipment to number of failures

and equipment repair times. Multivariate correlation analysis is a well known statistical technique used to measure the degree or the importance of the relationship between a dependent variable and a set of independent variables. Data obtained on two equipments from the 3-M system were used in conjunction with personnel characteristics of the crew associated with those equipments during selected time frames. Although the analysis was performed only on a pilot basis with a limited set of data, several significant relationships were determined.

FINDINGS, CONCLUSIONS, RECOMMENDATIONS

11. During the first phase of the study it was found that existing failure reporting systems do not yield meaningful data on human-initiated malfunctions. Most systems have no provisions for reporting information on human performance as related to failures. Many of the reporting systems surveyed were in various stages of being phased out of use. In most cases, a strong reluctance to report all failures, particularly human errors, was noted. What information was found to exist on human errors was very general and was not being used for human failure analysis. Indeed, meaningful analysis of the reported data did not appear feasible. Some provisions were being made, however, for inclusion of human-initiated failure data in the 3-M system. These data warrant further investigation for possible improvements that will make them useful in human reliability analysis.

12. During the later phases of the study the feasibility and applicability of two indirect approaches were determined, and mathematical models and equations were developed for their application. A pilot test on a limited data base was also conducted during the development of each technique. The results of the pilot tests revealed that both techniques are potentially extremely useful tools in human reliability analysis, and that they could lead to significant breakthroughs in the quantification of human performance.

Recommendations for Further Action

a. One of the major problems associated with failure reporting systems is their use as an information source for disciplinary or promotion-review purposes. It is recommended that BuPers initiate an educational program to clarify the basic purposes of these reporting systems.

b. Another problem associated with reporting systems is the design of the forms that are used to report failures. It is recommended that a study be conducted to design a failure reporting form which would assure, with some degree of confidence, the correct identification of the causes of failures.

c. Based on the feasibility of the two indirect approaches, proven in this study, it is recommended that they be further developed by extending their application to a larger data base and to other classes of equipment.

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Feedback from consumers is a vital element in improving products so that they better respond to specific needs. To assist the Chief of Naval Personnel in future planning, it is requested that the use and evaluation form on the reverse of this page be completed and returned. The page is preaddressed and franked; fold in thirds, seal with tape, and mail.

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I. INTRODUCTION AND BACKGROUND

GENERAL

1.1 This report represents the results of a research study on human reliability conducted by Operations Research Incorporated (ORI) under Contract Nonr 4451(00) for the New Developments Research Branch, Personnel Research Division, Bureau of Naval Personnel.

CONTRACT BACKGROUND

1.2 In recent years, the Navy has become more aware of the role of the human element in system effectiveness. Increasing emphasis has been placed on the personnel subsystem in new system development, and the need for new tools and techniques in human reliability analysis and prediction has become apparent. The recognition of this need is evidenced by SECNAVINST 3900.36, dated 27 January 1966.1/* The purpose of this document was to "establish policy for the guidance of efforts to increase the reliability of naval material and to assign responsibility for its achievement." It set forth the objective of achieving and maintaining "the highest level of reliability in naval material commensurate with economic, technological and logistics constraints in context with the operational requirements for the material."

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* Footnote numbers refer to correspondingly numbered items in Appendix F.

1.3 It also assigned to the Chief of Naval Personnel the responsibility to:

"1. Coordinate with the Chief of Naval Material and the technical bureaus and offices to develop and implement reliability educational programs for military personnel assigned to technical, contracting and quality assurance billets and assigned to the supervision of these activities.

2. Develop techniques, methods, and knowledge in the field of human reliability.

3. Participate in the human factors analysis for reliability in each Navy system as appropriate."

1.4 This research program was then initiated in response to SECNAVINST 3900.36 and was directed toward the following tasks:

a. Analyze existing failure reporting systems to determine the extent of the coverage and the availability of data on human-initiated malfunctions and failures.

b. Determine and delineate how available data from these systems, as they presently exist, can be used in support of the requirement for human reliability analysis.

c. Recommend and define further research to refine and improve the human reliability analysis function and the systems for collecting data on human-initiated malfunctions.

1.5 At the completion of the first task, it became apparent that the existing failure reporting systems did not yield data on human performance or, more directly, on human-initiated malfunctions. The conclusion led to further discussions with the scientific officer and resulted in the redirection of the contract effort. ORI proposed to explore approaches to human reliability which would not depend on human performance data from failure reporting systems as the sole or primary input. The contract was so redirected and the research effort was concentrated on the investigation and development of two "indirect" approaches to human reliability.

ROLE OF HUMAN RELIABILITY

1.6 Reliability has become a commonly used term in the design, development, production, and operation of weapon systems. It is generally accepted as one of the most significant contributors to system effectiveness and has become a fundamental characteristic of every component, module, subsystem, or total system. Until recently, the concept of reliability was considered only as it applied to hardware design and operation. However, technological advances and the complexities of modern weapon systems are imposing severe requirements on operating and maintenance personnel. As a result, the importance of the human element in the determination of total system reliability and, subsequently, total system effectiveness is beginning to be realized.

1.7 Over the past decade, the contribution of the personnel subsystem to system reliability and effectiveness and the degradation in system performance due to human error and human-initiated malfunctions have been subjects of numerous studies and research programs. The now-classic study in 1960 by Shapero, et al.[2] gave probably the first major impetus to these areas of investigation by showing that from 20 to 54 percent of all system malfunctions in nine missile systems under study were caused by human error and/or human-initiated malfunctions. Numerous subsequent studies by Meister,[3] Cooper,[4] Willis,[5] and others have substantiated the fact that a significant percentage of system unreliability was caused by human error.

1.8 Concurrent with the technological advancements, the techniques for conducting analysis of system reliability and effectiveness and the prediction of hardware reliability have also advanced considerably. With more extensive usage of the computer and automatic data processing (ADP), complex models are being applied through the use of volumes of data from laboratory and field operations. The degree of sophistication achieved in analytic techniques has created a science of systems analysis and replaced intuition with mathematical calculations.

1.9 The criticality of the human element in system effectiveness and the development of more sophisticated system analysis techniques places an added burden on human factors specialists as they try to assume their role and perform their functions in new weapon system development. In order to participate meaningfully in new system development and to influence equipment design, they must deal in terms that are commensurate with the tools and information available to systems and design engineers. The obvious conclusion is the often-stated requirements for the quantification of human performance.

1.10 Human factors or human engineering does not yet enjoy the widespread acceptance in system engineering circles that it deserves. In spite of the results of the previously cited studies, some people fail to recognize the criticality of the human element in system effectiveness. These same people will continually look for more advanced techniques in hardware design with a total disregard for the human component. Others, on the other hand, arbitrarily and indiscriminately blame most problems on lack of training or failure of supporting personnel to follow procedures. To convince systems systems analysts of the importance of the human element in systems analysis and to determine the contribution of the various characteristics of the personnel subsystem to human-initiated failures, there is a dire need for factual, quantified data on human performance.

1.11 It is to these problems that this research program on human reliability was directed. The heart of reliability analysis and prediction is the availability of extensive statistical or historical data derived from failure reporting of weapon system malfunctions while under test or during operation and maintenance. Through the analysis of failure reports, the malfunctions of a component, subsystem, or system can be pinpointed and causes determined. As it applies to equipment, this procedure has been initiated and has been in operation for some time in all branches of the Navy. Similarly, there is a definite need for reporting and analyzing human-initiated malfunctions and for determining their causes.

ORGANIZATION OF REPORT

1.12 Section II discusses the need for common terminology and definitions in the human reliability field. Some basic definitions which set the framework for this study and a detailed breakdown and identification of the various types of human error are also provided.

1.13 Section II also describes the broad scope of the human reliability study as it applies to the total life cycle of a system from its conception to its last day of operational usefulness. It addresses the problem of dealing with human reliability in such a broad context and calls for the limitation in scope to particular phases in the life cycle of weapon systems.

1.14 Section III relates the results of the first phase of the study which dealt with the investigation and analysis of existing failure reporting systems in relation to their treatment of human performance and human-initiated malfunctions. The section discusses the most significant problems associated with the reporting of failures caused by human errors and offers recommendations regarding basic improvements in failure reporting systems.

1.15 Section IV discusses the need for indirect approaches to human reliability which would not be dependent on the direct reporting of human-initiated malfunctions. Two approaches developed by ORI are described and the results of pilot applications of these techniques are provided.

1.16 Section V summarizes the study results and the conclusions derived from their analyses. A set of recommendations for specific actions to be instituted by the Navy and for future research studies is also provided.

1.17 Appendices A through D contain mathematical derivations, pilot test results, and computer programs for one of the two indirect approaches to human reliability. Appendix E describes the methodology used to evaluate hypotheses. Appendix F, the bibliography, lists (a) works referenced in the report and (b) works used for background information.

II. DEFINITION OF TERMS

INTRODUCTION

2.1 One of the prerequisites for conducting research in any discipline is a set of well-defined terms or parameters that are widely used by researchers in the field. For example, in the "hardware world" such terms as reliability, MTBF, performance measurement, etc., have been used for a number of years and have acquired universal meaning. One continuing problem that has plagued researchers in the field of human reliability is the lack of a well-established glossary of terms to provide a common base for study and analysis conducted in this field.

2.2 A report by the Department of Psychology of the University of Southern California[6] cites a good example of this lack of common terminology by quoting some definitions of maintainability from the EIA Task Group's Guide:

> "Maintainability is a quality of the combined features and characteristics of equipment design which permits or enhances the accomplishment of maintenance by personnel of average skills, under the natural and environmental conditions in which it will appear."
>
> "Maintainability is the assurance that specified maintenance procedures will be completed in a given environment within a satisfactory time."
>
> "Maintainability is the ease with which a device can be kept operating."

"Maintainability can . . . be defined. . . as the probability that the system can be returned to service in a given period of time. Maintainability as thus defined can be measured by the system mean-downtime."

"Maintainability is a measure of the speed and ease with which preventive maintenance can be performed or equipment malfunctions diagnosed and corrected."

2.3 On the other hand, the Reliability and Maintainability Training Handbook prepared by General Dynamics Astronautics 7/ offers the following definition:

"Maintainability is the speed or economy with which a system or component can be kept in, and/or restored to, full performance capability. A principally-used measure is the average number of failures restored per hour of Corrective Maintenance time which is the reciprocal of MTTR. Another is the fraction of attempts wherein restoration is completed in a specified time, or the probability that it will be completed in that time. Another is the functional time obtained per dollar cost of preventive and corrective maintenance."

2.4 Human reliability in itself has not been defined adequately, and researchers have attached different meanings to the whole concept. Meister, 3/ as an example, defines human reliability as "the probability that a job operation will be successfully performed by personnel at any required stage in system operation within a criterion time period."

2.5 Rabideau offers the following definition: "Personnel Subsystem reliability is a function of the frequency of occurrence of human error in the execution of required system functions, insofar as such error affects the system's outputs and component conditions." 8/

2.6 Captain Majesty of the Air Force Ballistic Systems Division attempted to express human reliability in terms of a figure of merit and "consequently, human reliability can be compared to hardware reliability . . . . Human performance, like hardware performance, must satisfy the performance requirements of the system." 9/

2.7 Similarly, most terms used in the field of human reliability or the quantification of human performance lack common definition.

DEFINITIONS

2.8 To provide a framework for this study and to attempt to reduce some of this confusion, the following three terms are defined as they are used in this report:

a. Human error. Any action of the human element of a system that is inconsistent with a predetermined behaviorial pattern established in the system specifications and in the resulting system design.

b. System failure or malfunction. Any system performance that does not meet the requirements established by design specifications and documentation. This definition further breaks down into two types of failures: total system failure, in which there is a complete breakdown in performance, and system degradation failure, in which the system fails to perform up to a specified level of performance over a period of time.

c. Human reliability. Probability that human error will not cause a system failure or malfunction.

Types of Human Error

2.9 Note that human errors that do not result in system failure are excluded from human reliability considerations in this report. As discussed by Meister in 1964, [10] only errors that affect the system performance have any meaning to the system analyst. As an example, the failure to perform an act which is discovered in time and is subsequently performed would be considered a human error, as previously defined; but, since it has no bearing on system performance, it would not be considered in any human reliability analyses. Further, because of the limitations imposed by data retrieval, discussed later in this report, obtaining information on this type of human error on a continuous basis is nearly impossible.

2.10 The lack of commonality in the attempt to classify the types of human error is also evident in the works of researchers in this field. The following are examples of some of these classifications.

> "Terminal error - all deviations from procedures which always result in failure of the operation.
> Risk error - omission of prescribed precautionary measures.
> Residual error - all other deviations from procedure." [11]

> "Design error - failures resulting from inadequate design.
> Fabrication error - failures resulting from poor workmanship in the factory.

"Operating error - failure resulting from personnel operating the equipment incorrectly in the field. There are several subcategories:

1. failure to follow procedures
2. use of incorrect procedures or lack of correct procedures
3. use of improper tools or lack of correct tools
4. motivational error

"Maintenance error — failure resulting from incorrect installation or repair of equipment in the field.

1. repair error
2. installation error
3. calibration error

"Contributory error — failure resulting partially from mechanical-electrical-electronic factors and partially from human error." [3]

"Performance of a required action incorrectly.
Failure to perform the required action.
Performance of a required action out of sequence.
Performance of a non-required action." [12]

"Errors of omission

1. errors of memory
2. errors of attention

"Errors of commission

1. errors of identification
2. errors of interpretation
3. errors of operation." [13]

2.11 In this report, the types of human error are broken down into two major categories, predictable human errors and random human errors.

2.12 Predictable human error refers to those occasions in which a causal relationship can be established between the inconsistent behavior (with respect to system specifications) and some external influence. There is a high degree of probability associated with the recurrence of these errors under identical or even similar circumstances. The number of this type of error can be reduced by modifying the external influences through the redesign of either the hardware or personnel subsystems or by the change of system specifications.

2.13 With respect to random human errors, it is recognized that the human element represents the most unpredictable and complex component of any system, since its psychophysical makeup creates a tendency toward random, nonpredictable behavioral patterns. Some of this irregular behavior cannot be attributed to any particular cause, and other causes, even though identifiable, will not logically be considered as criteria for a design change. Further, there is a very low degree of probability that under similar or even identical circumstances such errors will recur. This category of errors is termed random error.

2.14 Figure 1 illustrates a representative breakdown of various types of human errors which may be structured in the form of a failure or error analysis tree. The cause for any system or subsystem failure is first categorized as either an equipment-initiated malfunction or a human-initiated malfunction. If the human element is assumed to be the causal agent, the human error or failure can be further reduced to the two elements of predictable and random human errors. If it is deemed that the failure was caused by a random error, a component of human reliability has been identified and the analysis is therefore completed.

2.15 The design element of predictable error can be further broken down into equipment design and procedural problems. Equipment design includes what is normally considered a human engineering problem, in which the hardware design has an apparent deficiency from a human factors standpoint. This type of error should be reverted back to equipment failure and be included in equipment reliability considerations. Thus, it is either corrected by equipment redesign or, because of cost or other considerations, retained as a inherent reliability characteristic and figured into subsequent MTBF considerations.

2.16 Under procedural problems, two subcategories can be considered, those that involve equipment (tool) availability and those that involve the availability of proper procedures, which, in the negative sense, could mean the complete lack of tools or procedures or the availability of improper ones. Here again the analysis is completed since, essentially, the human element has been taken out of the causal relationship and the problem is reverted to a system redesign in the procedural or support equipment area.

2.17 It is pointed out that these types of errors do not include the selection of improper equipment (tools) or the selection of improper procedures, since both cases can be considered as either random error or a personnel characteristic that is an element of predictable error, as defined in the ensuing paragraph.

2.18 The personnel characteristics aspect of predictable human errors entails all those errors in the latter category that are directly attributable

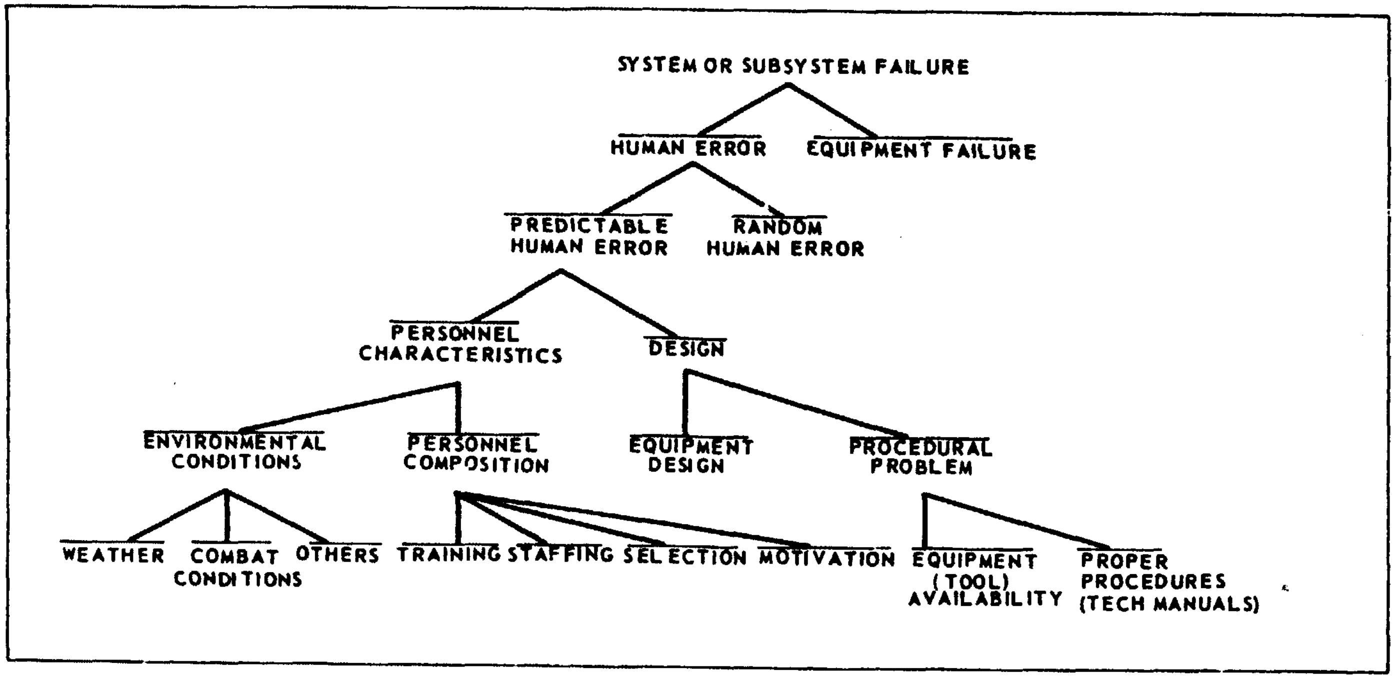


FIGURE 1. FAILURE ANALYSIS TREE

to the operator or to the composition of the personnel subsystem. Even in this category, a further breakdown yields a component that results from influences external to the personnel subsystem. This subcategory is termed "environmental conditions" and covers those human errors that are caused by external factors such as weather conditions, combat conditions, or sea states.

2.19 The number of occurrences of such errors can be reduced by a system redesign in which such things as relocation of certain equipment within the overall system configuration are considered, or by a specification change where, for example, using the system under certain conditions is deemed unfeasible.

2.20 The remaining component of personnel characteristics is identified as personnel composition. Here, we finally arrive at that aspect of predictable human error which is directly attributable to the human element and results from such contributing factors as training, staffing, selection, and motivation.

2.21 A detailed discussion of motivational errors in psychological terms is outside the scope of this report except for the random vs predictable error classifications that can also be applied to this area. There are "interpersonnel" motivational errors which result from insufficiency or lack of motivation of an entire group, and they should be the subject of system redesign consideration. "Intrapersonnel" motivational errors involve the psychological problems of individuals owing to special circumstances and, as such, are considered random errors and would not be considered in system design. The other three components of personnel composition meed no further elaboration.

2.22 It is significant to note that the last four factors (traditional elements of manpower management) represent only one of the final links in this analysis tree, even after a human error has been established as the cause for system failure or malfunction. Yet, when conducting interviews in the field, there is a tendency to attribute all breakdowns in the personnel subsystem to this one component and to the training factor in particular. However, until we can quantify human performance and determine the relative magnitudes of the various components at different levels of the analysis tree, it is difficult to disprove this misconception. If human reliability analysis techniques are going to be developed in a quantifiable form commensurate with system reliability techniques, data will have to be made available to support analysis as outlined in the foregoing discussion.

LIMITATIONS IN SCOPE

2.23 The concepts of human performance and human reliability have an application in all stages of the life cycle of a system, from its very beginning in the conceptual phase to the last day of its operational usefulness. Further, all system failures and malfunctions (except certain laboratory tests) can eventually be traced back to some form of human error, whether it occurred on the drawing board, in fabrication, in testing, in operation, or in maintenance. Along with a lack of definitions and uniform terminology, the consideration of the term "human reliability" in such a broad context is one of the factors most detrimental to performing research in this field. By attempts to analyze human reliability during the total life cycle of the system, all efforts are diffused to the point that it is extremely difficult, if not impossible, to achieve a significant breakthrough. It therefore becomes imperative to limit the scope of our research to certain specific phases of the system's life cycle.

2.24 It is considered that human reliability during design and production phases are subjects of a separate area of analysis. In no way does this distinction minimize the criticality of human error in these two phases, and there is a definite need for additional research in those areas. They are not, however, a part of human reliability as defined in this report. Rather, they are a part of equipment reliability that is inherent to the system when it is assimilated into the Navy inventory at the beginning of its operational phase. By definition, then, this report deals with human reliability during the operational phase (which includes operation and maintenance) of the system life cycle.

2.25 Failure reporting systems were scrutinized for data in both operation and maintenance areas of the system life cycle. Emphasis was placed on the maintenance area in the indirect approaches because maintenance "success" seems to depend more on the human element than on the operational environment. Also maintenance criteria were more easily quantifiable.

III. HUMAN-INITIATED MALFUNCTION DATA

GENERAL

3.1 Considerable effort has been expended by researchers in an attempt to quantify human performance. Numerous models and equations have been developed and many of them appear to be quite useful tools for predicting and/or measuring human reliability. Most researchers agree, however, that none of these models can be applied with any predictable degree of success until they can be validated through actual data obtained from the field.

3.2 Here, again, equipment reliability prediction and analysis have a significant jump on similar efforts in human reliability. As Meister[10,12] points out, the prediction of equipment reliability is based on historical record or performance data and the logic of assumed similarity between equipments. Throughout the years, a wealth of data has been collected on equipment performance which now forms the basis for reliability analyses. Of course, collecting data on equipment performance is considerably simpler than obtaining data on human performance. One can test equipment under controlled and simulated conditions in the laboratory with reasonable assurance that the same equipment will perform in the same manner under similar conditions in the field. Unfortunately, the human element is far more complex. One cannot test an individual in the laboratory and then predict with any degree of assurance that he will perform in the same manner under actual field conditions. There are so many variables that can and do affect human behavior and, in turn, performance, that it is virtually impossible to duplicate or simulate them under a controlled test environment. And, even if it were possible to test an individual in the laboratory and then predict his behavior in the field, there is little assurance that another individual would behave in a similar manner.

3.3 These problems do not indicate, as is sometimes felt, that it is useless to try to obtain data; rather, they point to the fact that we need even more data to overcome the problems to perform human reliability analyses than we need to perform equipment reliability analyses.

HUMAN-INITIATED MALFUNCTION REPORTING

3.4 At the onset of this research study, the decision was made that, rather than try to develop a new model for predicting human reliability, an investigation should be made as to what data are presently available in the Navy that can be used for human reliability analysis. To accomplish this investigation, an intensive review was conducted of the failure reporting systems presently used by the Navy. The investigation revealed that these systems are almost completely void of any information dealing with the human element. The first and most obvious item looked for was some direct means of distinguishing between equipment failures and human-initiated malfunctions. None of the systems directly yields data that will permit this type of distinction. In some cases, the list of codes used to identify the type and/or cause of failure does not even include any data that could be associated with the human element.

3.5 The following paragraphs describe the various systems investigated during this study. Copies of forms and printouts used by these systems were obtained and numerous individuals were interviewed who are presently or were then actively associated with these systems.

Electronic Equipment Failure/Replacement Report (EFRR) System

3.6 This reporting system was initiated in May 1961 by the Bureau of Ships [presently Naval Ships System Command (NAVSHIPSYSCOM)]. The system requires that a report be completed (BuShips 10550-1) for every repair action that involves the failure and/or replacement of electronic, electrical, or mechanical parts, units, or assemblies in equipments specified in the Electronic Information Bulletin (NAVSHIPS 900.002A). This requirement applies to all facilities using or repairing NAVSHIPSYSCOM electronic equipment.

3.7 With the advent of the Material and Maintenance Management (3-M) system, the EFRR has been completely phased out as it applies to operation and maintenance aboard ships. The EFRR system is still operational in shore facilities, and there is no evidence of any official document authorizing or directing the complete phase-out of the system.

3.8 The Electronics Maintenance Engineering Center (EMEC) is responsible for the operation of the system. Data gathered through

EFRR are available at this facility. Under the new organization, EMEC is presently identified as Norfolk Division, Naval Ship Engineering Center (NORDIV, NAVSEC). A computer program is presently being developed by this agency which will accept both EFRR and 3-M data to provide continuity in existing reports and ongoing analyses.

3.9 The report completed by the technician or engineer making the replacement or discovering the failure is forwarded to Code 679C, BuShips (now NAVSHIPS). Prior to 1965, analysis of the data was performed by private contractors and the results and forms were sent to EMEC, Norfolk. Since 1965, EMEC has been performing all analyses and data processing of the information made available by the system.

3.10 Figure 2 is a copy of the report form used by the system. The form does not identify the individual who operates or maintains the equipment, but rather, the individual who discovers the failure. The two may or may not be the same person (Item 2). Items 4 and 5 can yield information from which equipment down-time can be calculated. Items 18 and 20 provide type-of-failure and cause-of-failure codes, respectively. Tables 1 and 2 set forth the codes used in these two categories. No codes in either category are applicable to human-initiated malfunctions. A further problem associated with the system is that reports are often not completed for failures which did not require replacement of parts and were repaired immediately.

Casualty Reporting System (CASREPT)

3.11 Authority and details of CASREPT are found in "Operations Report" (NWIP 10-1 (A) Article 510, classified CONFIDENTIAL and NAVMATINST 4000.23, dated 25 Aug 66).

3.12 A casualty is defined as an impairment of any resource, including personnel, which does not permit full combat readiness of the naval element. Inputs to CASREPT of completed questionnaires are received in NAVSUPSYS-COMHQ. The items answered on these questionnaires for each casualty are shown in Table 3.

3.13 All naval elements, such as ships and shore stations, are responsible for reporting casualties that occur. The purpose of CASREPT is to keep CNO informed on the current combat readiness of all naval elements. The codes used to identify combat readiness are shown in Table 4. This system has been modified to coordinate it with the 3-M system.

3.14 The most relevant input item to the CASREPT report is the cause of the casualty. Code 0411 assigns one of the following base cause codes to the reason supplied by the Commander in charge of the naval element:

a. Material failure

b. Design failure

ELECTRONIC EQUIPMENT FAILURE/REPLACEMENT REPORT DD-787 (PROPOSED) — **REPORT BUSHIPS 10550-1**

1. DESIGNATION OF SHIP OR STATION			3. TYPE OF REPORT (CHECK ONE)	4. TIME FAIL. OCCURRED OR MAINT. BEGAN			
			1. ☐ OPERATIONAL FAILURE; 2. ☐ PREVENTIVE MAINTENANCE (POMSEE); 3. ☐ PREVENTIVE MAINTENANCE (NOT POMSEE); 4. ☐ STOCK DEFECTIVE; 5. ☐ REPAIR OF REPLACEABLE UNIT OR PLUG-IN ASSEMBLY; 6. ☐ OTHER	MONTH	DAY	YEAR	TIME
2. REPAIRED OR REPORTED BY				5. TIME FAIL. CLEARED OR MAINT. COMPL.			
NAME	RATE	AFFILIATION: 1. ☐ U.S. NAVY 2. ☐ CONTRACTOR 3. ☐ CIVIL SERVICE		MONTH	DAY	YEAR	TIME

EQUIPMENT

6. MODEL TYPE DESIGNATION		9. FIRST INDICATION OF TROUBLE (CHECK ONE)	10. OPERATIONAL CONDITION (CHECK ONE)	11. TIME METER READING		
		1. ☐ INOPERATIVE; 2. ☐ OUT OF TOLERANCE, LOW; 3. ☐ OUT OF TOLERANCE, HIGH; 4. ☐ INTERMITTENT OPERATION; 5. ☐ UNSTABLE OPERATION; 6. ☐ NOISE OR VIBRATION; 7. ☐ OVERHEATING; 8. ☐ VISUAL DEFECT; 9. ☐ OTHER, EXPLAIN	1. ☐ OUT OF SERVICE; 2. ☐ OPERATING AT REDUCED CAPABILITY; 3. ☐ UNAFFECTED	A. HIGH VOLTAGE		
7. EQUIP. SERIAL NO.	8. CONTRACTOR (NAVY CODE OR COMPLETE NAME)			B. FILAMENT /ELAPSED		
				12. REPAIR TIME	MAN-HOURS	TENTHS

REPLACEMENT DATA

13. LOWEST DESIGNATED UNIT (U) OR SUB-ASSEMBLY (SA)	14. LOWEST DES. U/SA SERIAL NO.	15. REFERENCE DESIGNATION (V-101, C-14, R11, ETC.)	16. FEDERAL STOCK NUMBER	17. MFR. OF REMOVED ITEM	18. TYPE OF FAILURE	19. PRIMARY OR SECOND-ARY FAIL ?	20. CAUSE OF FAILURE	21. DISPOSITION OF REMOVED ITEM	22. REPL. AVAILABLE LOCALLY ?
						P ☐ S ☐			Y ☐ N ☐
						P ☐ S ☐			Y ☐ N ☐
						P ☐ S ☐			Y ☐ N ☐
						P ☐ S ☐			Y ☐ N ☐
						P ☐ S ☐			Y ☐ N ☐

23. REPAIR TIME FACTORS								24. REMARKS
CODE	DAYS	HOURS	TENTHS	CODE	DAYS	HOURS	TENTHS	(CONTINUE ON REVERSE SIDE IF NECESSARY)

FIGURE 2. ELECTRONIC EQUIPMENT FAILURE/REPLACEMENT REPORT

TABLE 1

TYPE-OF-FAILURE CODES

BLOCK 18 - TYPE OF FAILURE
QUICK REFERENCE LISTING OF MOST OFTEN USED FAILURE CODES
(IF PROPER CODE CANNOT BE FOUND, REFER TO ALPHABETICAL LISTING BELOW)

ELECTRON TUBES

CODE	TYPE OF FAILURE
002	AIR LEAK
007	ARCING, ARCED
960	BROKEN ENVELOPE
001	GASSY
380	LEAKAGE
004	LOW GM OR EMISSION
131	MARGINAL PART REPLACEMENT
009	MICROPHONIC
053	MISFIRES (THYRATRONS)
008	NOISY
003	OPEN FILAMENT
560	POOR REGULATION
011	SCREEN DEFECTS (CATHODE RAY)
005	SHORTED, INTERMITTENT
306	SHORTED, PERMANENT
018	TESTED OK, DID NOT WORK

TRANSISTORS AND SEMICONDUCTOR DIODES

CODE	TYPE OF FAILURE
741	ALPHA CUT-OFF LOW
744	BACK RESISTANCE LOW
739	BETA LOW
743	FALL TIME, EXCESSIVE
745	FORWARD RESISTANCE HIGH
742	Ico HIGH
737	OPEN, BASE-TO-COLLECTOR
735	OPEN, BASE-TO-EMITTER
156	POOR RECOVERY TIME
734	RISE TIME, EXCESSIVE
740	SATURATION RESISTANCE HIGH
738	SHORTED, BASE-TO-COLLECTOR
736	SHORTED, BASE-TO-EMITTER
731	SHORTED, COLLECTOR-TO-EMITTER
749	STORAGE TIME, EXCESSIVE

PLUG-IN ASSEMBLIES

CODE	TYPE OF FAILURE
035	DRIFTS
088	GAIN, LOW
094	GAIN, NONE
360	INTERMITTENT OPERATION
387	LOW PERFORMANCE
089	MODULATION, LOW
096	MODULATION, NONE
022	NO OSCILLATION
462	OUTPUT, LOW
255	OUTPUT, NONE
258	OVERHEATS
560	POOR REGULATION
097	RESPONSE, POOR
091	SENSITIVITY, LOW
480	UNSTABLE

OTHER COMMON TYPE OF FAILURE CODES — ELECTRICAL, ELECTRONIC

CODE	TYPE OF FAILURE
007	ARCING, ARCED
080	BURNED OUT
130	CHANGE OF VALUE
320	HIGH VOLTAGE BREAKDOWN
350	INSULATION BREAKDOWN
380	LEAKAGE
008	NOISY
450	OPEN
082	OPEN, INTERMITTENT
460	OPEN PRIMARY
451	OPEN ROTOR
470	OPEN SECONDARY
452	OPEN STATOR
453	OPEN WINDING
520	PITTED
005	SHORTED INTERMITTENT
006	SHORTED PERMANENT
620	SHORTED PRIMARY
612	SHORTED ROTOR
630	SHORTED SECONDARY
612	SHORTED STATOR

OTHER COMMON TYPE OF FAILURE CODES — ELECTRO-MECHANICAL, MECHANICAL, CHEMICAL

CODE	TYPE OF FAILURE
710	BEARING FAILURE
780	BENT
040	BINDING, MECHANICAL
070	BROKEN
090	BRUSHES, IMPROPER TENSION
720	BRUSH FAILURE
150	CHATTERING
160	CONTACTS, CONNECTION DEFECTIVE
170	CORRODED
210	DETENT ACTION POOR
226	EXCESSIVE PLAY
567	HIGH CONTACT RESISTANCE
730	LOOSE
790	OUT OF ADJUSTMENT
570	RUSTY
770	SLIP RING OR COMMUTATOR FAILURE
164	SPEED INCORRECT
650	STICKY
945	STRUCTURAL FAILURE
020	WORN EXCESSIVELY

ALPHABETICAL LISTING

CODE	TYPE OF FAILURE
002	AIR LEAK
741	ALPHA CUT-OFF LOW
007	ARCING, ARCED
744	BACK RESISTANCE LOW
710	BEARING FAILURE
780	BENT
739	BETA LOW
060	BRITTLE
070	BROKEN
014	BROKEN BASE
960	BROKEN ENVELOPE
015	BROKEN GLASS
720	BRUSH FAILURE
090	BRUSHES, IMPROPER TENSION
080	BURNED OUT
120	CHAFED
130	CHANGE OF VALUE
140	CHARRED
150	CHATTERING
910	CHIPPED
180	CLOGGED
160	CONTACTS, CONNECTION DEFECTIVE
170	CORRODED
190	CRACKED
200	DENTED
210	DETENT ACTION POOR
230	DIRTY
035	DRIFTS
226	EXCESSIVE PLAY
743	FALL TIME, EXCESSIVE
240	FLAKING
745	FORWARD RESISTANCE HIGH
250	FRAYED
270	FROZEN
[illegible]	FUNGUS EFFECT
088	GAIN, LOW
094	GAIN, NONE
001	GASSY
290	GROOVED
300	GROUNDED
567	HIGH CONTACT RESISTANCE
320	HIGH VOLTAGE BREAKDOWN
742	Ico HIGH
340	INSTALLED IMPROPERLY
350	INSULATION BREAKDOWN
360	INTERMITTENT OPERATION
370	JAMMED
380	LEAKAGE
730	LOOSE
013	LOOSE BASE
012	LOOSE ELEMENTS
400	LOSS OF RESIDUAL MAGNETISM
004	LOW GM OR EMISSION
387	LOW PERFORMANCE
225	MANUFACTURER'S DEFECT (EXPLAIN)
131	MARGINAL PART REPLACEMENT
040	MECHANICAL BINDING
009	MICROPHONIC
053	MISFIRES (THYRATRONS)
750	MISSING
089	MODULATION, LOW
096	MODULATION, NONE
008	NOISY
022	NO OSCILLATION
920	NOT DETERMINED
737	OPEN, BASE-TO-COLLECTOR
725	OPEN, BASE-TO-EMITTER
450	OPEN, PERMANENT
003	OPEN FILAMENT
082	OPEN, INTERMITTENT
460	OPEN PRIMARY
451	OPEN ROTOR
470	OPEN SECONDARY
452	OPEN STATOR
453	OPEN WINDING
099	OTHER, EXPLAIN
161	OUTPUT INCORRECT
462	OUTPUT, LOW
255	OUTPUT, NONE
790	OUT OF ADJUSTMENT
295	OVERHEATS
928	PEELING
927	PINCHED
520	PITTED
010	POOR FOCUS
156	POOR RECOVERY TIME
560	POOR REGULATION
964	POOR SPECTRUM (MAGNETRON)
540	PUNCTURED
097	RESPONSE, NONE
734	RISE TIME, EXCESSIVE
570	RUSTY
740	SATURATION RESISTANCE HIGH
935	SCORED
011	SCREEN DEFECTS (CATHODE RAY)
091	SENSITIVITY, LOW
738	SHORTED, BASE-TO-COLLECTOR
736	SHORTED, BASE-TO-EMITTER
731	SHORTED, COLLECTOR-TO-EMITTER
005	SHORTED, INTERMITTENT
006	SHORTED, PERMANENT
620	SHORTED PRIMARY
612	SHORTED ROTOR
630	SHORTED SECONDARY
613	SHORTED STATOR
600	SHORTED TO CASE
610	SHORTED TO FRAME
615	SHORTED TO GROUND
640	SLIPPAGE
770	SLIP RING OR COMMUTATOR FAILURE
026	SOLDER JOINT DEFECTIVE
164	SPEED INCORRECT
650	STICKY
749	STORAGE TIME, EXCESSIVE
660	STRIPPED
945	STRUCTURAL FAILURE
018	TESTED OK, DID NOT WORK
947	TORN
965	TUNING DRIVE DEFECTIVE
670	UNBALANCED
480	UNSTABLE
690	VIBRATION EXCESSIVE
700	WEAK ELECTRICALLY
966	WINDOW SUCK-IN (MAGNETRON)
020	WORN EXCESSIVELY

TABLE 2

CAUSE-OF-FAILURE CODES

Code	Cause
1	Prime power surge
2	Handling damage
3	Shipping damage
4	Shock or vibration
5	Extreme cold ambient temperature
6	Extreme hot ambient temperature
7	Result of other part failure
8	Deterioration in use
9	Deterioration
0	Other, explain under "remarks"

TABLE 3

CASREPT CONTENTS

(Source: NWIP 10-1(A), Section 510)

ALFA:	Identification of major system, subsystem or equipment involved
BRAVO:	Readiness Code: Combat Ready, C-2 Combat Ready, C-3 (Marginal) Not Combat Ready, C-4
CHARLIE:	Estimated time for repairs
DELTA:	Extent of material damage/personnel injury
ECHO:	Cause, if known
FOXTROT:	If Equipment Failure: a. Identify failed item b. Whether item is on board c. Whether item is on allowance list
GOLF:	Other information of value, as appropriate (recently overhauled, requisitioning data, etc.)
HOTEL:	Ship's present position
DISTRIBUTION Action:	Senior Operational Commander Immediate Operational Commander COG Type Commander
Information:	CNO CNM COG Flt Cinc COG Bureau FOCCLANT or FOCCPAC SP (Polaris) Sub Safety Ctr (Subs) EMC NBTL Repair Activities

TABLE 4

COMBAT READINESS CODES (Material Condition)

(Source: OPNAV Inst 4700.19A)

<u>C-1 FULLY COMBAT READY</u>

Units are available to operating forces and have no equipment deficiencies restricting ability to execute assigned combat missions.

<u>C-2 COMBAT READY</u>

Units are available to operating forces and have only minor equipment/supply deficiencies that do not severely limit their capability to execute assigned combat missions.

<u>C-3 MARGINALLY COMBAT READY</u>

Units are available to the operating forces, but their capability of executing assigned combat missions is severely limited by equipment/supply deficiencies.

<u>C-4 NOT COMBAT READY</u>

Units that are available to the operating forces are unable to execute any portion of their assigned combat missions because of equipment/supply deficiencies.

c. Personnel error

d. Storm

e. Collision

f. Grounding

g. Fire

h. Explosion

i. Unknown

3.15 Outputs may be summarized by any of these base codes or by categories of the other input items. Discussions with personnel associated with the system revealed that the percentage of times Item c is indicated as the base cause varies from 1 to 10 percent of all codes used depending on the equipment in question. In all cases, the percentage is low and is not believed to reflect actual conditions.

3.16 Casualties are reported to Code 0411 when they are considered "significant" by the Commander in charge. Thus, because of the strong naval tradition to accomplish the job regardless of adversities, it is questionable whether all significant casualties are promptly reported to Code 0411. Commanders in charge realize that an abnormally high number of reported casualties may affect promotions.

Fleet Ballistic Missile (FBM) Weapon System - Trouble and Failure Report (TFR) Program*

3.17 The FBM Weapon System TFR Program has been established to communicate troubles and failures and associated corrective actions among FBM activities under the cognizance of the Special Projects Office (SPO). The system is also used by FBM Weapon System contractors as a basis for corrective action in manufacturing processes and quality control, for system modifications and redesign, and for correcting document errors.

3.18 The TFR Program consists of four major elements:

a. Reporting of FBM troubles and failures

b. Reporting of operating time on FBM equipment

c. Analysis, evaluation, and corrective action

d. Information feedback and Fleet liaison.

---

* Most of the information presented here regarding the TFR Program was taken from SP Instruction 3100.1B.[14]

The vehicle for reporting troubles and failures is SP Form 3100.1A (TFR), shown as Figure 3.

3.19 The Fleet Missile System Analysis and Evaluation Group (FMSAEG), under the direction of SPO, is responsible for the administration of the FBM Weapon System TFR Program and the performance of certain operations within the program. FMSAEG maintains and operates a center for receiving all TFRs, Elapsed Time Meter Records (ETMRs), and other records completed by all participating activities and, in turn, provides copies of these records to appropriate activities. This group continuously analyzes all data resulting from TFRs to identify problem areas, failure trends, or system quality or reliability degradation. The group also initiates TFR Corrective Action Reports (CARs), shown in Figure 4, as appropriate. FMSAEG maintains a computer file of TFR data generated which provides a central data bank of historical failure information.

3.20 The TEMRs have been developed for the reporting of operating times on FBM equipments so that the malfunctions which have been separately reported on TFRs can be correlated with the operating time of the pertinent equipment. A copy of the ETMR is presented as Figure 5.

3.21 Corrective action reporting in the TFR Program is one of the most significant features of the system because it provides a closed loop for the disposition of system failures and malfunctions. All contractors in the FBM Program participate in the TFR/CAR system. This system provides strong assurance that the malfunctions will be well defined and that the cause of the failure will be determined, thus initiating proper corrective action. FMSAEG prepares and distributes monthly TFR Summary Reports, the basic purpose of which is to provide timely feedback of corrective action information to program participants. Figure 6 is a flow chart which portrays the action and the information flow of the TFR Program.

3.22 The analysis and/or editing of TFRs is accomplished with the TFR Worksheet (Figure 7). This worksheet is designed to permit the transcription of the information contained on the TFR to a format that enables the key-punching of the desired information onto cards and transfer to tape. Information storage, processing, and retrieval is accomplished through a computer program called Variable Information Processing. Detailed instructions for completing the worksheet provide lists of words and phrases of common terminology to be used when completing Blocks 26 through 30. Two of these lists, "Types of Trouble or Failure" and "Description of Trouble or Failure," which are of significance in the content of this report are shown in Tables 5 and 6, respectively.

3.23 As evidenced by the foregoing discussion, the TFR program is primarily geared to equipment and total system considerations. Little or no provision is made for dealing with the human element. Admittedly, the description of the type and cause of a failure is accomplished through

FLEET ACTIVITY CHECK HERE IF CORRECTIVE ACTION INFO DESIRED ☑

SIGNATURE OF DEPARTMENT HEAD

FLEET BALLISTIC MISSILE WEAPON SYSTEM
TROUBLE AND FAILURE REPORT

SP Form 3100 1A

TFR NO 552900

1. PREPARING ACTIVITY: 512-3

2. DATE TROUBLE OR FAILURE DETECTED: DAY 09 MONTH AUG YEAR 1965

3. ORIGINAL TFR NO. OF ITEM REC'D — FOR USE BY REPAIR ACTIVITY: —

IDENTIFY TROUBLE OR FAILURE ITEM

4. BY SUBSYSTEM (USE SYMBOL SHEET)	NAV	MK MOD (IF APPLICABLE) —	SERIAL NO. (FOR OU MI TI) —
5. BY EQUIPMENT (USE SYMBOL SHEET)	WPN-3A		SERIAL NO. A8
6. BY COMPONENT (USE SYMBOL SHEET)	RC		SERIAL NO. A8
7. AND BY OTHER (SEE INSTRUCTION ON BACK)	2A10		SERIAL NO. 327

8. MFGR. PART/DWG. NO OF THE LOWEST LEVEL IDENTIFIED IN BLOCK 5, 6 OR 7: DWG NO 1506217 REV —

AND INDICATE WHETHER: ☐ REPAIRED ☐ ADJUSTED ☒ REPLACED BY NEW ITEM

9. IF NEW ITEM WAS INSTALLED GIVE FSN AND SERIAL NUMBER: FEDERAL STOCK NUMBER 6110-663-1041 SERIAL NO 562

10. REPAIR TIME (SEE DEFINITION ON BACK): 19.4 HOURS

11. WAS REFERENCE MATERIAL ADEQUATE? ☐ YES ☒ NO — If no, locate and explain here or separately in TFR Number → 552802

12. TROUBLE OR FAILURE DESCRIPTION: (Use following categories as guides)
(a) INDICATION OF TROUBLE/FAILURE (b) DESCRIPTION OF TROUBLE/FAILURE (c) PROBABLE CAUSE
(d) ACTION TAKEN & DISPOSITION OF FAILED ITEM (e) RECOMMENDATIONS

a. SMOKE WAS COMING FROM WPN-3A.

b. SERVICE TRANSFORMER HAD BURNED UP.

c. THERE WAS A BARE [illegible] VAC LEAD IN THE CABLE HARNESS CAUSING A SHORT CIRCUIT.

d. REPLACED TRANSFORMER. RETURNED OLD ONE TO SUPPLY FOR REPAIR. INSULATED BARE LEAD IN CABLE HARNESS

e. THE 70 VAC SERVOLINE IS NOT FUSED AND SHOULD BE. THE 70 VAC SERVOLINE SUPPLIES EITHER EXCITATION OR OPERATING VOLTAGE TO THREE MOTORS. IF ANY OF THESE MOTORS SHORT CIRCUIT, EITHER THE MOTOR OR THE TRANSFORMER WOULD BURN UP, SINCE THE LINE IS UNPROTECTED. IN THIS CASE THE TRANSFORMER BURNED UP. RECOMMEND FUSING THE CIRCUIT.

THIS COPY FOR: FMSAEG, CORONA, CALIFORNIA (TFR), 91720

FIGURE 3. FBM WEAPON SYSTEM TFR

SP FORM 3100/1C (Rev. 1-64) Previous editions obsolete. TFR/CAR NO. 12124

FLEET BALLISTIC MISSILE WEAPON SYSTEM TFR/CORRECTIVE ACTION REPORT

1. PREPARING ACTIVITY	2. DATE TFR/CAR ORIGINATED	3. SUBSYSTEM
SPERRY POLARIS Q.A.	31 August 1965	NAVIGATION
4. EQUIPMENT	**5. COMPONENT**	**6. OTHER**
AN/WPN-3A	RC	2A10
7. FAILED ITEM (3,4,5,6)	**8. APPLICABLE TFR NUMBERS**	
P/N 1506217	552900	

9. AMPLIFYING INFORMATION

SSB(N) 512 recommends fusing the 80 VAC servo line to prevent the burning up of either the motor or the transformer.

10. INVESTIGATION ASSIGNMENT

H. R. Smith

11. INVESTIGATION, ANALYSIS AND RECOMMENDED ACTION

A review of the circuitry reveals that a single fuse is used to protect the reported transformer and two others. The common fuse is in the primary. It is possible for a single transformer to be overloaded without blowing the fuse, if the other transformers are simultaneously operating without overload.

The addition of fuses would be difficult and expensive, since the location of the transformer assembly and the wiring to other modules using 2A10 as voltage sources does not lend itself to convenient placement of the fuses.

Failure information received to date does not justify redesign at this time to add fuses. However, future TFRs will be screen for early detection of any expansion of the problem area reported.

A recommendation has been made to increase the OBRP Spares from zero to one per boat.

SIGNATURE E. B. Huntley DATE 15 Sep 1965

12. SP FIELD OFFICE REMARKS

Concur with recommendations.

SIGNATURE J. Noble DATE 27 Sep 1965

MAIL TO: OFFICER IN CHARGE (TFR), U.S. NAVAL FLEET MISSILE SYSTEMS ANALYSIS AND EVALUATION GROUP, CORONA CALIFORNIA 91720

FIGURE 4. FBM WEAPON SYSTEM TFR/CAR

FLEET BALLISTIC MISSILE WEAPON SYSTEM
ELAPSED TIME METER RECORD
PORTABLE READINESS INSTRUMENTATION
(PORT V, Q, AND TEST EQUIPMENTS)

[illegible]

HULL NO. [illegible]	DATE (Day, Month, Year)	TIME

INSTRUCTIONS

Record all indicated elapsed times at approximately the same time on Monday of each week. Be sure Hull Number or activity name, date, and time have been filled in. As soon as possible, air mail original to: Officer in Charge (TFR), U.S. Naval Fleet Missile Systems Analysis and Evaluation Group, Corona, California 91720.

"V" SET

EQUIPMENT	MODEL NO.	MODEL SERIAL NO.	METER LOCATION	READING
POWER DISTRIBUTION CENTER	3515		TOP/FRONT/LEFT	
A/D CONVERTER AND MULTIPLEXER	[illegible]		(A) TOP/FRONT/LEFT	
			(B) TOP FRONT/RIGHT	
AUDIO TAPE RECORDER	3511		TOP FRONT/CENTER	
ULCER PROCESSOR	[illegible]		TOP FRONT/CENTER	
ANALOG POWER SUPPLY	3525		TOP FRONT/LEFT	
EVENTS PROCESSOR	[illegible]		TOP FRONT CENTER	
TIMING GENERATOR	3519		TOP FRONT/CENTER	
INCREMENTAL TAPE RECORDER	[illegible]		TOP CENTER/RIGHT	
BUFFER MEMORY	[illegible]		TOP FRONT CENTER	
PROGRAMMER	[illegible]		TOP FRONT/CENTER	
DIGITAL POWER SUPPLY	3513		TOP FRONT CENTER	

"Q" SET

EQUIPMENT	MODEL NO.	MODEL SERIAL NO.	METER LOCATION	READING
AC VOLTAGE STANDARD	3527		* SEE FOOTNOTE	
[illegible]	3523		TOP FRONT/CENTER	

TEST SET

EQUIPMENT	MODEL NO.	MODEL SERIAL NO.	METER LOCATION	READING
TEST ELECTRONICS	[illegible]		TOP FRONT/RIGHT	
DIGITAL PRINTER	[illegible]		TOP/REAR/RIGHT	
DIGITAL VOLTMETER	[illegible]		TOP FRONT LEFT	
OSCILLOSCOPE	3530		TOP FRONT LEFT	

* If AC Voltage Standard is installed in the Power Distribution Center (Model 3515) meter is located on BOTTOM FRONT CENTER of PDC chassis, otherwise the meter is visible from front of AC Voltage Standard

FIGURE 5. FBM WEAPON SYSTEM ETMR

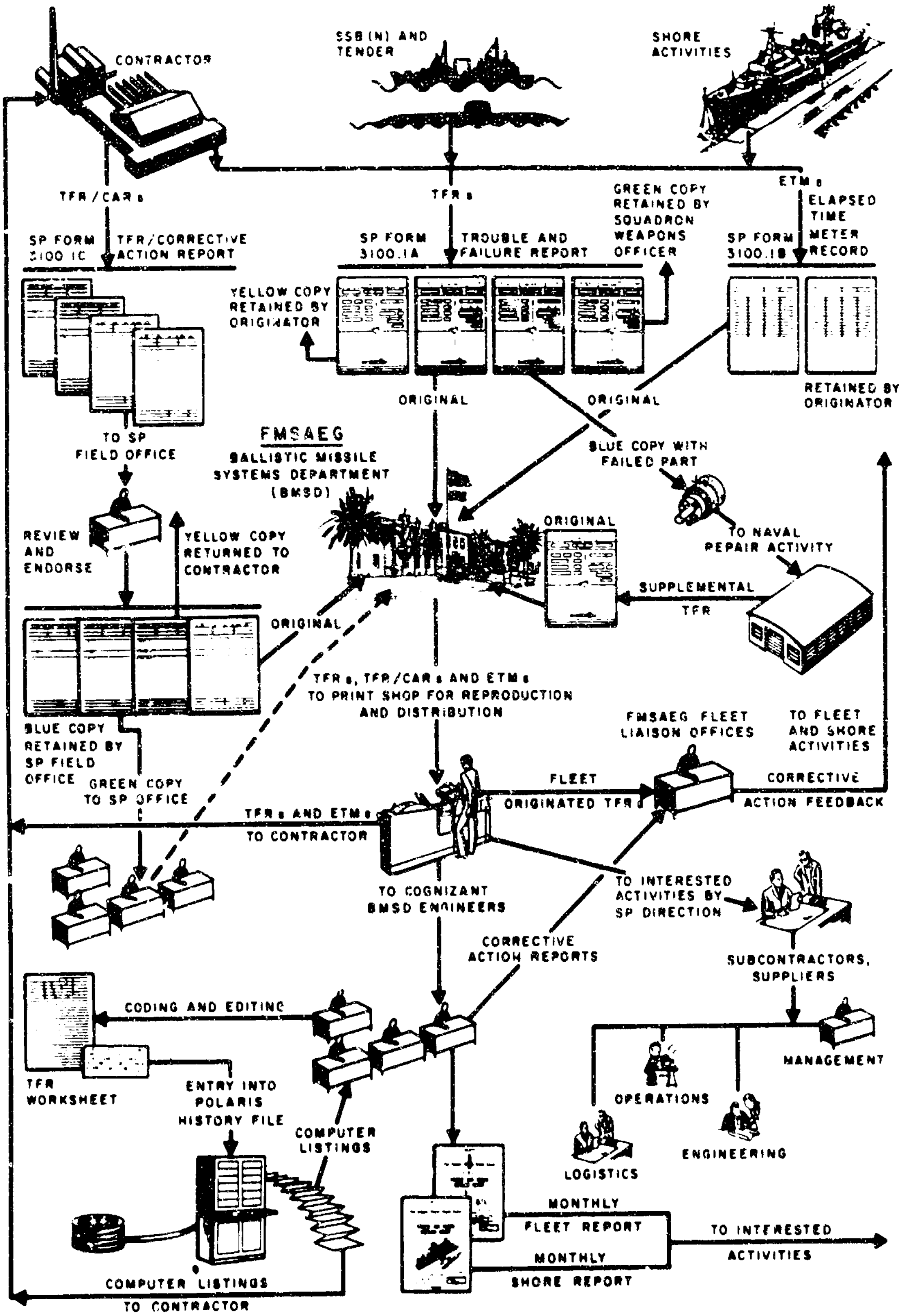


FIGURE 6. TFR PROGRAM FLOW CHART

TFR WORKSHEET
11 MO FMUAEG-3100/1 (IR-65)

1 F&S. NO.	2 BATCH NUMBER	3 C A REQUEST (CIRCLE ONE) [redacted] C	4 T F R NUMBER
5 ACTIVITY	6 PATROL NO / 7 CLASS [redacted]	8 DAY/MONTH/YEAR	9 ORIGINAL T F R NUMBER
10 SUBSYSTEM	11 MK	12 SERIAL NUMBER	
13 EQUIPMENT			14 SERIAL NUMBER
15 COMPONENT			16 SERIAL NUMBER
17. OTHER			18 SERIAL NUMBER
19 DRAWING NUMBER	/	20. ACTION (CIRCLE ONE) REP ADJ RPL	
21. FEDERAL STOCK NUMBER [redacted] - [redacted]		22 SERIAL NUMBER	23. REPAIR TIME HOURS ____ . ____
24 REF MATL ADEQUATE (CIRCLE ONE) YES NO	25 DOCUMENTATION ER NO.	26 TYPE OF TROUBLE OR FAILURE *	

27 DESCRIPTION OF TROUBLE OR FAILURE
*

28. PART
*

29 DISPOSITION OF FAILED ITEM (CIRCLE ONE)
* [redacted] SUPPLY SCRAP USE AS IS TENDER VENDOR REINSTALL

30. NARRATIVE DESCRIPTION
* [redacted]

FIGURE 7. TFR WORKSHEET

TABLE 5

TFR TYPES AND DESCRIPTIONS

Type	Description
Assembly	The failure occurred or was discovered during assembly operations and testing, such as missile assembly at PMFA/MAB.
Documentation	The TFR reports a document inadequacy.
Expended normally	The component, such as a missile battery, performed satisfactorily and was expended in the process. In this case, the TFR is used as a shipping document.
FAT	The failure occurred or was discovered during final acceptance tests at the factory.
Installation	The TFR was written to document the failure of a spare during installation and testing operations before deployment.
Installation spare	The TFR was written to document the failure of a spare during installation and testing operations at the shipyard before deployment.
Life	The calendar or operating life of the component was exceeded, or the remaining calendar or operating life was insufficient for deployment. The word "Life" is to be modified by a subfield as follows: Life/calendar or Life/operating.
Overhaul	The failure occurred or was discovered during SSBN or Tender overhaul operations. This category also applies to items replaced although not specifically considered failed components.
Overhaul spare	The TFR was written to document the failure of a spare during overhaul operations.
PMMP-627-A (for example)	The TFR refers to components failed or replaced in compliance with specific preventive maintenance programs. The program-identifying number must be included as indicated.
Recall	The TFR refers to components returned on compliance with specific SP recall directives. This type of TFR will seldom be a valid failure, and in most cases the item is returned for special investigations and the word "Recall" appears on the TFR.
Receiving	The failure occurred or was discovered during the intial receiving inspection and test operations on new components received by shore activities directly from the vendor, such as missile components at PMFA/ICPB.
Recertification	The component did not fail but for one reason or another was returned for recertification. The word "Recertification" appears on this type of TFR.
Refit	The failure occurred or was discovered during refitting operations performed as part of the refit program. The word "Refit" appears on this type of TFR. This category is used on PMFA or PMFP TFRs on missile components in the same manner as the category "Overhaul" for SSBN and Tender equipment.
Repair	The trouble or failure occurred or was discovered during retesting or repair of fleet returned failed components.
Repair spare	The TFR was written to document the repair of a failed spare by a repair activity.
Routine	The trouble or failure occurred or was discovered during normal routine operations and tests on board SSBNs and Tenders. This category will also apply to failures of test and checkout equipment during normal operations at shore stations.

TABLE 5 (Cont)

Type	Description
SPALT/0000	The TFR was written to document difficulties encountered in the accomplishment of an authorized alternation (SPALT, SHIPALT, SPALTRA, ORDALT, WEPALT), or to report inadequacies in materials or instructions provided for the accomplishment of alterations.
Spare	The failed component was a spare part, e.g., a defective spare which was removed from stock for inspection and test. This category is most applicable to SSBN and Tender spares. It is not a useful category for PMFA or PMFP TFRs since many components delivered to these activities are not always assigned to a system, and therefore, all such units could be erroneously considered spares.
Special test	The failure occurred during compatibility testing aboard Tenders or SSBNs or at shore activities. This category includes the testing operations performed on SSBNs in the shipyards which cannot be classed as routine or installation.
Surveillance	The failure occurred while performing inspection and testing on components in storage in accordance with a surveillance program.
	General Failure Categories (Subfields)
Functional	Any unsatisfactory performance during testing or operation or any nonconformance to operating requirements. It is to be used to modify the "Type of TFR" categories if applicable.
Handling	Any defect that can be attributed to handling by Navy personnel.
Unconfirmed	Any previously reported failure not verified by the subsequent activity retesting the component. It is to be used to modify the repair-type category only, if applicable, as follows: repair/unconfirmed.
Workmanship	Any defect which can be attributed to the oversight or carelessness of factory personnel.
Design	Any defect or unsatisfactory performance reported on the TFR as a design deficiency (not an analysis by FMSAEG).
Shipyard	Any defect which is reported on the TFR as caused by an oversight or by carelessness of shipyard personnel.

TABLE 6

STANDARD FAILURE DESCRIPTOR PHRASES

Adjustment/improper	Gain/low	Pressure/low
Alignment/improper	Humidity/excessive	Regulation/poor
Arcing/excessive	Identification/missing	rpm/low
Back resistance/low	Idle current/low	Residual magnetism/ lacking
Balance/improper	Impedance/mismatch	Resistance/low
Bandwidth/narrow	Index	Response/slow
Bias/high	Inductance/low	Roll/improper
Calibration/improper	Insulation/split	Sequence/incorrect
Capacitance/low	Jitter	Sensitivity/low
Circuit/open	Leakage/nitrogen	Soldering/poor
Clearance/improper	Lubrication/inadequate	Staging/improper
Contamination/oil	Null	Surface/scratched
Crimping/inadequate	Operation/improper	Switching/incorrect
Current/excessive	Output/noisy	Temperature/low
Cycling/improper	Packaging/improper	Tolerance/low
Fatigue	Part/missing	Transducer excitation/ low
Feedback/improper	Phase/shifted	Unknown
Fit/loose	Polarity/reversed	Voltage/low
Flooded	Positioning/improper	Wear/excessive
Frequency/drifting	Power	
Friction	Precharge/low	

detailed narratives; however, all indications are that human-initiated malfunctions are seldom found in the reports. The closed-loop system, with contractor participation through CARs, should provide a vehicle for identifying human-initiated failures, but experience proves otherwise.

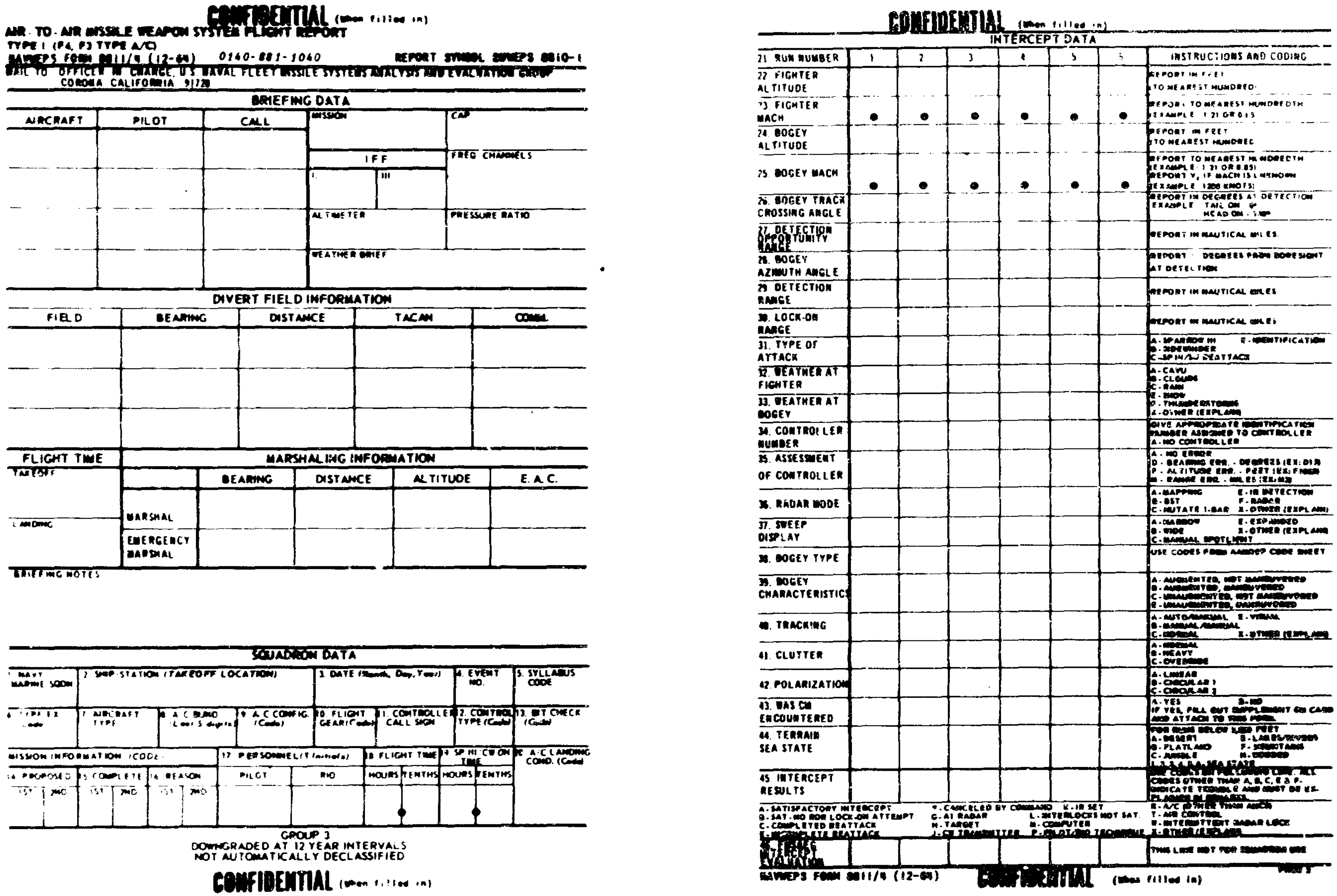
Surface Missile System and Air Launch Missile System Performance and Failure Reporting

3.24 Performance and failure reporting as related to these two categories of missile systems are also under the cognizance of FMSAEG in Corona, California. The type of information available is essentially the same in both areas. A detailed analysis is performed in conjunction with each firing and a considerable amount of information is compiled primarily from firing reports and telemetry data. Because of the general similarities between the two system categories, only two basic programs are described in detail in this report: (a) Air-Launch Guided Missile Systems Performance Data Reporting Program, and (b) Surface Missile System Status Log.

3.25 Air-Launch Guided Missile Systems Performance Data Reporting Program. The purpose of the program is to collect air-launch weapon system data from representative fleet squadrons under day-to-day operating conditions. Weapon system performance data reports are collected routinely on all air-launch missile firings and attempted firings and on all operations involving countermeasures which attempt to degrade system performance. Special performance data are also collected as required on a sampling basis to meet requirements not satisfied by routine reports.

3.26 The data collection program operates as follows. Routine report forms (NAVWEPS Forms 8811/4, 8811/5, 8811/6, and 8812/1, as applicable) are completed each time an air-launch missile firing attempt is made, or each time the weapon system is employed in a countermeasure environment. Examples of these forms are shown in Figures 8 through 10. To provide necessary data on subsystems or operations not obtained routinely, FMSAEG administers individual sampling programs in specific problem areas. In most instances, these programs require highly individualized data forms in lieu of the routine data forms mentioned previously. Figure 11 presents the code sheets used in conjunction with the report forms.

3.27 With the aid of telemetry data, in-depth analysis can be performed and the performance of the systems under test evaluated with reasonable accuracy. The analysis of the results of these findings have revealed that up to 10 percent of all the failures can be attributed to the human element. Indications are that this figure is considerably lower than the actual percentage. Unfortunately, outside of pointing to the significance of the problem, this type of information is of little use to the human reliability analyst. There has been virtually no attempt made to analyze the human-initiated failures to try to relate them to personnel characteristics. The Flight Crew History shown in Figure 12 could be used for more meaningful analysis by comparing crew characteristics with failures.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AIR-TO-AIR MISSILE WEAPON SYSTEM FLIGHT REPORT

TYPE I (F4, F3 TYPE A/C)

NAVWEPS FORM 8811/4 (12-64) 0140-881-1040 REPORT SYMBOL NAVWEPS 8810-1

MAIL TO OFFICER IN CHARGE, U.S. NAVAL FLEET MISSILE SYSTEMS ANALYSIS AND EVALUATION GROUP CORONA CALIFORNIA 91720

BRIEFING DATA

AIRCRAFT	PILOT	CALL	MISSION	CAP
			IFF: I / III	FREQ CHANNELS
			ALTIMETER	PRESSURE RATIO
			WEATHER BRIEF	

DIVERT FIELD INFORMATION

FIELD	BEARING	DISTANCE	TACAN	COMM

FLIGHT TIME	MARSHALING INFORMATION				
TAKEOFF		BEARING	DISTANCE	ALTITUDE	E.A.C.
	MARSHAL				
LANDING	EMERGENCY MARSHAL				

BRIEFING NOTES

SQUADRON DATA

1. NAVY MARINE SQDN	2. SHIP STATION (TAKEOFF LOCATION)	3. DATE (Month, Day, Year)	4. EVENT NO.	5. SYLLABUS CODE
6. TYPE EX Code	7. AIRCRAFT TYPE	8. A.C BUNO (Last 5 digits)	9. A.C CONFIG. (Code)	10. FLIGHT GEAR (Code)
11. CONTROLLER CALL SIGN	12. CONTROL TYPE (Code)	13. BIT CHECK (Code)		

MISSION INFORMATION (CODE)			17. PERSONNEL (Initials)		18. FLIGHT TIME	19. SP HI CW ON TIME	20. A/C LANDING COND. (Code)
14. PROPOSED (1ST, 2ND)	15. COMPLETE (1ST, 2ND)	16. REASON (1ST, 2ND)	PILOT	RIO	HOURS / TENTHS	HOURS / TENTHS	

GROUP 3
DOWNGRADED AT 12 YEAR INTERVALS
NOT AUTOMATICALLY DECLASSIFIED

CONFIDENTIAL (when filled in)

CONFIDENTIAL (when filled in)

INTERCEPT DATA

21. RUN NUMBER	1	2	3	4	5	6	INSTRUCTIONS AND CODING
22. FIGHTER ALTITUDE							REPORT IN FEET TO NEAREST HUNDRED
23. FIGHTER MACH	.	.	.	.	.	.	REPORT TO NEAREST HUNDREDTH (EXAMPLE 1.21 OR 0.15)
24. BOGEY ALTITUDE							REPORT IN FEET TO NEAREST HUNDRED
25. BOGEY MACH	.	.	.	.	.	.	REPORT TO NEAREST HUNDREDTH (EXAMPLE 1.21 OR 0.85) REPORT V, IF MACH IS UNKNOWN (EXAMPLE 1200 KNOTS)
26. BOGEY TRACK CROSSING ANGLE							REPORT IN DEGREES AT DETECTION EXAMPLE TAIL ON 0° HEAD ON 180°
27. DETECTION OPPORTUNITY RANGE							REPORT IN NAUTICAL MILES
28. BOGEY AZIMUTH ANGLE							REPORT DEGREES FROM BORESIGHT AT DETECTION
29. DETECTION RANGE							REPORT IN NAUTICAL MILES
30. LOCK-ON RANGE							REPORT IN NAUTICAL MILES
31. TYPE OF ATTACK							A-SPARROW III, B-SIDEWINDER, C-SP III/SJ REATTACK, E-IDENTIFICATION
32. WEATHER AT FIGHTER							A-CAVU, B-CLOUDS, C-RAIN, E-SNOW, D-THUNDERSTORMS, X-OTHER (EXPLAIN)
33. WEATHER AT BOGEY							
34. CONTROLLER NUMBER							GIVE APPROPRIATE IDENTIFICATION NUMBER ASSIGNED TO CONTROLLER; A-NO CONTROLLER
35. ASSESSMENT OF CONTROLLER							A-NO ERROR, D-BEARING ERR. - DEGREES (EX: D15), F-ALTITUDE ERR. - FEET (EX: F1000), M-RANGE ERR. - MILES (EX: M3)
36. RADAR MODE							A-MAPPING, B-BST, C-NUTATE 1-BAR, E-IR DETECTION, F-RADAR, X-OTHER (EXPLAIN)
37. SWEEP DISPLAY							A-NARROW, B-WIDE, C-MANUAL SPOTLIGHT, E-EXPANDED, X-OTHER (EXPLAIN)
38. BOGEY TYPE							USE CODES FROM AMBOGY CODE SHEET
39. BOGEY CHARACTERISTICS							A-AUGMENTED, NOT MANEUVERED; B-AUGMENTED, MANEUVERED; C-UNAUGMENTED, NOT MANEUVERED; D-UNAUGMENTED, MANEUVERED
40. TRACKING							A-AUTO/MANUAL, B-MANUAL/MANUAL, C-NORMAL, E-VISUAL, X-OTHER (EXPLAIN)
41. CLUTTER							A-MINIMAL, B-HEAVY, C-OVERRIDING
42. POLARIZATION							A-LINEAR, B-CIRCULAR 1, C-CIRCULAR 2
43. WAS CM ENCOUNTERED							A-YES, B-NO; IF YES, FILL OUT SUPPLEMENT CM CARD AND ATTACH TO THIS FORM
44. TERRAIN SEA STATE							FOR RUNS BELOW 5,000 FEET: A-DESERT, B-FLATLAND, C-JUNGLE, E-LAKES/RIVERS, F-MOUNTAINS, H-WOODED; 1-5 A.A.F. SEA STATE
45. INTERCEPT RESULTS							USE CODES IN FOLLOWING LINE. ALL CODES OTHER THAN A, B, C, E & F INDICATE TROUBLE AND MUST BE EXPLAINED IN REMARKS
46. FMSAEG EVALUATION							THIS LINE NOT FOR SQUADRON USE

A-SATISFACTORY INTERCEPT; B-SAT. NO RDR LOCK-ON ATTEMPT; C-COMPLETED REATTACK; E-INCOMPLETE REATTACK; F-CANCELED BY COMMAND; G-AI RADAR; H-TARGET; J-CW TRANSMITTER; K-IR SET; L-INTERLOCKS NOT SAT.; M-COMPUTER; P-PILOT/RIO TECHNIQUE; R-A/C (OTHER THAN AICS); T-AIR CONTROL; U-INTERMITTENT RADAR LOCK; X-OTHER (EXPLAIN)

NAVWEPS FORM 8811/4 (12-64) CONFIDENTIAL (when filled in) PAGE 2

FIGURE 8. AIR-TO-AIR MISSILE WEAPON SYSTEM FLIGHT REPORT
(Pages 1 and 2)

CONFIDENTIAL (when filled in)

FIRING DATA

Item							Instructions
47 INTERCEPT RUN NUMBER							WRITE IN APPLICABLE INTERCEPT RUN NUMBER
48 LAUNCHER STATION CODE							WRITE IN LAUNCHER STATION CODE FROM MISSILE ID SECTION (COL. 69)
49 TYPE FIRING							A - ACTUAL OR ATTEMPTED (SINGLE) B - ACTUAL OR ATTEMPTED (RIPPLE) C - SIMULATED
50 FIRING RANGE	•	•	•	•	•	•	REPORT TO NEAREST TENTH IN NAUTICAL MILES (EXAMPLE 2.3)
51 ASPECT TO BOGEY HEADING							REPORT IN DEGREES EXAMPLE: TAIL ON 0° HEAD ON 180°
52 FIGHTER ALTITUDE							REPORT IN FEET (TO NEAREST HUNDRED)
53 FIGHTER MACH	•	•	•	•	•	•	REPORT IN NEAREST HUNDREDTH (EXAMPLE: 1.43 OR 0.85)
54 FIGHTER MANEUVER							A - NORMAL TURN F - NONE B - PUSH OVER C - SNAP UP E - HIGH "G" TURN
55 BOGEY ALTITUDE							REPORT IN FEET (TO NEAREST HUNDRED)
56 BOGEY MACH	•	•	•	•	•	•	REPORT TO NEAREST HUNDREDTH (EXAMPLE: 1.43 OR 0.85)
57 MISS DISTANCE							REPORT IN FEET (TELEMETERED OR ESTIMATED) OR USE CODE A - DIRECT HIT X - OTHER B - BALLISTIC (EXPLAIN)
58 FUZE OR WARHEAD ACTION							A - NORMAL B - NONE X - OTHER (EXPLAIN-GIVE TIME OR DISTANCE FROM LAUNCH)
59 LAUNCH ACTION							A - NORMAL F - JETTISON B - ACCIDENTAL D - MISFIRE (missile expended) E - MISFIRE (missile not expended)
60 HOW WAS MISSILE ASSESSED							A - EYEBALL B - TELEMETRY X - OTHER (EXPLAIN)
61 PHASE EVALUATION							THIS SPACE NOT FOR SQUADRON USE

SPARROW III SUPPLEMENT

Item							Instructions
62 MISSILE MODE							A - NARROW GATE B - WIDE GATE X - OTHER (EXPLAIN)
63 FIRING PROCEDURE							A - NORMAL FIRING B - BORESIGHT C - INTERLOCKS OUT (OVERRIDE) E - MANUAL TRACK
64 WEATHER AT FIRING							A - CAVU X - OTHER (EXPLAIN)

SIDEWINDER SUPPLEMENT*

Item							Instructions
65 BACKGROUND AFFECTING GUIDANCE							A - NONE B - CLOUD C - SUN X - OTHER (EXPLAIN)

MALFUNCTION ANALYSIS - POST FLIGHT

Item							Instructions
66 MISSILE MALFUNCTION							USE CODES FROM AAMREP CODE SHEET AND EXPLAIN (IN REMARKS) AS REQUIRED
67 LAUNCHER MALFUNCTION							
68 AWCS MALFUNCTION							

NAVWEPS FORM 8811/4 (12-64) PAGE 3

MISSILE IDENTIFICATION DATA

SP III AND S/W				SPARROW III			SIDEWINDER				
LAUNCHER STATION										LAUNCHER BOTTLE PRESSURE (S/W 1C)	
69. CODE*	LOCATION (ALL MISSILES) (ALL AIRCRAFT)	70. RUN NUMBER OF UNSAT LIGHT OR TONE	*71. WARHEAD TYPE	*72. SELECT LIGHT	*73. READY LIGHT	74. GUIDANCE AND CONTROL UNIT: SEEKER SERIAL NUMBER / CONTROL SERIAL NUMBER	*75. TONE	76. FUZE TYPE	77. GUIDANCE AND CONTROL UNIT: SERIAL NUMBER, INDICATE P OR G	78. TAKEOFF (PSIG)	79. LANDING (PSIG)
A	PORT WING OUTBOARD OR SINGLE										
B	PORT WING INBOARD										
C	PORT FUSELAGE FORWARD										
D	PORT FUSELAGE AFT										
E	STBD FUSELAGE AFT										
F	STBD FUSELAGE FWD.										
G	STBD WING INBOARD										
H	STBD WING OUTBOARD OR SINGLE										

*Use codes from Code Sheet

REMARKS: Use this space for necessary explanations as indicated by instructions, c... requirements and in instances where coding seems inadequate.

NAVWEPS FORM 8811/4 (12-64) **CONFIDENTIAL** (when filled in) PAGE 4

FIGURE 8 (Cont)
(Pages 3 and 4)

PROJECT SPARROW SHOOT MISSILE RECORD

1IND-FMSAEG-8811/12 (1-66)

AIM-7D SERIAL

INSTRUCTIONS: Upon the designation of a missile for the SPARROW SHOOT PROJECT, the Build-Up Section will be completed and the form attached to the missile for subsequent testing and loading. Upon the completion of the missile loading on the firing aircraft, the form will be turned in to the Evaluation Team for completion and forwarding to FMSAEG, Corona, California.

A. BUILD-UP SECTION

1 ACTIVITY	2 DATE	3 SEEKER S/N	4 CONTROL S/N
5 IGNITER MK-MOD	6 IGNITER LOT NO.	7 WARHEAD MK-MOD	8 WARHEAD S/N
9 MOTOR MK-MOD	10 MOTOR S/N	11 SPECIAL REMARKS	

B. TESTING SECTION *(Use same coding as for GMSR-NAVWEPS 8800/2)*

1 ACTIVITY	2 DATE	3 TEST SET *(Type, S/N, Calib date)*
4 OPERATING TIME	a. EXTERNAL POWER	b. INTERNAL POWER

5 TEST RESULTS *(Check one)*
☐ GO ☐ NO-GO *(Item)* ☐ NO-GO *(T.E.)* ☐ NO-GO *(Pers)* ☐ NO-GO *(Other)*

6 TYPE OF FAILURE, ETC.

C. LOADING SECTION *(To be filled out by loading crew.)*

1 SQUADRON	2. LOADING DATE

3 LOADING CREW *(List each members name, rate, and approximate number of Sparrow III's previously loaded)*

D. MISSILE DISPOSITION *(To be completed by Evaluation Team)*

1 MISSILE EXPENDED ☐ YES ☐ NO

2 IF NO, CHECK MISSILE POST-FLIGHT DISPOSITION ☐ MISFIRED ☐ RETURNED AND READY FOR RESCHEDULING ☐ RETURNED AND REQUIRES RETEST

EVALUATOR SIGNATURE

E COMMENTS ON MISSILE LOADING AND PREFLIGHT PROCEDURES *(List any discrepancies noted in standard loading preflight procedures. Use reverse side if necessary.)*

FIGURE 9. PROJECT SPARROW SHOOT MISSILE RECORD

SECRET *(when filled in)*

AIR-TO-AIR MISSILE WEAPON SYSTEM FLIGHT REPORT
COUNTERMEASURES SUPPLEMENT
NAVWEPS FORM 8811/6 (12-64) 0140-881-10..

When completed, attach to applicable Air-to Air Missile Weapon System Flight Report, and
MAIL TO OFFICER IN CHARGE, U S NAVAL FLEET MISSILE SYSTEMS ANALYSIS AND EVALUATION GROUP
CORONA, CALIFORNIA 91720

SQUADRON DATA

NAVY MARINE SQUADRON NUMBER	DATE			EVENT NUMBER	PERSONNEL (3 initials)	
	MONTH	DAY	YEAR		PILOT	RIO

REMARKS: (Comment on which CCM Techniques Proved most effective, plus any information pertinent to Run or Mission.)

GROUP-3
DOWNGRADED AT 12-YEAR INTERVALS
NOT AUTOMATICALLY DECLASSIFIED

SECRET *(when filled in)*

FIGURE 10. AIR-TO-AIR MISSILE WEAPON SYSTEM FLIGHT REPORT

CODE SHEET FOR TYPE I (F4, F3, TYPE A/C)
AIR-TO-AIR MISSILE WEAPON SYSTEM FLIGHT REPORT

IT IS CONSIDERED FEASIBLE FOR THE CODES ON THIS SHEET TO BE ENTERED ON THE AAWREP FORM PRIOR TO OR IMMEDIATELY FOLLOWING THE MISSION. FOR THOSE ITEMS WHICH SHOULD BE CODED DURING FLIGHT, CODES WILL APPEAR DIRECTLY ON THE FORM.

NOTE: Use a dash (–) in all cases in which the item is not applicable.

SQUADRON DATA

6. TYPE OF EXERCISE
- A – AAWEX
- B – MISSEX
- C – LANT MISSEX
- E – WESTPAC MISSEX
- F – MIDPAC MISSEX
- G – EASTPAC MISSEX
- H – MED MISSEX
- K – PREWEP TRAEX
- L – WEPTRAEX
- P – COMPEX
- R – NORMAL TRAINING
- T – O.R.I.
- X – OTHER (EXPLAIN)
- M – FLEET OPS

9. AIRCRAFT TANK CONFIGURATION
- 1 – ONE TANK
- 2 – TWO TANKS
- 3 – THREE TANKS
- 4 – CLEAN (NO TANKS)
- X – OTHER (EXPLAIN)

10. FLIGHT GEAR
- A – NORMAL
- B – EXPOSURE SUIT
- C – PRESSURE SUIT

12. TYPE OF CONTROLLER
- A – MISSILE RANGE · RADAR
- B – SELF CONTROLLED
- C – CIC
- E – GCI
- T – MULTIPLE (EXPLAIN)
- X – OTHER (EXPLAIN)

DATA LINE
- F – ATDS
- G – SAGE
- H – MTDS
- J – NTDS

VOICE
- K – MTDS
- L – NTDS
- M – SAGE
- P – ATDS
- R – WF-2/E-1B

13. BIT CHECK
- AA – SAT PERFORMANCE
- BB – NOT PERFORMED

UNSAT BITS
- 0A – BIT ZERO – B+
- 0B – BIT ZERO – DISPLAY
- 1C – BIT ONE – DETECTION
- 1D – BIT ONE – ACQUISITION
- 1E – BIT ONE – COMP
- 2F – BIT TWO – RANGE TRACK
- 2G – BIT TWO – COMP
- 3H – BIT THREE – ANGLE TRACK
- 4J – BIT FOUR – COMP
- 4P – BIT FOUR – AOJ/HOJ
- 5L – BIT FIVE – COMP
- 6M – BIT SIX – COMP
- 7R – BIT SEVEN – IR
- 9X – MULTIPLE UNSAT BITS (EXPLAIN)

14. MISSION PROPOSED

NON-WEAPON SYSTEM TYPE
- 3 – ANY NON-WEAPON TYPE

WEAPON SYSTEM TYPE
- A – SPARROW III LAUNCH
- B – SIDEWINDER LAUNCH
- C – SP III + S/W LAUNCH
- E – AIR-TO-AIR SUPERIORITY
- F – COMBAT AIR PATROL
- G – ESCORT FIGHTER
- H – INTERCEPT TRAINING
- K – SPECIAL WEAPONS
- L – RESEARCH AND DEVELOPMENT
- M – SCRAMBLE
- R – CW FLIGHT TEST
- X – OTHER (EXPLAIN)

15. MISSION COMPLETION
- A – COMPLETED
- B – PARTIALLY COMPLETED
- C – NOTHING COMPLETED
- E – AIRCRAFT NOT LAUNCHED

16. REASON FOR DEGREE COMPLETED
- A – SAT COMPLETION
- B – TM OR INSTRUMENT TROUBLE
- C – MISSILE TROUBLE
- E – LAUNCHER TROUBLE
- F – CANCELLED BY COMMAND
- G – AI RADAR TROUBLE
- H – TARGET TROUBLE
- J – CW TRANSMITTER TROUBLE
- K – IR SET TROUBLE
- M – COMPUTER TROUBLE
- P – RADIO AND COMMUNICATION TROUBLE
- R – A/C TROUBLE (OTHER THAN AMCS)
- T – AIR CONTROL TROUBLE
- X – OTHER (EXPLAIN)

20. AIRCRAFT LANDING CONDITION
- A – UP

DOWN BECAUSE OF.
- B – AIRFRAME
- C – ORDNANCE
- E – ELECTRONICS
- F – POWER PLANT
- T – MULTIPLE (EXPLAIN)
- X – OTHER (EXPLAIN)

INTERCEPT DATA

38. BOGEY TYPE

AIRCRAFT TYPES
- A – A4
- B – F4B, F4C
- C – F3B
- E – F8
- F – F101, F104, F105
- G – F102, F106
- H – B52, KC135, 707, DC8
- K – EA6A
- L – EF10B
- P – E1B, E2A
- R – A3A
- T – A5
- X – OTHER (EXPLAIN)

OTHER THAN A/C TYPES
- 2 – DELMAR
- 3 – AQM-37A
- 4 – QF9F
- 5 – POGO
- 6 – HVAR
- 7 – AQM-34
- 8 – PARA FLARE
- 9 – BQM-34A
- 10 – TDU-22A/B
- X – OTHER (EXPLAIN)
- S – SURFACE (EXPLAIN)

MALFUNCTION ANALYSIS - POST FLIGHT

66. MISSILE MALFUNCTION
- A – CHECKS SAT
- B – IGNITER SAFE-ARM NOT ARMED (SP III)
- C – SAFETY PIN NOT REMOVED

CHECKS UNSAT (USE FOLLOWING CODES AND EXPLAIN TYPE OF TEST EQUIPMENT USED)
- E – HEAD HYDRAULICS STREAMED (SP III)
- F – EPU-BATTERY FIRED (SP III)
- G – HPU FIRED (SP III)
- H – GAS GRAIN FIRED (S/W)
- K – NITROGEN PRESSURE TROUBLE (S/W-IC)
- T – MULTIPLE (EXPLAIN)
- X – OTHER (EXPLAIN)

67. LAUNCHER MALFUNCTION
- A – CHECKS SAT
- B – MOTOR FIRE LEAD IMPROPERLY CONNECTED (SP III)
- C – UMBILICAL NOT RETRACTED (SP III)
- E – LAUNCHER CHECKS UNSAT (EXPLAIN)

68. AMCS MALFUNCTION
- A – CHECKS SAT
- B – VERTICAL GYRO
- G – AI RADAR TROUBLE
- J – CW ILLUMINATOR
- K – IR SET TROUBLE
- M – COMPUTER TROUBLE
- T – MULTIPLE (EXPLAIN)
- X – OTHER (EXPLAIN)

MISSILE IDENTIFICATION DATA

70. GIVE RUN NUMBER OR CODE NUMBER (BELOW) ON WHICH TONE WAS CHECKED UNSAT.
- 7 – ALL RUNS
- 8 – DECK ONLY
- X – OTHER (EXPLAIN)

71. WARHEAD TYPE - (SPARROW III AND SIDEWINDER)
- A – EXERCISE (SPOTTING CHARGE)
- B – LIVE (EXPLOSIVE)
- C – INERT
- E – TM
- X – OTHER (EXPLAIN)

72, 73, & 75. SPARROW III SELECT LIGHT AND READY LIGHT AND SIDEWINDER TONE
- A – YES
- B – NO (FAILURE)
- C – INTERMITTENT
- E – YES ON DECK NO IN AIR
- F – TUNED UP LATE
- G – NOT CHECKED
- X – OTHER (EXPLAIN)

76. FUZE TYPE
- A – MK 322
- B – MK 323

11ND-PMSAEG-8811/3 (11-66)

FIGURE 11. AIR-TO-AIR MISSILE WEAPON SYSTEM FLIGHT REPORT CODE SHEET
(Page 1)

CODE SHEET FOR TYPE II (F8, A4, A6 TYPE A/C)
AIR-TO-AIR WEAPON SYSTEM FLIGHT REPORT

11ND-FMSAEG-8811/5 (6-64)

CODES ON THIS SHEET MAY BE ENTERED ON THE AAMREP FORM PRIOR TO OR IMMEDIATELY FOLLOWING THE FLIGHT. OTHER CODES WILL APPEAR DIRECTLY ON THE AAMREP FORM.

NOTE: Use a dash (–) in all cases in which the item is not applicable.

SQUADRON DATA

8. TYPE OF EXERCISE
- A - AAWEX
- B - MISSEX
- C - LANT MISSEX
- E - WESTPAC MISSEX
- F - MIDPAC MISSEX
- G - EASTPAC MISSEX
- H - MED MISSEX
- K - PREWEP TRAEX
- L - WEPTRAEX
- P - COMPEX
- R - NORMAL TRAINING
- T - O.R.I
- X - OTHER (EXPLAIN)

9. FLIGHT GEAR
- A - NORMAL
- B - EXPOSURE SUIT
- C - PRESSURE SUIT

11. TYPE OF CONTROLLER
- A - MISSILE RANGE - RADAR
- B - SELF CONTROLLED
- C - CIC
- E - GCI
- T - MULTIPLE (EXPLAIN)
- X - OTHER (EXPLAIN)

DATA LINK
- F - ATDS
- G - SAGE
- H - MTDS
- J - NTDS

VOICE
- K - MTDS
- L - NTDS
- M - SAGE
- P - ATDS
- R - WF-2

12. MISSION PROPOSED

NON-WEAPON SYSTEM TYPE
- 3 - ALL NON-WEAPON TYPE

WEAPON SYSTEM TYPE
- A - SPARROW III LAUNCH
- B - SIDEWINDER LAUNCH
- C - SP III + S/W LAUNCH
- E - AIR-TO-AIR SUPERIORITY
- F - COMBAT AIR PATROL
- G - ESCORT FIGHTER
- H - INTERCEPT TRAINING
- K - SPECIAL WEAPONS
- L - RESEARCH AND DEVELOPMENT
- P - SCRAMBLE
- R - CM FLIGHT TEST
- X - OTHER (EXPLAIN)

13. MISSION COMPLETION
- A - COMPLETED
- B - PARTIALLY COMPLETED
- C - NOTHING COMPLETED
- E - AIRCRAFT NOT LAUNCHED

14. REASON FOR DEGREE OF COMPLETION
- A - SAT COMPLETION
- B - TM OR INSTRUMENT TROUBLE
- C - MISSILE TROUBLE
- E - LAUNCHER TROUBLE
- F - CANCELLED BY COMMAND
- G - AI RADAR TROUBLE
- H - TARGET TROUBLE
- J - CW TRANSMITTER TROUBLE
- K - IR SET TROUBLE
- M - COMPUTER TROUBLE
- P - RADIO & COMMUNICATION TROUBLE
- R - A/C TROUBLE (OTHER THAN AMCS)
- T - AIR CONTROL TROUBLE
- X - OTHER (EXPLAIN)

17. AIRCRAFT LANDING CONDITION
- A - UP

DOWN BECAUSE:
- B - AIRFRAME
- C - ORDNANCE
- E - ELECTRONICS
- F - POWER PLANT
- T - MULTIPLE (EXPLAIN)
- X - OTHER (EXPLAIN)

MALFUNCTION ANALYSIS - POSTFLIGHT

54. MISSILE
- A - CHECKS SAT
- H - GAS GRAIN FIRED
- K - NITROGEN PRESSURE TROUBLE (S/W – 1C)
- T - MULTIPLE (EXPLAIN)
- X - OTHER (EXPLAIN)

55. LAUNCHER
- A - CHECKS SAT
- E - CHECKS UNSAT (EXPLAIN)

56. AMCS
- A - CHECKS SAT
- G - AI RADAR TROUBLE
- K - IR SET TROUBLE
- M - COMPUTER TROUBLE
- T - MULTIPLE (EXPLAIN)
- X - OTHER (EXPLAIN)

FIGURE 11. AIR-TO-AIR MISSILE WEAPON SYSTEM FLIGHT REPORT CODE SHEET (Page 2)

PROJECT SPARROW SHOOT - FLIGHT CREW HISTORY

1. DATE	2. SQUADRON	3a. PILOT (Full Name)	3b. RIO (Full Name)

4. FMSAEG Assigned Number	PILOT a.	RIO b.	
FLIGHT TIME			
5. Total			
6. F4 Type			
7. Jet			
PREVIOUS TRAINING (8-14 answer yes or no)			
8. R.A.G. (Replacement Air Group)			
9. East Coast (VF-101)			
10. West Coast (VF-121)			
11. No Formal R.A.G. Training			
12. RAG Grad Within 6 months			
13. RAG Grad Within 1 Year			
14. RAG Grad More Than 1 Year			
15. Years Designated Naval Aviator/RIO			
16. Age			
NUMBER OF PREVIOUS TOURS			
17. Day Fighter			
18. All Weather Interceptor			
19. V.A.			
20. Other			
TOTAL CARRIER ARRESTED LANDINGS			
21. In Type (F4)			
22. Total Jet			
23. Total - All Models			
CREW EXPERIENCE (Approximately)			TOTAL
24. Total Hours Crew Has Flown Together As A Crew			
25. Total Hours Crew Has Flown Together In Last 6 Months			
26. Average Number Intercepts Flown Per Month			
27. Total Number Intercepts Flown		+	c.
NUMBER OF MISSILES FIRED			
28. AIM-7 Series			
29. AIM-9 Series			
30. Date of Last AIM-7 Firing			
31. Pilot/RIO As A Team (AIM-7)			
32. Pilot/RIO As A Team (AIM-9)			

233-91-(2-66)

FIGURE 12. FLIGHT CREW HISTORY

3.28 Figure 13 shows a Firing Report which is used in conjunction with Surface Missile Systems. The analyses performed on these systems do not appear to be as detailed as those performed for the Air-Launch Systems.

3.29 Surface Missile System Equipment Status Log. This system was established for reporting the operational status of the nonexpendable equipment of Surface Missile Systems. The reporting system is designed to enable the data to be correlated with the Maintenance Data Collection Subsystem (MDCS) which is part of the 3-M system. Report 8821/5 (Figure 14) is submitted weekly giving the status of the equipment for each day of the week and also each time there is a change in the status. Table 7 provides the definitions of the various status categories.

3.30 From these reports from all ships, system availability is determined based on the percentage of time the system was up and the percentage of down-time. There is no indication of how accurately the status of the equipment is assessed and reported at any given time aboard ship. Systems availability could be used by relating it to crew composition. This type of analysis is similar to those outlined in Section IV.

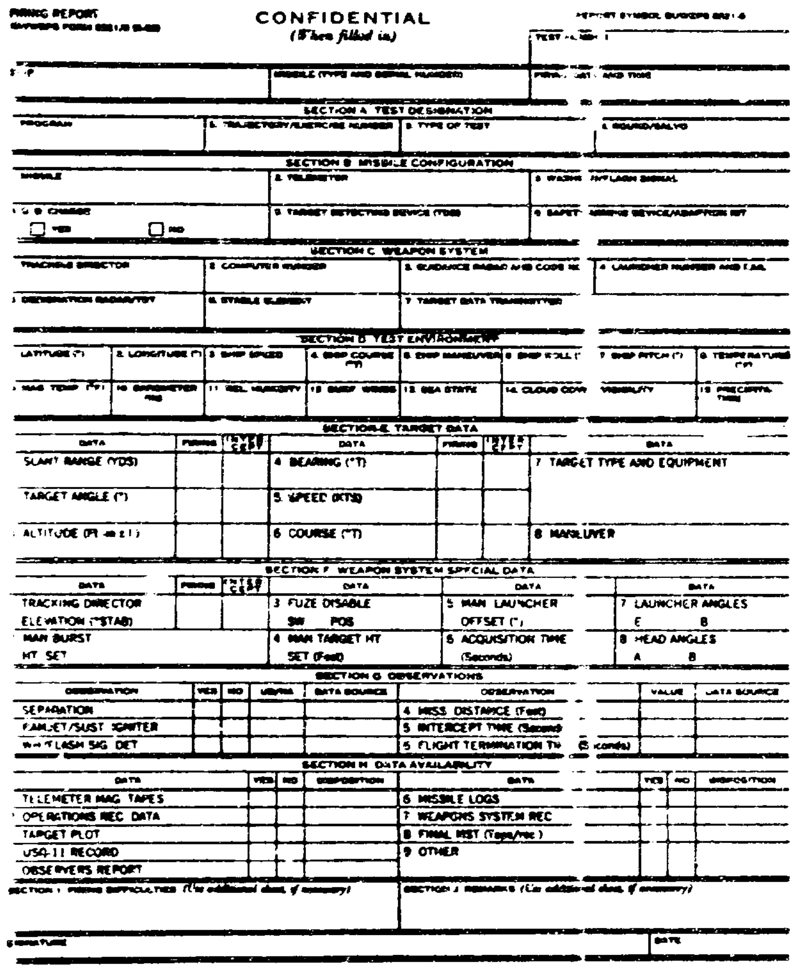
3-M System*

3.31 It is difficult to discuss the operations of the 3-M system because it is still in a stage of development; consequently, changes, modifications, and additions are incorporated quite frequently. The following discussion takes into consideration the most recent changes.

3.32 The 3-M system consists of two subsystems: The Planned Maintenance System (PMS) and MDCS. PMS is designed to provide procedures, schedule phasing, manpower plans, and material requirements for preventive maintenance. MDCS is established to report extensive data on corrective maintenance transactions.

3.33 MDCS is the only portion of the 3-M system that can provide data in support of human reliability analysis. MDCS is designed to provide a means of recording maintenance actions in substantial detail so that a great variety of information may be retrieved concerning maintenance actions and the performance of equipment involved. In addition to recording maintenance actions performed, the system provides data concerning the initial discovery of the malfunction, how equipment malfunctioned, how many man-hours were expended, which equipment was involved, what repair parts and materials were used, what delays were incurred, the reasons for delay, and the technical specialty or rating of the person who performed the maintenance.

* Much of the information on the 3-M system was taken from the 3-M Manual, OPNAV 43P2. 15/

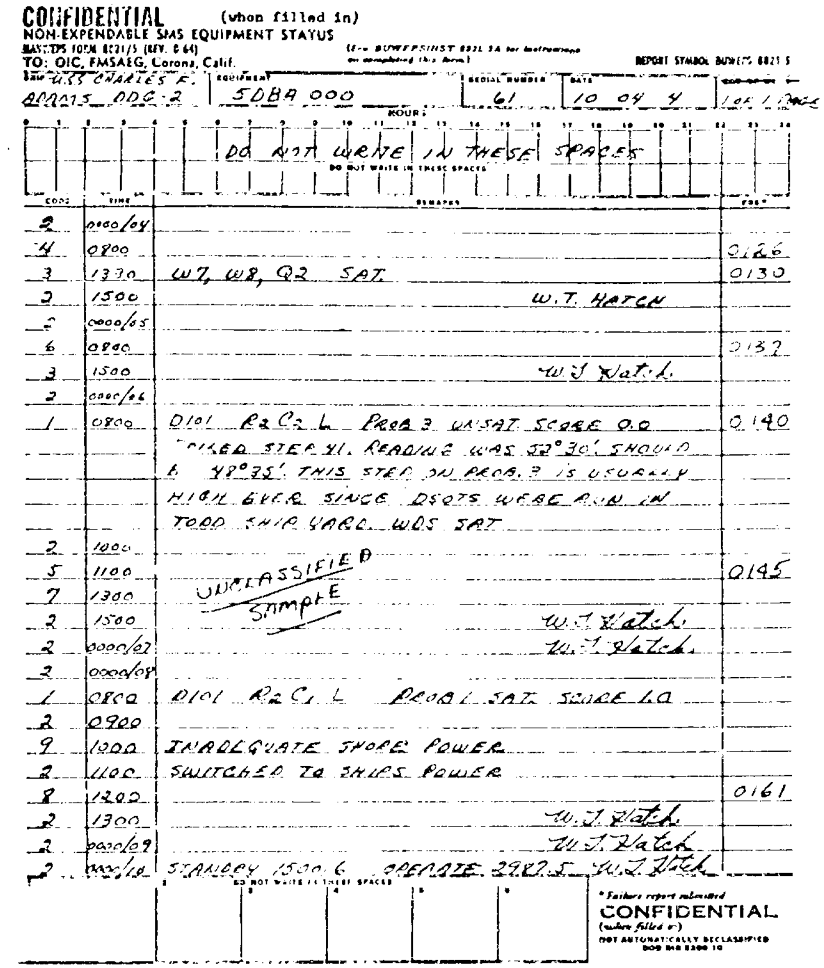


CONFIDENTIAL
(When filled in)

FIRING REPORT

SECTION A TEST DESIGNATION		
PROGRAM	TRAJECTORY/EXERCISE NUMBER	TYPE OF TEST
SECTION B MISSILE CONFIGURATION		
MISSILE	TELEMETER	WARHEAD
SECTION C WEAPON SYSTEM		
TRACKING DIRECTOR	COMPUTER NUMBER	LAUNCHER NUMBER AND RAIL
SECTION D TEST ENVIRONMENT		
LATITUDE	LONGITUDE	SHIP SPEED
SECTION E TARGET DATA		
SLANT RANGE (YDS)	4 BEARING (°T)	7 TARGET TYPE AND EQUIPMENT
TARGET ANGLE (°)	5 SPEED (KTS)	
ALTITUDE	6 COURSE (°T)	8 MANEUVER
SECTION F WEAPON SYSTEM SPECIAL DATA		
TRACKING DIRECTOR ELEVATION (°STAB)	3 FUZE DISABLE SW POS	5 MAN LAUNCHER OFFSET (°)
MAN BURST HT SET	4 MAN TARGET HT SET (Feet)	6 ACQUISITION TIME (Seconds)
	7 LAUNCHER ANGLES E B	8 HEAD ANGLES A B
SECTION G OBSERVATIONS		
SEPARATION	4 MISS DISTANCE (Feet)	
FAN JET/SUST IGNITER	5 INTERCEPT TIME (Seconds)	
WHIPLASH SIG DET	5 FLIGHT TERMINATION TIME (Seconds)	
SECTION H DATA AVAILABILITY		
TELEMETER MAG TAPES	6 MISSILE LOGS	
OPERATIONS REC DATA	7 WEAPONS SYSTEM REC	
TARGET PLOT	8 FINAL MST (Tape/rec)	
USQ-11 RECORD	9 OTHER	
OBSERVERS REPORT		
SECTION I FIRING DIFFICULTIES	SECTION J REMARKS	
SIGNATURE	DATE	

FIGURE 13. FIRING REPORT



CONFIDENTIAL (when filled in)
NON-EXPENDABLE SMS EQUIPMENT STATUS
TO: OIC, FMSAEG, Corona, Calif.

SHIP	EQUIPMENT	SERIAL NUMBER	DATE	
U.S.S. CHARLES F. ADAMS DDG-2	5DBA 000	61	10 04 4	1 of 1 Page

DO NOT WRITE IN THESE SPACES

CODE	TIME	REMARKS	
2	0000/04		
4	0800		0126
3	1330	W7, W8, Q2 SAT.	0130
2	1500	W. T. HATCH	
2	0000/05		
6	0800		0132
3	1500	W. T. Hatch	
2	0000/06		
1	0800	D101 R2 C2 L PROB 3 UNSAT SCORE 0.0	0140
		FIXED STEP 41. READING WAS 52°30' SHOULD	
		BE 49°35'. THIS STEP ON PROB. 3 IS USUALLY	
		HIGH EVER SINCE DSOTS WERE RUN IN	
		TODD SHIP YARD. WAS SAT	
2	1000		
5	1100	UNCLASSIFIED	0145
7	1300	SAMPLE	
2	1500	W. T. Hatch	
2	0000/07	W. T. Hatch	
2	0000/08		
1	0800	D101 R2 C1 L PROB 1 SAT SCORE 1.0	
2	0900		
9	1000	INADEQUATE SHORE POWER	
2	1100	SWITCHED TO SHIPS POWER	
8	1200		0161
2	1300	W. T. Hatch	
2	0000/09	W. T. Hatch	
2	0000/10	STANDBY 1500.6 OPERATE 2987.5 W. T. Hatch	

CONFIDENTIAL
NOT AUTOMATICALLY DECLASSIFIED

FIGURE 14. NON-EXPENDABLE SMS EQUIPMENT STATUS REPORT

TABLE 7

STATUS CATEGORY DEFINITIONS AND CODES

Code Number	Status Category Definition
1	Operating Full or Reduced Capability. Equipment is energized and is being operated at full or reduced capability. a. Operable at Full Capability - Capable of operation with no known impairments or degradations. b. Operable at Reduced Capability - Having known impairments or degradations, but still capable of operation and of accomplishment of a significant part of the tactical mission.
2	Ready or Standby. Equipment is partially energized and is believed to be operable at full or reduced capability. For some equipment, full power may be applied but the operate or transmit switch is not activated.
3	Secured. Equipment is not energized but is believed to be operable at full or reduced capability.
4	Inoperable - Active Maintenance. The equipment is not capable of operating at full or reduced capability on demand. The equipment is undergoing corrective or preventive maintenance.
5	Inoperable - Waiting Spares. The equipment is not capable of operating at full or reduced capability on demand. The equipment cannot be restored to an operable status until receipt of needed parts.
6	Inoperable - Modifications. The equipment is not capable of operating at full or reduced capability. The equipment cannot be restored to an operable status until completion of the modifications.
7	Inoperable - Outside Help. The equipment is not capable of operating at full or reduced capability on demand and requires the assistance of outside personnel and/or equipment to restore it to an operable status.
8	Inoperable - Administrative. The equipment is not capable of operating at full or reduced capability on demand. Ship's operations, activities, or procedures prohibit maintenance action. Equipment is inoperable but no maintenance is being performed.
9	Inoperable - Support Equipment. The equipment is not capable of operating at full or reduced capability on demand because of the failure of some other piece of equipment, such as power equipment, test equipment, switchboards, dehydration equipment, or pressurization equipment.

3.34 The MDCS provides a document on which maintenance personnel record, at the source, designated information concerning planned or corrective maintenance actions. The information is recorded in a coded configuration which permits machine processing. Each maintenance action is reported in this manner. Copies of the documents prepared by supply personnel for issuing parts resulting from these maintenance actions provide material and cost information to the Maintenance Data Collection Center for each activity.

3.35 Routine preservation (chipping, painting, and cleaning) and daily or weekly Planned Maintenance actions are reported.

3.36 Documentation in the MDCS is accomplished by the completion of one or more forms, as applicable, aboard ship. The following describes the three most significant forms.

a. OPNAV Form 4700-2B, Shipboard Maintenance Action, is used to record the completion of planned maintenance actions, corrective maintenance actions, and authorized alterations that have been performed at the shipboard level by shipboard personnel. All planned maintenance actions except daily and weekly preventive maintenance are recorded (see Figure 15).

b. OPNAV Form 4700-2D, Deferred Action, is used to report corrective maintenance actions that are deferred due to ship's operations, lack of repair parts, or the requirement for outside assistance. It is used to record the reason for deferral and to report the completion of the deferred action. From this form, information relating to maintenance action deferrals can be analyzed (see Figure 16).

c. OPNAV Form 4700-2C, Work Request, is used to document the need and request for outside repair or "manufacture" assistance. It is used for workload planning by repair activities (i.e., tenders, repair ships).

3.37 Figure 17 presents a functional flow diagram of the Shipboard Maintenance Action Report. Tables 8 and 9 show the "How Malfunctioned" and the "When Discovered" codes, respectively; and Table 10 presents the most significant "Action Taken" codes.

3.38 All data provided by the 3-M system are processed through ADP in the Mechanicsburg, Pennsylvania, facility as are all the standard and special reports. Since all the information is on tape, it is more appropriate to present here all the data elements which are presently punched from the source document rather than to provide a listing of the standard reports. Table 11 presents a list of the data elements punched from the various forms used by the MDCS.

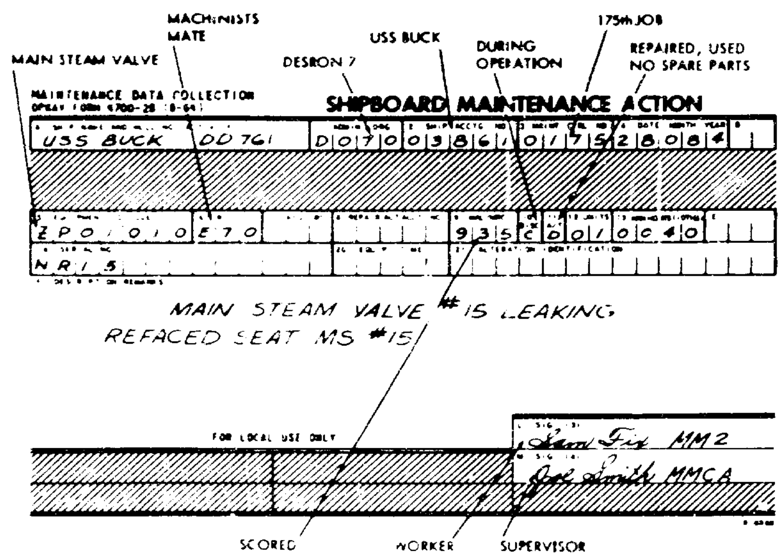


FIGURE 15. SHIPBOARD MAINTENANCE ACTION FORM

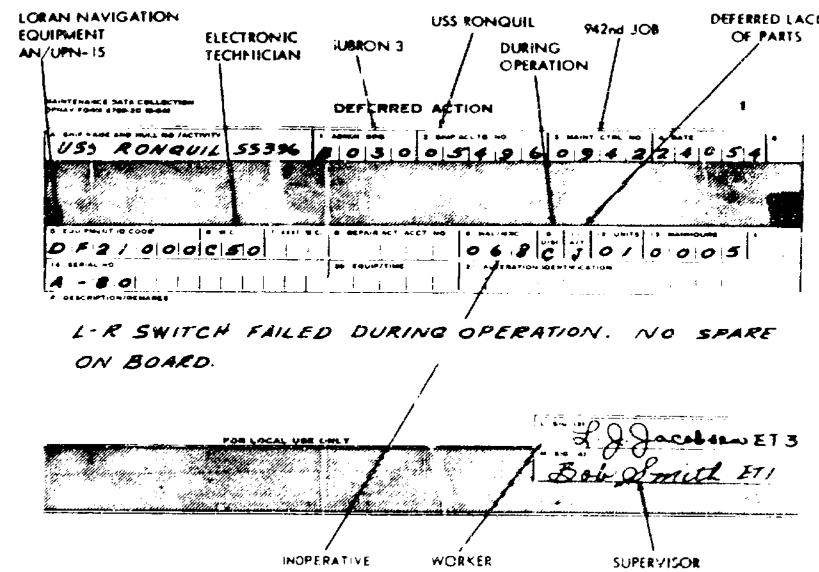


FIGURE 16. DEFERRED ACTION FORM

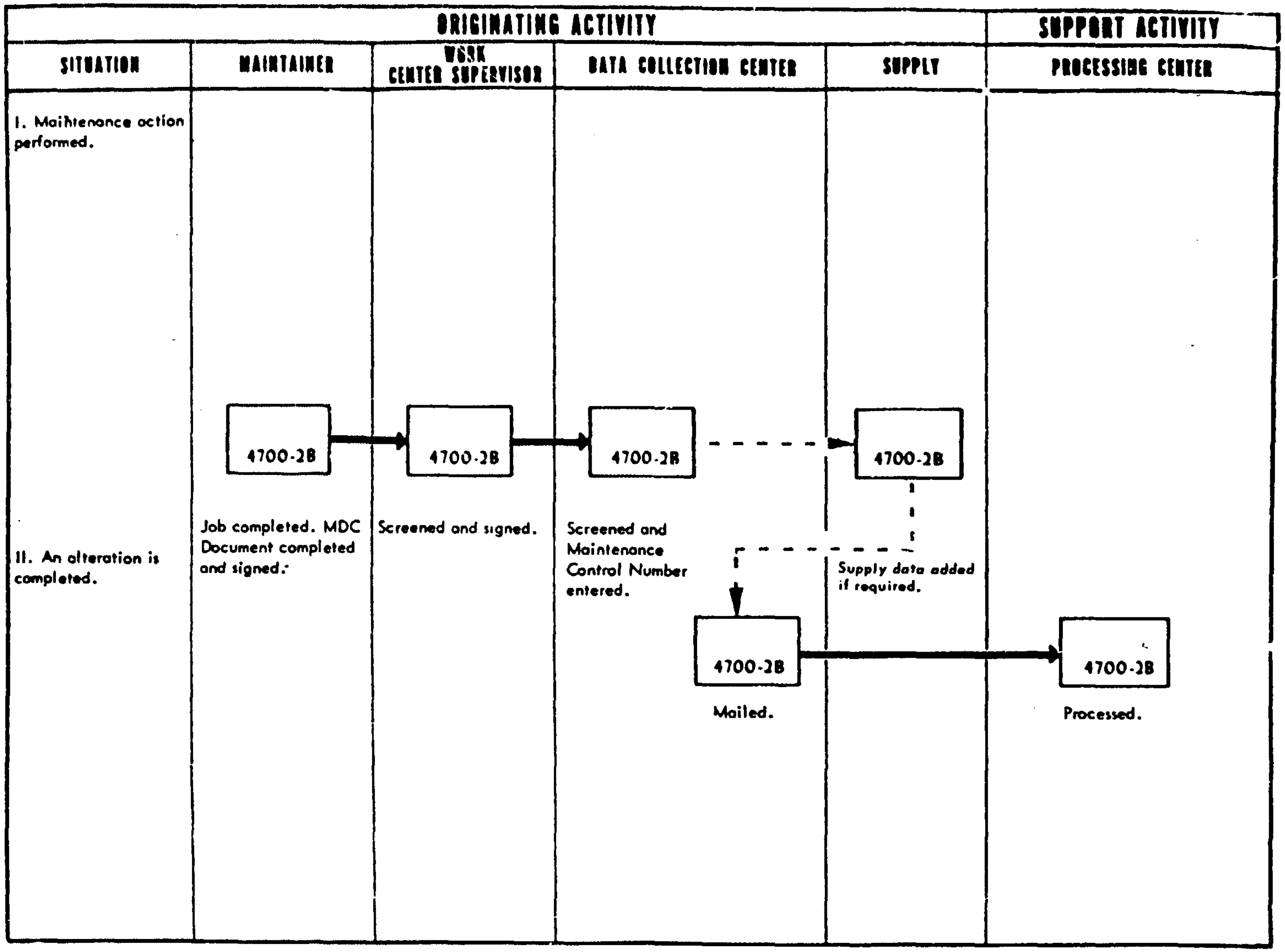


FIGURE 17. FUNCTIONAL FLOW DIAGRAM OF SMA REPORT

TABLE 8

"HOW MALFUNCTIONED" CODES

NUMERICAL ORDER	
000	No Malfunction
004	Low GM or Emission
007	Arcing, Arced
008	Noisy
015	Broken Glass
020	Worn Excessively
021	Overloaded
023	Blown
050	Blistered
051	Failed to Tune
054	Faulty Part, Material
068	Inoperative
070	Broken
080	Burned Out
088	Low Gain
091	Low Sensitivity
093	Missing Part
099	Other
116	Cut
117	Deteriorated
120	Chafed
127	Adjustment, Improper
135	Binding
148	Eroded
160	Contacts Connection Defective
161	Output, Incorrect
169	Voltage, Incorrect
170	Corroded
175	Clearance over Max
180	Clogged
185	Contaminated
190	Cracked
196	Shorted or Grounded
214	Grooved
225	Manufacturer's Defect
226	Excessive Play
230	Dirty
231	Elongated
233	Erratic
235	Dry
239	Improper Fit
242	Failed to Operate
255	No Output
259	Oversize
270	Frozen
275	Under Size
276	Weak
300	Grounded
315	RPM Fluctuating
346	Misaligned
360	Intermittent Operation
370	Jammed
374	Internal Failure
381	Leaking
428	Incorrect Reading
439	Plugged
440	Old Age
450	Open
458	Out of Balance
462	Output Too Low
464	Overspeed
472	Fuze Blown
512	Split
524	Pressure Too Low
576	Ruptured
585	Sheared
649	Sweep Malfunction
660	Stripped
665	Terminals Reversed
680	Unstable
690	Vibration Excessive
692	Video Faulty
693	Audio Faulty
700	Weak Electrically
701	Warped
710	Bearing Failure
720	Brush Failure
722	Weld Cracked or Broken
730	Loose
748	Frequency-Erratic
750	Missing
771	Scale Excessive
780	Bent
819	Contacts Do Not Open/ Close Properly
884	Lead or Terminal Broken
900	Burned
910	Chipped
929	Peeling
935	Scored
947	Torn
962	Low Power
978	Wall Thickness Not to Specification
984	Low Specific Gravity
991	Salinity Too High
992	Lost at Sea

TABLE 9

"WHEN DISCOVERED" CODES

Code	Description
A	When Lighting Off/Starting
B	When Securing
C	During Equipment Operation
D	During Preventive Maintenance (Requirement of MRC Cards)
E	Special Inspections (INSURV, Material or other Requirements Specified by Tech. Bureaus, Flt/Tycoms)
F	Underwater Hull Inspection
G	During Repair or Upkeep
H	Upon Receipt from Supply Stores
J	Unknown
K	Not Otherwise Coded
L	During Development, Test & Evaluation (For Specified Equipment Only)
0	Entered Any Time the Action Taken is A or B or the How Mal Code is 000

TABLE 10

"ACTION TAKEN" CODES

A.	PLANNED MAINTENANCE:	This code will only be used to show compliance with a maintenance requirement card (MRC) in the Planned Maintenance System. All MRC's except daily and weekly will be reported. Corrective maintenance arising from a PMS action will be documented as a separate maintenance action using When Discovered Code D.
B.	PREVENTIVE MAINTENANCE (OTHER THAN MRC):	This code will be used to show compliance with preventive maintenance requirements specified by Technical Bureaus or Fleet/Type Commanders and are NOT contained in MRC's under PMS.
C.	REPAIR (USE OF SPARE PARTS):	This code will be used when the repair is accomplished by the installation of parts. Do not use this code when only minor consumables are used.
D.	REPAIR (NO SPARE PARTS REQUIRED):	This code will be used when the repair is accomplished without the use of spare parts except for minor consumable items such as gaskets, packing solder, welding, fasteners, nuts, bolts, etc.
E.	TEST AND/OR ADJUST:	This code will be used only when the total maintenance action consists of testing and/or adjusting the item identified in the EIC.
F.	TROUBLESHOOT:	This code will be used only on the 4700-2B form. It is used to show that most or all of the manhours (Block 13) represent time spent in locating malfunctions rather than actual repair time. It will be used only if no other Action Taken Code is more appropriate.
G.	ALTERATION:	This code will be used for the installation of SHIPALT, ORDALTS, BOAT ALTS, FIELD CHANGES, ETC.
H. J. K.	SHIP's OPERATIONS: SUPPLY, LACK OF PARTS: OUTSIDE ASSISTANCE:	These codes will be used to document the manhours spent in a maintenance action (Including unsuccessful trouble shoot) which cannot be completed because of ship's operations, supply, or awaiting outside assistance. Ship's Operations are defined as ship's movements or activities which prohibit maintenance. Supply is defined as lack of parts or material required to complete a maintenance action (parts/material NOT on board).
K.	(Cont)	Outside assistance is defined as maintenance actions that cannot be accomplished or completed aboard ship due to lack of authorization, insufficient equipment, facilities, funds, etc.
L.	REMOVE:	This code will be used only when the total maintenance action consists of the removal of the item identified in the EIC.
M.	INSTALL:	This code will be used only when the total maintenance action consists of the installation of the item identified in the EIC.
N.	ASSEMBLY/ DISASSEMBLY:	This code will be used only when the total maintenance action consists of the assembly and/or the disassembly of the item identified in the EIC.
P.	MANUFACTURE:	This code will be used when the manufacture of an item is in direct support of maintenance.
Q.	MANUFACTURE (HABITABILITY AND MISCELLANEOUS ITEMS):	This code will be used only by repair ships and facilities to show actions on non-maintenance items.
R.	SERVICE:	This code will be used only when a service action such as rigging, staging, lighting, docking, etc., is in direct support of maintenance.
S.	SURVEY (NON-REPAIR ACTIVITIES ONLY):	This code will be used only when manhours have been expended on an item which is found to be beyond economical repair and/or surveyed.
	WORK REQUEST ACTIONS	
T.	CANCEL:	This code will be used only by repair ships and activities to document the fact that a maintenance action has started, and the action has been cancelled for any reason by proper authority.
U.	DISAPPROVED:	This code will be used only by squadron or division commanders to indicate that a requested job has been disapproved.
V.	WILL INVESTIGATE FURTHER:	For repair activity use only.
W.	JOB ACCEPTED WITH MODIFICATION:	This code will be used to indicate a work request has been accepted but will be modified by the repair activity and will not be fully complied with as requested.
X.	ACCEPTED:	For repair activity only

TABLE 11

DATA ELEMENTS

Administrative Organization	Assigned Assisting Work Center
Unit Identification Code	Estimated Man-Hours
Maintenance Control Number	Requesting Work Center
Date (day-month-year)	Serial-Job Description
Type Availability Code	Desired Completion Date (day-month-year)
Equipment Identification Code	Service Code
Work Center	Start Date (day-month-year)
Assisting Work Center	Source Code
Repair Activity Unit Identification Code	Unit of Issue
MAL/MRC	Unit Identification Code
When-Discovered Code	Maintenance Control Number
Action Taken Code	Cog Symbol
Units	Federal Stock Number
Man-Hours (tenths)	Additional (TSMC)
Serial/Noun	CID/APL/AEL/AN
Card Code	Reference Symbol
Alteration Identification	Quantity
Equipment Time	Unit Price
Equipment Down Time	Card Code (FO)
Assigned Work Center	

3.39 The 3-M system is continually expanding and will eventually cover all types of systems and equipment. Presently, its coverage is most extensive in the electronics area. The 3-M system is designed primarily as a maintenance accounting system providing information on material and manpower usage in terms of quantities, costs, and man-hours in the maintenance area. Although the system does contain some data on failures in terms of types, causes, and down time, the coverage in this area is not sufficient for in-depth failure analysis.

3.40 This coverage is particularly insufficient regarding human-initiated malfunctions. In its present operating mode, the 3-M system has no provisions for identifying human-initiated failures. The only treatment of human performance deals with time to repair which can be compared with a previously established standard.

3.41 It is significant to note that some major revisions to 3-M are presently being pilot-tested. These revisions contain certain features which will have an important bearing on the failure reporting aspect of the system. A change in the coding system for identifying failures is being tested which, if incorporated, will result in a significant improvement. First, there are two separate coding structures established to distinguish between failed-part condition (type of failure) and cause of failure. Further, the cause of failure is broken down into three categories: environment, quality of part, and personnel. Thus, a vehicle is being provided for identifying human-initiated malfunctions. Tables 12 and 13 present the primary failed-part condition and cause code structures.

3.42 Unfortunately, the subcategories under personnel are not particularly meaningful. It is highly questionable that, even if all the information were available on a particular failure, "lack of skills" could be distinguished from "lack of training." Also, "maintenance" and "operating accident" are not very descriptive phrases for identifying a human error. However, the major step has been taken in separating human-initiated failures, and some of the more specific definitions of the type of personnel error will evolve through actual usage and further analyses.

Fleet ASW Data Analysis Program (FADAP)

3.43 FADAP was established to provide an evaluation of the capabilities of present or future ASW forces to accomplish ASW missions. A history of tactical evolutions and current ASW exercises provides a data base for this evaluation. This data base can be used for exercise reconstruction, for use in programming ASW force levels, and as inputs to associated research, development, and procurement programs. Long-range objectives of FADAP are to satisfy Navy needs for ASW operational data, to use FADAP data for training and readiness, and to satisfy ASW analysis and evaluation capability needs.

TABLE 12

PRIMARY FAILED PART CONDITION CODE

Code	Description	Code	Description
780	Bent	428	Incorrect reading
070	Broken	082	Intermittent open
900	Burned	083	Intermittent short
080	Burned out	381	Leaking
171	Burred	004	Low GM or emission
130	Change of value	344	Melted
910	Chipped	450	Open
180	Clogged	003	Open filament
027	Collapsed	429	Peeled
160	Contacts conn. defective	520	Pitted
170	Corroded	964	Poor spectrum
190	Cracked	540	Punctured
479	Crushed	935	Scored
116	Cut	011	Screen defects
200	Dented	196	Shorted or grounded
117	Deteriorated	018	Test OK, did not work
230	Dirty	947	Torn
145	Dished/bulged	666	Twisted
231	Elongated	628	Wiped
036	Encapsulation, faulty	020	Worn excessively
061	Fused	099	Other (submit special reporting form)
001	Gassy		

TABLE 13

PRIMARY FAILED PART CAUSE CODE

Code	Description
	Environment
1A	Collision
1B	Corrosion
1C	Extreme temperature
1D	Fire damage
1E	Foreign object damage
1F	Malfunction of associated equipment
1G	Shock
1H	Weather damage
1J	Vibration, excessive
1K	Wet
1L	Other (submit special reporting form)
	Quality of Part (Procured Material)
2A	Defective material
2B	Improper fit
2C	Improper packaging
2D	Inadequate insulation
2E	Missing part
2F	Poor/incorrect electrical connections
2G	Poor/incorrect mechanical connections
2H	Poor surface/machining
2J	Wrong part
2K	Improperly assembled, manufacturer
2L	Improperly assembled, user
2M	Improper lubrication
2N	Other (submit special reporting form)
	Personnel
3A	Handling damage
3B	Lack of skills
3C	Lack of training
3D	Maintenance accident
3E	Operating accident
3F	Other (submit special reporting form)

3.44 Exercise data collected by FADAP are organized into five major files:

a. The Exercise Control File records background parameters which are relatively unchanging throughout the exercise.

b. The Vehicle Fitment File records all equipment carried by individual aircraft types and ships participating in the exercise.

c. The Exercise Incident File records critical scenes of actions in terms of "incident-defining events." Three types of events are:

1. Valid initial detection

2. A "no-detection" event

3. A false contact.

(This is the key file in the data library.)

d. The LOFAR File contains incident-defining events generated by LOFAR sonobuoys and SOSUS. These events are in a separate file because of their security features.

e. The Environment File contains meteorological and oceanographic conditions associated with the incidents.

3.45 Data are initially stored in the ASW and submarine force fleet libraries for staff analysis. After format conversion, they are forwarded to the Naval ASW Data Center which was established in Washington in 1965.

3.46 One of the difficulties in the application of FADAP is the enormous manpower requirements during exercises to record, reconstruct, and analyze incidents. These severe demands may conflict with the actual operation of the exercise.

3.47 The data elements in various files do not contain data easily related to human errors. The alternative reasons for "no-detection" events are:

a. Insufficient signal for recognition

b. Signal masked by background noise

c. Signal masked by own ship's noise

d. Target at extreme range

e. Own ship otherwise tactically engaged

f. Sensor equipment impaired or inoperative

g. Environmental interference

h. Other (specify)

i. Unknown.

3.48 None of the alternatives (except possibly h) permits the admission of human error as the cause of the "no-detection" event. Recently, however, the ASWFORLANT Scientific Advisory team has been directed to become the lead research team in the development of the FADAP Human Factors File.

PROBLEMS IN HUMAN-INITIATED FAILURE REPORTING

3.49 One underlying problem in any failure reporting system is that even if provisions are made for identifying human errors, the reporter is reluctant to incriminate himself or his fellow workers. Unfortunately, this reluctance is not unfounded, as there is a great tendency to use these reports for performance evaluation, especially in support of disciplinary actions and in promotion considerations. Interviews with personnel associated with the various reporting systems revealed that "human error" as reported by these systems is a definite factor in promotions. Specific examples were cited where unfavorable reports on individuals delayed their promotions and the failure report was used as evidence. Other incidents were mentioned where supervisors refused to sign any failure or malfunction report which implicated an individual or the crew as a whole.

3.50 It is clearly indicated that until these reports are used only for the purposes of reliability and effectiveness analyses and not for disciplinary purposes, there is little hope that meaningful data can be obtained on human performance or, for that matter, that the accuracy and usefulness of any data for analysis of equipment performance and reliability can be depended upon.

3.51 Another significant problem associated with the failure codes used by these systems is the number of possibilities that are made available for the reporter's choice. Most systems use over 100 different codes to identify a failure. The lists of these codes are diluted by such non-descriptive items as "broken," "inoperative," "failed-to-operate," or "deteriorated," which are certainly not very informative. There is a great tendency among reporters to commit to memory a few common catch-all codes and to use them extensively to identify failure.

3.52 During the course of this study, the failure history over a period of 9 months of a number of AN/SQS-23 Sonar Systems and AN/SPS-40 Radar Systems were analyzed. The analysis showed that of 94 different codes available to identify type of failure, approximately 50 percent were never used and, of those used, 7 to 9 codes identified over half the total number of failures. Table 14 shows the results of the analysis. The use of non-descriptive, catch-all phrases, such as "broken" or "inoperative," is a major contributor to this inaccuracy. It is much too easy for the technician to apply one of these phrases to cover a multitude of situations as he is filing his report. Another problem in reporting systems is the apparent interchangeable usage of causes for failure with types of failure. As an example, "terminals reversed" indicates why a system or subsystem might have failed, whereas "burned out" or "blown" indicates how the equipment failed or malfunctioned.

TABLE 14

FAILURE CODE USAGE

Systems	Number of Maintenance Actions	Number of Failure Codes Available	Number of Codes Used	Percentage of Codes Used	Codes Used Accounting for over 50 Percent of Maintenance Actions
AN/SPS-40 Radar	225	94	54	57	9 of 54
AN/SQS-23 Sonar	276	94	47	50	7 of 47

3.53 Another source of inaccuracy associated with the failure codes used by various reporting systems is that the same set of codes is used for all types of systems and equipments. This method further reduces the ability of accurately identifying the failure by the selection of the proper codes, since several codes have no relation to the systems in question. A significant improvement could be achieved in the reporting forms if the failure-identifying codes were tailored to each type of system or equipment and the same codes could be retained to identify common failures. As an example, a missile system failure report would need certain unique codes that would have no application to a communications system failure report.

3.54 The dual role of operators and maintenance personnel as reporting agents poses another problem in obtaining valid data. As long as the possibility exists for incriminating oneself or fellow workers through failure reporting, the probability of obtaining accurate information will remain very low. Industry was faced with a similar problem, which it solved by separating quality control from manufacturing. The possibility of introducing a quality control agent into the failure reporting effort should be investigated. The operator would thus be relieved of the responsibility for determining the causes and types of failure and for preparing a failure report. This function would be performed by a quality control agent who would ideally belong to a different organizational entity. This development would not necessarily result in an increased number of personnel, because the operators' time would no longer be consumed by the completion of failure reports, and a small number of them might therefore be replaced by quality control agents. These agents, of course, would be used in the fleet only during peacetime exercises, but shore-based operations would not necessarily be limited in this way. This concept is presently being practiced in many areas where, for example, contractor personnel perform the reporting function or prepare an independent report which is subsequently used for failure analysis.

CONCLUSIONS

3.55 The foregoing discussions led to the previously stated finding that existing failure reporting systems do not yield data on human-initiated malfunctions. Most of these systems have no provisions for reporting information on the relation of human performance to failures. Many of the systems do contain information which could be used for human reliability analyses which employ the indirect techniques outlined in Section IV of this report.

3.56 The problem of self-incrimination associated with reporting human-initiated malfunctions is further amplified by the Navy's use of information obtained from these systems for personnel evaluation. The use of these reports should be relegated to analysts and effective systems management.

3.57 One of the major problems in existing failure reporting systems is the forms that are used by these systems. The forms often contain superfluous or confusing information which detracts from the main purposes of the reports. The coding structure identifying types and causes of failure often contains several nondescriptive items or catch-all phrases that are meaningless from the standpoint of reliability analysis. The same codes are used for all categories of equipment even though some of the codes have application to only specific equipments or systems.

3.58 The introduction of a "quality control" agent into the failure reporting cycle might make the reports more accurate and might lead to the inclusion of information on human performance.

3.59 Specific recommendations for improvement of, and studies dealing with, human-initiated malfunction reporting are presented in Section V.

IV. INDIRECT APPROACHES

INTRODUCTION

4.1 As discussed in the preceding section, reporting of human-initiated malfunctions poses some significant problems, some of which may require major changes in operating philosophy and to existing reporting systems. However, as was discussed in preceding sections, without meaningful data on human performance human reliability will not be able to take its rightful place in systems effectiveness considerations. The researcher in the field of human reliability is thus faced with the dilemma of needing data from the "hardware world" but discovering that the same "world" is not particularly sympathetic to his problem of obtaining the required information.

4.2 ORI has developed two techniques which, in the final analysis, complement each other to provide meaningful information on human performance which can then serve as the basis for human reliability analysis. These two techniques are referred to as indirect approaches, because neither relies on the direct reporting of human-initiated failures and malfunctions. Rather, they both use equipment failure data and information on the composition of the crew which operates and maintains the equipment.

4.3 One of these techniques is termed the Elementary Reliability Unit Parameter Technique (ERUPT). This approach, which groups the components of a weapon system into elementary reliability units (ERUs), provides a means of inferring two human performance parameters from available equipment reliability and maintenance data.

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4.4 The second approach relates certain personnel characteristics of individuals operating and maintaining the equipment to numbers of failures and equipment repair times by the application of multivariate correlation analysis techniques.

4.5 During the course of this study, the feasibility and applicability of the two approaches were investigated, and mathematical models and equations were developed for their application. A pilot test on a limited data base was also conducted during the development of the two techniques.

4.6 The remainder of this section describes the formulation and application of the two models. The appendices to this report contain the mathematical development of the models and the detailed results of the pilot tests.

ERUPT

4.7 ERUPT quantifies two measures of human performance during maintenance as part of a model which evaluates system readiness. The most significant feature of the technique is that the quantification of these human performance parameters can be accomplished by using equipment failure and maintenance data without relying on human-initiated failure reporting.

Description of the Model

4.8 ERUPT, for human reliability analysis, is embodied in a model expressing weapon system readiness. Two of the parameters that comprise the model are specifically related to human performance during maintainability.

a. α – the probability that failure is detected and repaired during maintenance

b. β – the probability that maintenance does not induce failure.

4.9 The model consists essentially of equations and computational routines for deriving system measures of effectiveness from failure and maintenance parameters. Two such measures of effectiveness have been defined.

a. Readiness reliability. Probability that the weapon is operable at the time of its operating mission or, more generally, probability that the weapon is in "go" condition when it is needed.

b. Mission-tactic reliability. Probability that the weapon will successfully carry out a given mission with a prescribed tactic, assuming the weapon is ready (operable) at the beginning of the mission.

4.10 Of these two measures, only readiness reliability was considered in this research effort, since only the two human performance parameters, α and β, were applicable to that aspect of system effectiveness. The characteristics of the weapon system used in the development of the technique are such that no human interaction is required during its actual operational phase. However, the results of this feasibility study clearly indicate that the same techniques can be applied with some modifications to other systems in all phases of their operational usefulness.

4.11 The equations for readiness reliability are given in Appendix A.

<u>ERU</u>

4.12 One of the most important concepts associated with the application of ERUPT is the grouping of system components into ERUs. The selection of ERUs is based on the maintenance level established for the system. Maintenance level in this context is defined as the lowest type of equipment indenture at which maintenance is performed. Level of indenture is a term describing the breakdown of a system or equipment into its components. Thus, if the first level of indenture were the whole equipment, then the second level would be the components that make up the equipment.

4.13 It is significant that the selection of ERUs does not pose a problem for anyone who is reasonably familiar with the system, the function of the various components or subsystems, and the maintenance plan for that system. The latter is involved with the throwaway concept which identifies the level of indenture of the system at which equipments or components will be maintained and repaired rather than replaced. Failure of an ERU implies no useful input and, therefore, a no-go condition. This ERU failure will also imply that the system is in a no-go condition.

4.14 The skill level of the maintenance technician is also related to the indenture level at which the equipment is maintained and repaired. The following chart illustrates this point. The shaded areas indicate the indenture levels at which a technician of a given skill level can be utilized.

Skill Level \ Level of Indenture	High	Medium	Low
High			
Medium			
Low			

4.15 The lower the indenture level, the higher the skill level that will be required on the part of the technician. He will be required to perform more detailed and complex maintenance and repair functions, the more detailed the component he repairs. Conversely, as the indenture level is raised, the maintenance and repair activities become less critical and, consequently, a technician with a lower skill level can meet the manpower requirement, although a higher skilled technician could still be used.

4.16 This form of analysis can be carried one step further to include α and β. Intuitively, it can be stated that the probability of detecting and repairing a failure or of not inducing a failure will increase with the skill level of the technician and will increase as the indenture level is increased. As the indenture level increases, the maintenance or repair activity is less complex and repairs will also probably occur at longer time intervals. Thus, different values of α and β can be calculated for each of the nine areas on the chart.

4.17 This type of analysis can have a major impact on the selection of the optimum packaging technique to be employed in the development of a new weapon system. The impact of different packaging concepts on α and β and the skill levels of the technician can be readily ascertained. This approach lends itself to trade-off analyses, particularly when costs are estimated for training personnel to various skill levels and costs are estimated for the equipment using different packaging concepts. Limiting factors of equipment size and weight dictated by usage also affect the packaging concept and thus can be related to the personnel parameters.

4.18 Readiness reliability for the weapon system is the product of the readiness reliabilities of individual ERUs. The formulation of ERU readiness reliability considers the impact of exercise and maintenance on an ERU until the time it is called on to carry out a prescribed mission.

4.19 The model for the calculation of ERU readiness reliability functions by first using ERU failure and maintenance data to estimate values of the human performance parameters (α and β). Data needed are as follows:

a. Probability that the ERU, which is in a nonfailed condition at the time a test is initiated, survives the test (derived from laboratory test data)

b. Storage time between planned maintenance of each ERU

c. The mean time to failure established for each ERU

d. Number of maintenances before repair/replacement of the ERU since the beginning of storage or since last repair of the ERU if corrective maintenace has been done previously.

4.20 The method for estimation of values for α and β parameters for an ERU is based on actual shipboard failure experience and maintenance data for the ERU. Essentially, a mathematical function involving α, β, and other hardware parameters represents the probability that the actual pattern of failures occurred, given various values of the parameters. A computer programmed search is then initiated to identify the set of values for α and β which would maximize that probability. That set of values is the maximum likelihood estimate of α and β. A complete mathematical formulation of the calculation of the human performance parameters is included in Appendix A. The general thought is that, if "inherent" or "true" hardware component failure rates can be determined under controlled conditions, then the expected reliability of the ERUs can be calculated. Then, based on failure rates of these ERUs under actual conditions obtained from maintenance reports, it will be possible to infer the α's and β's from the differences.

4.21 With the values of α and β just calculated, two data elements, in addition to those in paragraph 4.19, are required to calculate the readiness reliability for each ERU at any time following manufacture. The additional data needed are:

a. Storage time of the ERU between last planned maintenance and time of the operating mission

b. Number of tests of ERU before its operating mission.

4.22 Figure 18 shows graphically the events and associated probabilities that comprise the life cycle of an ERU until the time of its operating mission. Arrows show the various times that the ERU can go from a nonfailed to a failed condition and vice versa.

4.23 When the readiness reliability is calculated for each ERU, the readiness reliability for the entire weapon system is found simply by multiplying the ERU readiness reliabilities. It should be emphasized that the equations developed for readiness reliability are applicable to any weapon system which meets the underlying assumptions of the model.

4.24 However, it also is true that the readiness reliability measure of effectiveness is not the only measure that can accept ERUPT human reliability parameters; they can be incorporated equally as well into other models of system reliability.

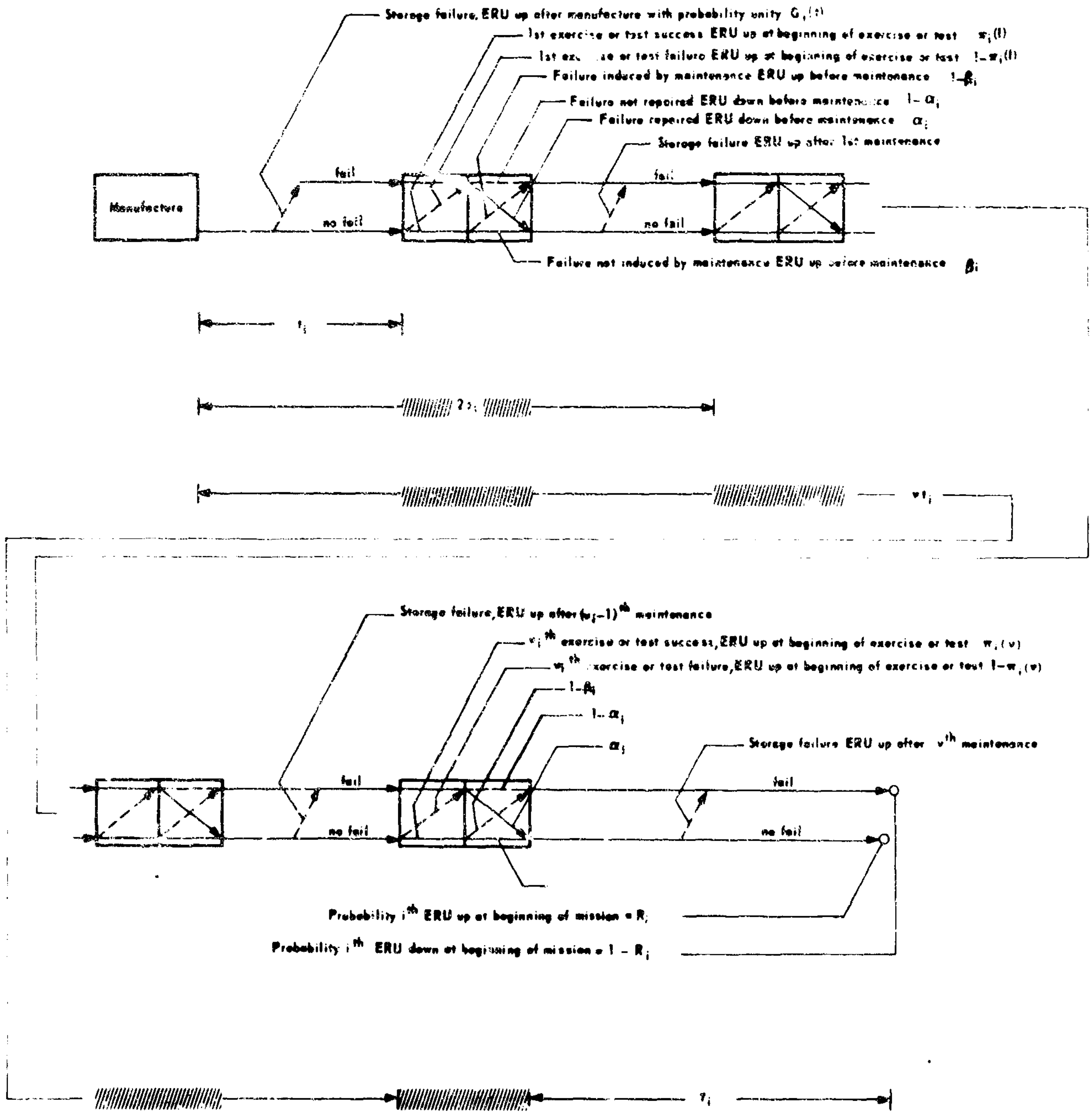

FIGURE 18. TYPICAL ERU LIFE CYCLE BEFORE TIME OF MISSION

Test Results

4.25 Calculation of α and β. The mathematical formulation that provides statistical estimates of α and β (Appendix A) was tested by using input data which, although not from an operating weapon system, are believed to be realistic. Appendix D shows the sets of data used with the formulations, together with values of α and β calculated from the data. Also shown is a copy of the computer printout for the first set of data.

4.26 In interpreting test case 1 results, a total of five different samples (ΣN_i) of shipboard corrective maintenances showed that two were not preceded by preventive maintenance before the repair, two were preceded by one preventive maintenance before the repair, and one was preceded by two preventive maintenances. The best statistical estimates of α and β, based on those experiences and the failure distribution shown, are $\alpha = 0.98$ and $\beta = 0.33$. These values seem reasonable because corrective maintenances were occurring so quickly that it is unlikely that malfunctions were being overlooked (α) to any great extent. However, it does seem possible that malfunctions were being induced frequently during the preventive maintenances (β).

4.27 Contrast that example with test case 4 in which 8 to 10 preventive maintenances preceded each repair or corrective maintenance action. In this case, it seems likely that the malfunctions were not being detected promptly during preventive maintenances. This is reflected in the low 0.16 value of α estimated.

4.28 The input specifications, flow chart, and computer program instructions for the estimation of α and β are given in Appendix B.

Sensitivity Analysis of α and β

4.29 Under a separate subcontract with the Naval Ordnance Laboratory (NOL), ORI did preliminary work on the sensitivity on system readiness reliability to changes in α and β the human reliability maintenance parameters. The assessment was in support of the development program of a new weapon system.

4.30 Significant among the findings was the fact that readiness reliability is quite sensitive to human maintenance parameters. The weapon system consisted of 275 ERUs and, to bring the readiness reliability to an acceptable level, it was necessary to bring the probability of detecting a malfunction and the probability of not inducing a malfunction very close to unity.

4.31 Parameters and Assumptions Used. Table 15 shows the readiness parameters used in this assessment and the assumptions necessary for this preliminary sensitivity analysis.

4.32 Table 16 presents the selected values of the model input parameters which were used in the computations.

4.33 In Figure 19, the calculation of the readiness reliability based on various combinations of these values is plotted against α, the probability of detecting a malfunction which fails in storage or test.

4.34 As shown in the plot, readiness reliability falls off rapidly for α near 0.9 as β moves away from unity and ERU storage failure rates increase. However, with β near unity and low storage failure rates, α has very little impact on readiness.

4.35 Comparison of curves with all parameters held constant except β shows the large impact of β on readiness reliability. A decrease in β from 1.0000 to 0.9990 causes a decrease in readiness ranging from 0.08 to 0.18 depending on the values of the other parameters. This fact dictates that there must be unusual emphasis placed on the attainment of values of β close to unity for complex weapon systems with a large number of ERUs.

4.36 This demonstration clearly shows the advantages of an analytic model. Such sensitivity analyses can show which of the parameters is most responsible for large decreases in system readiness reliability and can provide relative quantitative values of the significance of each of the parameters.

Conclusions

4.37 The ERUPT approach appears to be feasible for human reliability analysis and has several advantages over other approaches investigated. To summarize the key features again:

a. It does not require direct reporting of human errors by personnel who may be extremely biased

b. It requires only hardware failure and maintenance data

c. The data required are simple and will not necessitate new data collection studies

d. Based on the specific weapon system readiness reliability model used to test the feasibility of the ERUPT approach, system readiness reliability is extremely sensitive to values of β (the probability that maintenance does not induce failure).

TABLE 15

READINESS PARAMETERS

Parameter	Assumptions
Storage time between maintenances	Same for all ERUs
Storage failure rate	Fraction of functional failure rate for electronic ERUs; zero for mechanical ERUs
Probability of surviving test	Same for all ERUs
Probability of repairing storage or test failures	Same for all electronic ERUs; unity for mechanical ERUs
Probability of maintenance not inducing failure	Same for all electronic ERUs; unity for mechanical ERUs

TABLE 16

READINESS RELIABILITY INPUT VALUES

α	β	π	λ_i'	t, months
0.900	0.9990	1.00	$\lambda_i/1000$	3
0.950	1.0000		$\lambda_i/100$	12
0.990				
0.995				
1.000				

α = probability of repairing malfunction in ERU which occurs in storage or test.

β = probability of not inducing malfunction in ERU which survives storage and test.

π = probability of ERU surviving test.

λ_i' = storage failure rate of i^{th} ERU.

λ_i = functional failure rate of i^{th} ERU.

t = time between maintenances in months.

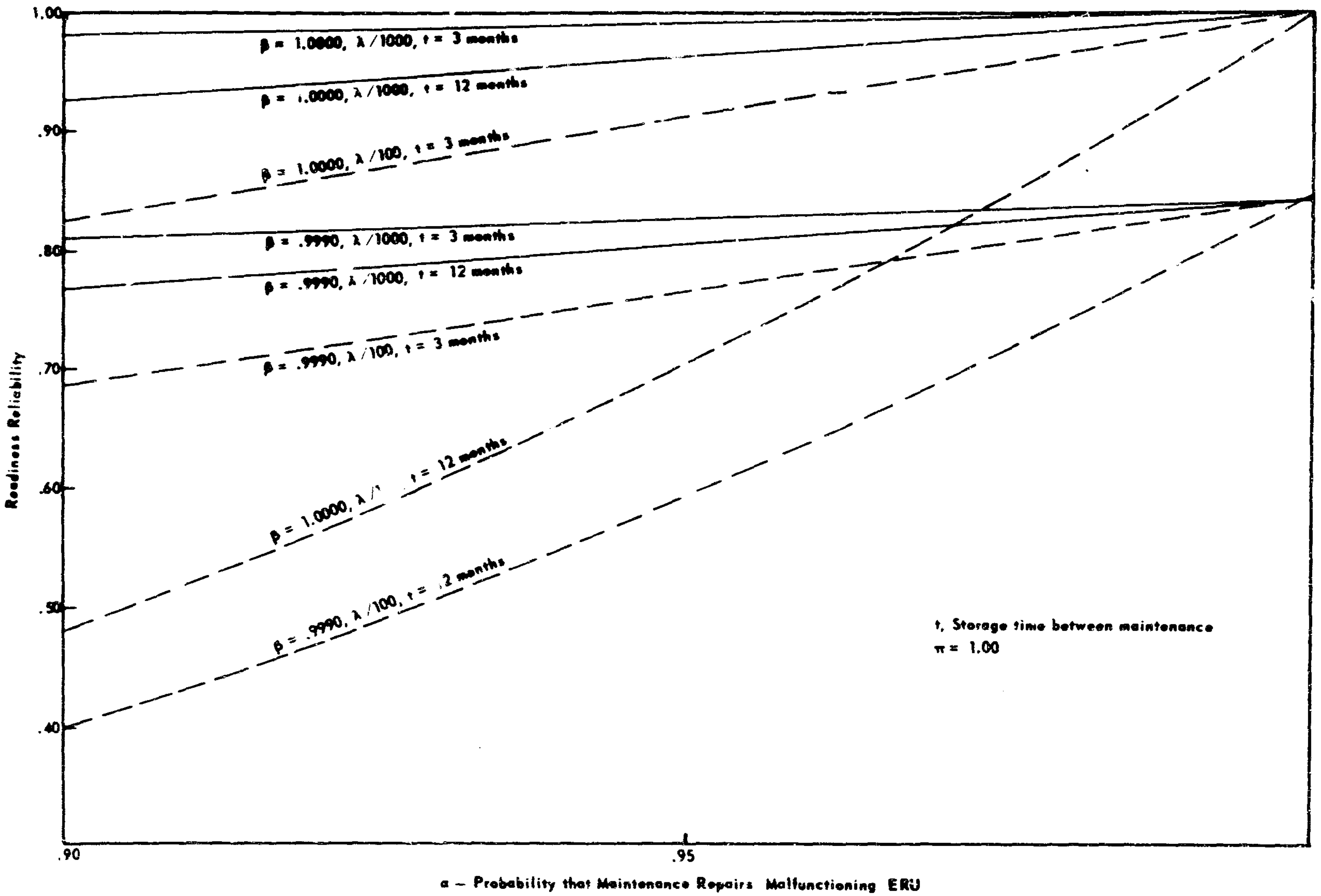

FIGURE 19. SENSITIVITY ANALYSIS OF α AND β

4.38 This research has indicated that meaningful quantitative information on human performance can be derived by an indirect method of hardware failure and maintenance data. The ERUPT approach provides a basis for meaningful human reliability analysis and is felt to have wide applicability to present and planned new weapon systems.

MULTIPLE CORRELATION APPROACH

Introduction

4.39 Present Navy failure reporting systems do not yield data on human errors or human performance. This general conclusion is developed in Section III.

4.40 The multiple correlation approach attempts to derive some useful information on human reliability from present systems. This approach does not attempt to provide a numerical value for human reliability as a part of system effectiveness. Instead, the technique attempts to identify personnel characteristics which show the greatest effect on the rate of equipment failure and repair through multiple correlation analysis.

4.41 Multiple correlation analysis is a well-known statistical technique used to measure the degree or importance of the relationship between a dependent variable (or criterion) and a set of independent variables (or predictors). The relative importance of each of the predictors can be assessed. Initially, hypotheses are formulated concerning this relationship between dependent and independent variables. Multiple correlation analyses then assess the interrelationships between these variables.

4.42 If multivariate correlation analysis can identify those personnel characteristics which significantly influence equipment failure and/or mean time to repair, it will make a great contribution to the establishment of requirements for recruitment, training, and distribution of personnel. The following paragraphs describe the approach, show the results of a pilot application, and make recommendations for verification of these results and the extension of the technique to new equipments.

Description of the Approach

4.43 The two reporting systems presently operating in the Navy and chosen for use in the multivariate analysis approach were the 3-M system and the Active Duty Enlisted Master File maintained in Pers 19.

4.44 The 3-M system can provide preventive and corrective maintenance actions data for specific equipments over time as part of MDCS. A more complete description of the 3-M system is presented in Section III of this report.

4.45 Two measures of equipment failure and repair were identified from 3-M reports: first, the number of malfunctions or corrective actions taken during specified periods of time and, second, the mean time taken to repair these malfunctions.

4.46 Discussions with experienced naval personnel led to the formulation of hypotheses concerning personnel characteristics which may be highly correlated with these two measures. The hypotheses required personnel dat which were available from the Active Duty Enlisted Master File under Pers 19.

4.47 The Active Duty Enlisted Master File contains hundreds of personnel characteristics related to the identification, qualifications, education, and assignment of all active duty enlisted personnel. After consideration of the hypotheses, seven personnel characteristics were selected for use from this file.

a. Age

b. Pay grade

c. Number of months since Active Duty Base Date (ADBD)

d. Number of months until Expiration of Active Obligated Service (EAOS)

e. Years of formal education

f. Possession of Navy Enlisted Classifications (NEC) pertinent to equipment under study

g. Training time in specialized "C" schools, i.e., "C" schools directly related to equipment under study.

4.48 The AN/SPS-40 radar and the AN/SQS 23B sonar were selected for the feasibility study. The selection of these equipments was based on the availability of data which were believed to be reasonably accurate during the time period chosen for the test.

4.49 The AN/SPS-40 radar is operated by Radarmen (RD) and maintained by Electronics Technicians (ET). The AN/SQS-23B sonar is operated and maintained by Sonar Technicians (ST).

4.50 The assumption was made that both operators and maintenance personnel affect the equipment rate of failure (number of malfunctions) through their errors. Therefore, personnel data from both the RD and ET ratings were correlated with 3-M equipment failures for the AN/SPS-40 radar. Similarly, personnel data for the ST rating were used to test for significant statistical relationships with the number of malfunctions for the AN/SQS-23B sonar.

4.51 It can also be hypothesized that personnel characteristics of both operators and maintenance personnel (RD and ET) are correlated with mean time to repair for the AN/SPS-40 radar. Similarly, personnel data from the ST rating can be correlated with mean time to repair for the AN/SQS-23B sonar.

4.52 Data were acquired for both equipment and personnel parameters for the period of October 1965 through September 1966. They were subsequently grouped into 3-month intervals because it was felt that this period of time would allow significant variance in the values of the parameters, and would also permit a sufficient number of sample data points to establish significant relationships.

4.53 Equipment failure and maintenance 3-M data for the AN/SPS-40 radar were available for the three quarters, October-December 1965, January-March 1966, and April-June 1966. Data for the AN/SQS-23B sonar were available for the same three quarters plus the July-September 1966 quarter.

4.54 Equipment maintenance and personnel data were used from a selected sample of ships which had sonar or radar equipment on board during the time periods selected and for which both personnel and equipment data were available. Table 17 identifies the ships used in the sample by type and hull number.

4.55 After some manual data tabulation, equipment failure, repair, and personnel data for each ship in each 3-month period were correlated. Thus, the number of malfunctions in the AN/SPS-40 on the DD 846 that occurred in the January-March 1966 quarter was compared with the personnel characteristics of all ETs aboard for that quarter. The number of malfunctions was also compared with the personnel characteristics of the RDs aboard the same ship in the same quarter. Each set of values for the equipment and personnel data for a given ship in one of the selected 3-month periods is a sample point for use in the multivariate correlational analyses. The methodology used is described in Appendix E.

TABLE 17

SHIPS CHOSEN FOR THE ANALYSIS

AN/SPS-40 Radar		AN/SQS-23B Sonar
DD 692	DD 785	CLG 7
DD 693	DD 787	DD 836
DD 694	DD 788	DD 851
DD 698	DD 823	DD 852
DD 699	DD 843	DD 870
DD 703	DD 846	DD 888
DD 755	DD 862	
DD 759	DD 869	
DD 761	DD 871	

4.56 The criterion variables used in the analysis and applied to each of the equipments are:

a. Mean number of man-hours to repair
b. Mean number of man-hours to repair by type of failure
c. Number of repairs (malfunctions)
d. Number of repairs by type of failure.

4.57 Criterion variable c reflects a count of the total number of repairs that occurred on each ship in each quarter. Variable d classifies these into one of 94 different types of malfunctions as coded by the 3-M system. Criterion variables a and b are self-explanatory.

4.58 The following predictor variables were used in the analysis and applied to each of the equipments:

1. Average age
2. Average pay grade *
3. Average number of months since ADBD
4. Average number of months until EAOS
5. Years of formal education
6. Percent of personnel allowance actually aboard
7. Percent of personnel with NEC pertinent to equipment **
8. Average weeks of training time in specialized "C" schools
9. Average number of months since ADBD for the highest ranked man
10. Years of formal education of the highest ranked man ***
11. Average number of months remaining to EAOS for all men serving their first enlistment. ****

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* In calculating variables 2 and 5, a numerical pay grade was assigned to pay grades and years of education.

** Reference was made to the Manual of Navy Enlisted Classifications[16/] to determine NECs applicable to the equipments; these were:

Equipment	Applicable NECs
AN/SPS-40	1514
AN/SQS-23B	0407, 0484, 0486, 0487, 0488, 0494, 0496

*** In calculating variable 10, a numerical code was assigned to year of education.

**** Men serving their first enlistment are defined as those whose ADBD subtracted from their EAOS resulted in a number less than or equal to 4 years.

4.59 All of the predictor variables were applied to all men in each of the RD, ET, and ST ratings who were aboard a given ship during a given quarter selected for the sample.

4.60 The alternate hypotheses based on these variables are:

a. Average age is negatively correlated with average time to repair and number of malfunctions

b. Average pay grade is negatively correlated with average time to repair and number of malfunctions

c. Average number of months for all personnel since ADBD is negatively correlated with average time to repair and number of malfunctions

d. Average number of months for all personnel until EAOS is negatively correlated with average time to repair and number of malfunctions

e. Average formal education is negatively correlated with average time to repair and number of malfunctions

f. Percent of personnel allowance actually aboard is positively correlated with mean time to repair and negatively correlated with number of malfunctions

g. Percent of personnel with NEC pertinent to equipment is negatively correlated with mean time to repair and number of malfunctions

h. Average training time in specialized "C" schools is negatively correlated with mean time to repair and number of malfunctions

i. Time since ADBD for the highest ranked man is negatively correlated with mean time to repair and number of malfunctions

j. Formal education of the highest ranked man is negatively correlated with mean time to repair and number of malfunctions

k. Average number of months remaining until EAOS for all men serving their first enlistment is negatively correlated with mean time to repair and number of malfunctions.

4.61 The null hypothesis associated with each of these hypotheses is that the personnel (or predictor) characteristic is not related to the equipment (or criterion) variable.

4.62 In addition, multiple correlations were run using a combination of personnel characteristics in order to find significant relationships with each of the equipment parameters.

4.63 Initial correlation analyses between equipment repairs and malfunctions in each quarter and characteristics of the personnel in the same quarter showed no significant multiple correlations. These results point out that the characteristics of the people working on the equipment in any quarter have little effect on the number of malfunctions in that same quarter.

4.64 However, it also seemed plausible that their errors may not result immediately in malfunctions or lengthy repairs but may cause failures in succeeding quarters. Thus, analyses have been made that correlate personnel data in one quarter with the equipment failure parameters 3 months or 6 months later.

4.65 Also considered was the possibility that changes from quarter to quarter in personnel and equipment failure data would be more sensitive to significant relationships than the actual data. Inspection of the personnel showed a fairly low turnover from one quarter to the next. Using the changes in personnel and failure data also eliminates any possible trends which may occur on a given ship over a series of time periods causing spuriously high correlations. Therefore, a limited number of analyses was done using changes rather than actual data. The number was limited because of the resulting decreased sample size.

4.66 Table 18 shows all of the analyses run with the sample size for each. Correlations were run using the "no output" malfunction of the AN/SPS-40 and the "burned out" malfunction of the AN/SQS-23B as the criterion variables. These two malfunctions were chosen because they occurred more frequently than any other on the respective equipments.

<u>Results</u>

4.67 <u>Summary</u>. Five multiple correlations are significantly different from zero at the 95 percent confidence level. All significant multiple correlations relate personnel characteristics from one quarter to equipment failures or repairs occurring in the next quarter.

4.68 There were also 9 gross correlations involving 6 personnel parameters which were significantly different from zero.

TABLE 18

CORRELATION CASES RUN

Description	Case Number	Sample Size
Radarman		
Actual data		
All malfunctions reported		
No lag	1	50
Lag 3 months	2	33
Lag 6 months	3	16
"No output" malfunction		
No lag	4	24
Lag 3 months	5	18
Change data		
All malfunctions reported		
No lag	6	31
Lag 3 months	7	15
Electronic technicians		
Actual data		
All malfunctions reported		
No lag	8	50
Lag 3 months	9	33
Lag 6 months	10	16
"No output" malfunctions		
No lag	11	24
Lag 3 months	12	18
Change data		
All malfunctions reported		
No lag	13	31
Lag 3 months	14	15
Sonar technicians		
Actual data		
All malfunctions reported		
No lag	15	23
"Burned out" malfunction		
No lag	16	16
Change data		
All malfunctions reported		
No lag	17	17

4.69 Multiple Correlations. There are five significant multiple correlations.

a. Changes from quarter to quarter in the average time since ADBD and average formal education of the radarmen are significantly related to the quarterly changes in the total number of AN/SPS-40 malfunctions. The actual correlation was 0.693 and one can be 95 percent confident that the true correlation is greater than 0.23.*

b. The percentage of electronics technicians with an NEC pertinent to the AN/SPS-40 radar and with the average training time in specialized "C" schools is significantly related to the total number of malfunctions. The actual correlation was 0.482 and, with 95 percent confidence, it can be said that the true value of the correlation is greater than 0.13.*

c. Changes from quarter to quarter in the average time since ADBD and the percentage of radarmen aboard to the radarman allowance are significantly related to changes from quarter to quarter in the mean time to repair all malfunctions of the AN/SPS-40. The actual correlation was 0.809 and there is again 95 percent confidence that the true correlation is greater than 0.53.*

d. The average time until EAOS for both electronics technicians serving their first enlistment and all ETs combined and the percentage of electronics technicians with an NEC pertinent to the AN/SPS-40 are significantly related to the mean time to repair all malfunctions. The actual correlation was 0.616 and statistical theory indicates 95 percent confidence that the actual correlation is greater than 0.34.*

e. Changes from quarter to quarter in the average pay grade and the percentage of electronic technicians with an NEC pertinent to the AN/SPS-40 are significantly related to the quarterly changes in the mean time to repair all malfunctions of the AN/SPS-40. The actual correlation was 0.646 and again, it is 95 percent certain that the true correlation is greater than 0.15.*

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* Approximate value obtained through interpolation in graphs.[17]

4.70 There are several interesting observations that can be made concerning these findings. First, each significant relationship involved characteristics of personnel in the quarter prior to the equipment failure or repair.

Time Lag to Failure	Significant Correlations	Nonsignificant Correlations	Total
Cases with no lag	0	18	18
Cases with 3-month lag	5	7	12
Cases with 6-month lag	0	4	4

4.71 This observation suggests that there may be a lag between the time a person causes a failure in some manner and the time when the failure actually occurs and is repaired.

4.72 The second observation that can be made is that all significant multiple correlations involved the AN/SPS-40 radar. None occurred with the AN/SQS-23B sonar, which may be attributable to the reduced sample size.

4.73 Third, none of the multiple correlation analyses involving specific malfunctions was significant. All significant analyses used the total number of all types of malfunctions. This situation may be due to the generally small sample sizes available for specific malfunctions.

4.74 Complete listings of all maximum multiple correlation coefficients are found in Tables 19 and 20. An ORI computer program furnished correlations for all possible combinations of personnel characteristics with each of the equipment parameters. For each multiple correlation analysis using a different number of variables, only that analysis showing the highest correlation was selected for exhibit. In all cases, the correlation coefficients were adjusted (decreased) for degrees of freedom and sample size according to the formula presented in Appendix E. This adjustment accounts for the fact that some have a value of zero. Beside each coefficient are the coded numbers for the personnel characteristics entered into the multiple correlation analysis.* Blank spaces in the table result because not all personnel characteristics were used in each correlation analysis either because of lack of data or as a result of the judgment that there was no logical reason why it should be related with the criterion.

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*The numbers correspond to the predictor variables numbered in paragraph 4.58.

TABLE 19

MAXIMUM MULTIPLE CORRELATION COEFFICIENTS[a] (R) WITH NUMBER OF MALFUNCTIONS

Description of Cases	For 2 Variables		For 3 Variables		For 4 Variables		For 5 Variables		For 6 Variables		For 7 Variables		For 8 Variables		For 9 Variables	
	R	Predictors[d]	R	Predictors	R	Predictors	R	Predictors	R	Predictors	R	Predictors	R	Predictors	R	Predictors
RADARMAN																
Actual data																
All malfunctions reported																
No lag	0.137	4,11	0.044	3,4,11	0	–	0	–	0	–	0	–				
Lag three months	0.268	3,5	0.375	2,3,5	0.420	1,2,3,5	0.398	1,2,3,4,5	0.362	1,2,3,4,5,6						
Lag six months	0.146	4,6	0.193	3,4,6	0	–	0	–	0	–						
"No output" malfunction																
No lag	0.460	1,2	0.460	1,2,4	0.426	1,2,4,5	0.378	1,2,4,5,6	0.314	1,2,3,4,5,6						
Lag three months	0.507	2,6	0.502	2,5,6	0.520	1,2,3,11	0.523	1,2,3,6,11	0.464	1,2,3,4,6,11	0.373	1,2,3,4,5,6,11				
Change data																
All malfunctions reported																
No lag	0.341	1,2	0.507	1,2,6	0.491	1,2,3,6	0.529	1,2,4,6,9	0.536	1,2,4,5,6,9	0.520	1,2,4,5,6,9,10	0.494	1,2,3,4,5,6,9,10		
Lag three months	0.593[c]	3,5	0.767[b]	2,4,5	0.782[b]	2,4,5,6	0.793	2,3,4,5,6	0.814	1,2,3,4,5,6						
ELECTRONIC TECHNICIANS																
Actual data																
All malfunctions reported																
No lag	0.203	4,7	0.215	2,4,7	0.214	2,4,7,8	0.183	2,4,5,7,8	0.220	1,2,4,5,7,8	0.179	1,2,3,4,5,7,8	0.073	1,2,3,4,5,7,8,11		
Lag three months	0.482[c]	7,8	0.485[b]	4,7,8	0.533[b]	1,3,7,8	0.545	2,4,7,8,11	0.550	1,3,4,7,8,11	0.536	1,2,3,4,7,8,11	0.518	1,2,3,4,5,7,8,11		
Lag six months	0.466	3,11	0.586	1,3,11	0.584	1,3,5,11	0.530	1,3,5,8,11	0.464	1,3,5,7,8,11	0.343	1,3,4,5,7,8,11	0	1,2,3,4,5,7,8,11		
"No output" malfunction																
No lag	0.202	2,8	0.260	2,7,8	0.236	2,5,7,8	0.153	2,4,5,7,8	0.226	2,4,5,7,8,11	0	–	0	–		
Lag three months	0.486	2,8	0.479	2,4,8	0.431	2,3,4,8	0.366	2,3,4,5,8	0.248	2,3,4,5,7,8	0	–	0	–		
Change data																
All malfunctions reported																
No lag	0	–	0	–	0	–	0	–	0	–	0	–	0	–	0	–
Lag three months	0.520	4,7	0.634	5,7,11	0.718	3,5,7,11	0.759	3,4,5,7,11	0.771	3,4,5,7,8,11	0.735	2,3,4,5,7,8,11	0.689	2,3,4,5,7,8,9,11	0.608	1,2,3,4,5,7,8,9,11
SONAR TECHNICIANS																
Actual data																
All malfunctions reported																
No lag	0.479	5,6	0.465	4,5,6	0.529	3,5,7,8	0.505	1,3,5,7,8	0.469	1,3,5,6,7,8	0.414	1,2,3,4,5,7,8	0.347	1,2,3,4,5,6,7,8		
"Burned out" malfunction																
No lag	0.343	6,8	0.369	2,6,8	0.280	4,5,6,8	0.093	1,2,5,6,8	0	–	0	–	0	–		
Change data																
All malfunctions reported																
No lag	0.203	3,6	0	–	0	–	0	–	0	–	0		0	–		

a/ All correlations have been adjusted to take into account sample size and degrees of freedom.

b/ The correlation is significantly different from zero at the 95% confidence level.

c/ The correlation is significantly different from zero at the 95% confidence level, and the addition of another personnel variable does not significantly increase the correlation.

d/ Numbers refer to personnel characteristics as indicated in original list in paragraph 4.58.

TABLE 20

MAXIMUM MULTIPLE CORRELATION COEFFICIENTS [a] ($\bar{R}$) WITH MEAN TIME TO REPAIR

Description of Cases	For 2 Variables		For 3 Variables		For 4 Variables		For 5 Variables		For 6 Variables		For 7 Variables		For 8 Variables		For 9 Variables	
	R	Predictors [d]	R	Predictors	R	Predictors	R	Predictors	R	Predictors	R	Predictors	R	Predictors	R	Predictors
RADARMAN																
Actual data																
All malfunctions reported																
No lag	0.317	1,4	0.334	1,4,6	0.346	1,3,4,6	0.311	1,3,4,6,11	0.275	1,3,4,5,6,11	0.232	1,2,3,4,5,6,11				
Lag three months	0.387	2,4	0.378	2,4,6	0.340	2,3,4,6	0.296	1,2,4,5,6	0.235	1,2,3,4,5,6						
Lag six months	0.295	1,3	0.390	4,5,6	0.349	1,3,4,5	0.435	1,3,4,5,6	0.411	1,2,3,4,5,6						
"No output" malfunction																
No lag	0.360	2,3	0.332	1,2,3	0.290	1,2,3,5	0.203	1,2,3,5,6	0	1,2,3,4,5,6						
Lag three months	0.225	1,2	0.581	1,2,4	0.555	1,2,4,5	0.510	1,2,3,4,5	0.485	1,2,3,4,5,6	0.372	1,2,3,4,5,6,11				
Change data																
All malfunctions reported																
No lag	0.157	1,6	0.278	1,6,9	0.260	1,6,9,10	0.222	1,5,5,9,10	0.167	1,2,5,6,9,10	0	–	0	–		
Lag three months	0.809 [c]	3,6	0.801 [b]	3,4,6	0.783	3,4,5,6	0.958	1,3,4,5,6	0.722	1,2,3,4,5,6						
ELECTRONIC TECHNICIANS																
Actual data																
All malfunctions reported																
No lag	0.188	7,8	0.218	4,7,11	0.241	1,4,5,7	0.254	3,4,5,7,11	0.217	2,3,4,5,7,11	0.162	1,2,3,4,5,7,11	0.063	1,2,3,4,5,7,8,11		
Lag three months	0.486 [b]	4,8	0.616 [c]	4,7,11	0.659 [b]	4,7,8,11	0.651 [b]	4,5,7,8,11	0.651 [b]	1,2,4,7,8,11	0.636	2,3,4,5,7,8,11	0.626	1,2,3,4,5,7,8,11		
Lag six months	0.317	3,8	0.359	1,3,8	0.442	2,4,8,11	0.371	1,3,4,8,11	0.260	1,3,4,7,8,11	0	–	0	–		
"No output" malfunction																
No lag	0.199	4,11	0.292	1,4,11	0.204	1,4,8,11	0.134	1,4,7,8,11	0	–	0	–	0	–		
Lag three months	0.235	2,11	0.284	2,4,11	0.277	2,3,4,11	0.552	2,3,4,7,11	0.601	1,2,3,4,5,7,11	0.545	1,2,4,5,7,8,11	0.469	1,2,3,4,5,7,8,11		
Change data																
All malfunctions reported																
No lag	0.271		0.314	2,8,9	0.346	4,7,8,9	0.321	1,4,7,8,9	0.275	1,4,7,8,9,11	0.203	1,2,4,7,8,9,11	0	–	0	–
Lag three months	0.646 [c]		0.685 [b]	1,2,7	0.687	1,2,7,8	0.681	2,3,7,8,9	0.696	1,2,5,7,8,11	0.669	1,2,5,7,8,9,11	0.615	1,2,3,5,7,8,9,11	0.510	1,2,3,4,5,7,8,9,11
SONAR TECHNICIANS																
Actual data																
All malfunctions reported																
No lag	0.313	1,5	0.338	1,2,8	0.393	2,3,4,8	0.371	1,2,3,4,8	0.297	1,2,3,4,6,8	0.198	1,2,3,4,6,7,8	0	–		
"Burned out" malfunctions																
No lag	0.677	6,8	0.723	2,6,8	0.711	4,5,6,8	0.701	1,2,5,6,8	0.664	1,2,4,5,6,8	0.612	1,2,3,4,5,6,8	0.537	1,2,3,4,5,6,7,8		
Change data																
All malfunctions reported																
No lag	0.459	2,3	0.399	2,3,7	0.529	1,2,3,8	0.534	1,2,3,4,8	0.517	1,2,3,4,6,8	0.507	1,2,3,4,5,6,8	0.437	1,2,3,4,5,6,7,8		

[a] All correlations have been adjusted to take into account sample size and degrees of freedom.

[b] The correlation is significantly different from zero at the 95% confidence level.

[c] The correlation is significantly different from zero at the 95% confidence level and the addition of another personnel variable does not significantly increase the correlation.

[d] Numbers refer to personnel characteristics as indicated in original list in paragraph 4.58.

4.75 Some measure of the relative importance of the personnel characteristics which make up the significant multiple correlations is the β coefficient shown in Table 21. The larger the coefficient, the closer it relates to and influences the equipment variable.

4.76 Gross Correlations. Table 22 shows that average formal education, the percentage of personnel allowance actually aboard, and the percentage of the crew with an NEC pertinent to the equipment had the greatest number of significant results. These are the correlations which are significantly different from zero.

4.77 Nine gross correlations were significantly different from zero. Tables 23 and 24 present all correlations calculated for each of the personnel characteristics.

4.78 Tables 23 and 24 also show all gross correlation coefficients after adjustment for sample size. Again, zero values are caused by the adjustment. These coefficients show the relationship of each personnel characteristic with the equipment variables.

4.79 Limitations. The prime limitation in the study is the nonrandom selection of ships for the sample. The nonrandom selection was necessary because of the differing quality of the 3-M reporting by ships. Ships were selected which had the most accurate data. As a result, significant findings related to the sample ships may not necessarily apply to personnel and equipment on ships not included in the sample. A study involving a significantly larger randomly selected data base should be performed to verify the findings.

4.80 Those personnel characteristics which were found to be highly related to the AN/SPS-40 or AN/SQS-23B failure frequency and repair times may not be the same characteristics which are correlated to failure and maintenance parameters for other equipments.

4.81 Conclusions. This research demonstrates the ability of multiple correlation analysis to pinpoint personnel characteristics which influence equipment failures and repair times. Its use does not require additional data collection but uses existing Navy data systems. The computations are extremely laborious and require ADP. The availability of the ORI multivariate analysis computer program greatly facilitates the use of a computer in the application of this technique.

TABLE 21

BETA COEFFICIENTS FOR ALL SIGNIFICANT MULTIPLE CORRELATIONS

Description of Cases	Personnel Characteristics										
	1	2	3	4	5	6	7	8	9	10	11
NUMBER OF MALFUNCTIONS											
Radarman											
Change data											
All malfunctions											
Lag three months			-0.79		-1.26						
Electronic technicians											
Actual data											
All malfunctions											
Lag three months							+0.40	-0.33			
MEAN TIME TO REPAIR											
Radarman											
Change data											
All malfunctions											
Lag three months			-0.39			-1.40					
Electronic technicians											
Actual data											
All malfunctions											
Lag three months				+0.69			-0.48				-0.61
Change data											
All malfunctions											
Lag three months		-0.53					-0.73				

TABLE 22

SIGNIFICANT GROSS CORRELATIONS

Personnel Characteristics	No. of Significant Correlations With No. of Malfunctions	No. of Significant Correlations With Mean Time to Repair	Total Significant Correlations
Average age			
Average pay grade		1	1
Average time since ADBD		1	1
Average time until EAOS		1	1
Average formal education		2	2
Percentage personnel allowance actually aboard	1	1	2
Percentage personnel with pertinent NEC	1	1	2
Average training time			
Time since ADBD for highest ranked man			
Formal education for highest ranked man			
Time until EAOS for men on first enlistment			

TABLE 23

GROSS CORRELATION COEFFICIENTS a/ (R) FOR ALL CASES WITH NUMBER OF MALFUNCTIONS

Description of Cases	Case	Personnel Characteristics b/ 1	2	3	4	5	6	7	8	9	10	11
RADARMAN												
Actual data												
All malfunctions reported												
No lag	1	0	0	0	0	0	0.075					
Lag three months	2	0	-0.274	-0.035	0	-0.289	0					0.143
Lag six months	3	0	0	0	0	0	0					
"No output" malfunction												
No lag	4	0	0.387	0	0	0	-0.174					
Lag three months	5	0	0.435	0	0	0	0					0
Change data												
All malfunctions reported												
No lag	6	0	0.099	0	-0.130	0	0.079			0	0	
Lag three months	7	0.200	-0.383	-0.203	0	-0.370	0					
ELECTRONIC TECHNICIANS												
Actual data												
All malfunctions reported												
No lag	8	0	0	0	-0.047	0		0.109	0			0
Lag three months	9	0	0	0.149	0	-0.177		0.345c/	0			0
Lag six months	10	0	0.227	0.269	0	0		0	0			0
"No output" malfunction												
No lag	11	0	-0.145	0	0	0		0	0.177			0
Lag three months	12	-0.216	-0.436	-0.031	0	0		0	0.232			0
Change data												
All malfunctions reported												
No lag	13	0	0	0	0	0		0	0	0		0
Lag three months	14	0	0	0	-0.372	-0.151		0.410	0	0		0
SONAR TECHNICIANS												
Actual data												
All malfunctions reported												
No lag	15	0	0	0	0.302	-0.183	-0.457c/	0.152	0			
"Burned out" malfunctions												
No lag	16	0	0	0	0.118	-0.152	-0.176	0	0			
Change data												
All malfunctions reported												
No lag	17	0	0	-0.163	0	0	0	0	0			

a/ All correlatio... have been adjusted to take into account sample size and degrees of freedom.

b/ The column hea ing numbers refer to personnel characteristics as indicated in the original list in paragraph 4.58.

c/ The correlation i signif'cantly different from zero at the 95% confidence level.

TABLE 24

GROSS CORRELATION COEFFICIENTS[a] (R) FOR ALL CASES WITH MEAN TIME TO REPAIR

Description of Cases	Case	Personnel Characteristics[b] 1	2	3	4	5	6	7	8	9	10	11
RADARMAN												
Actual data												
All malfunctions reported												
No lag	1	0.275	0	0.125	0.292[c]	0	0					0.115
Lag three months	2	0.224	0.245	0.264	0.285	0	-0.209					
Lag six months	3	0	0	0	0	0.209	0					
"No output" malfunction												
No lag	4	0	0.122	-0.057	0	0	0					
Lag three months	5	0	0.271	0	0	0	0					0
Change data												
All malfunctions reported												
No lag	6	0	0	0	0	0	0.174			0.076	0.084	
Lag three months	7	0.343	0.566[c]	0.572[c]	0	0	-0.800[c]					
ELECTRONIC TECHNICIANS												
Actual data												
All malfunctions reported												
No lag	8	0.080	0	0	0	0		-0.179	-0.189			0
Lag three months	9	0.168	0	0	0.077	0		-0.339	-0.427[c]			0
Lag six months	10	0	-0.150	-0.289	0	0		0	0			0
"No output" malfunction												
No lag	11	-0.116	0	0	0	0		0	0			0
Lag three months	12	0	-0.169	0	0	0		0	0			0
Change data												
All malfunctions reported												
No lag	13	0	0.208	0	-0.215	0		0	0.061	0		0
Lag three months	14	0.180	0	0	0	0		-0.565[c]	-0.305	0		0
SONAR TECHNICIANS												
Actual data												
All malfunctions reported												
No lag	15	0	0	0	0	0.185	0	0	0.271			
"Burned out" malfunction												
No lag	16	0	0	0	0	0.192	-0.523[c]	0	0			
Change data												
All malfunctions reported												
No lag	17	0	-0.422	0	0	0	0	0	0			

a/ All correlations have been adjusted to take into account sample size and degrees of freedom

b/ The column heading numbers refer to personnel characteristics as indicated in the original list in paragraph 4.58.

c/ The correlation is significantly different from zero at the 95% confidence level.

V. SUMMARY OF RESULTS AND RECOMMENDATIONS

RESEARCH RESULTS

5.1 The research effort focused on two major areas: a survey and analysis of existing failure reporting systems, and the investigation of alternative indirect approaches to determine human performance and to quantify the human reliability contribution to weapon system effectiveness.

5.2 It was found that existing failure reporting systems do not yield meaningful data on human-initiated malfunctions. Most systems have no provisions for reporting information on human performance as related to failures. Many of the reporting systems surveyed were in various stages of being phased out of use. In most cases, a strong reluctance to report all failures, particularly human errors, was noted. What information was found to exist on human errors was very general in nature and was not being used for human failure analysis. Indeed, meaningful analysis of the reported data did not appear feasible. Some provisions were being made, however, for inclusion of human-initiated failure data in the 3-M system as described in paragraph 3.41. These provisions warrant further investigation for possible improvements that will make them useful in human reliability analysis.

5.3 In attempting to develop an indirect approach to human reliability analysis, two techniques were investigated, both of which rely on equipment failure reporting rather than human error reporting. One technique is ERUPT. This approach, by grouping the components of a weapon system into elementary reliability units, provides a means of inferring two human performance parameters from available equipment reliability and maintenance data. The second approach relates certain personnel characteristics of individuals operating and maintaining the equipment to the number of failures and equipment repair times by the application of multivariate correlation analysis techniques.

5.4 In the course of this study, the feasibility and applicability of these two approaches were determined and mathematical models and equations were developed for their applications. A pilot test on a limited data base was also conducted during the development of the two techniques.

RECOMMENDATIONS

5.5 The conduct of the study and the conclusions point to a number of recommendations which logically fall into two categories, those for immediate action and those for further research and study. This section delineates these recommendations.

Immediate Action

5.6 Recommendation 1. One of the major problems associated with failure reporting systems is their use for disciplinary purposes. It is strongly recommended that BuPers take immediate action to initiate an educational program clarifying the basic purposes of these reporting systems. This educational program should emphasize the need for accurate data on failures. The program should further emphasize that the data are required for the enhancement of technical analyses and further study, rather than for the evaluation of personnel and promotion decisions.

5.7 Recommendation 2. The Shipboard Maintenance Action Form (Figure 15) of the 3-M system provides for the name, rating, and grade of the person who performs the maintenance action being reported. This information would be extremely useful in conducting analyses such as the ones outlined in Section IV. These data are presently not being keypunched and, consequently, are not available in routine or special 3-M reports. It is recommended that the next revision to the 3-M manual incorporate the instructions for keypunching these elements.

Further Research and/or Study Programs

5.8 Recommendation 1. The ERUPT approach appears to be feasible and is believed to be one of the most promising techniques thus far developed for human reliability analysis. It is therefore strongly recommended that this approach be further developed by extending its application to classes of weapon systems other than the one employed during its formulation. Its usage should also be investigated in system effectiveness analyses during various phases of the weapon system development cycle.

5.9 The following specific tasks are recommended as part of this subsequent study program:

a. Investigate the application of ERUPT to various classes of weapon systems as it applies to system readiness reliability.

b. Investigate the application of ERUPT to other classes of systems where human reliability parameters are an integral part of the system effectiveness considerations in all phases of the system life cycle. This task will include the formulation of human performance parameters other than α and β delineated in the description of the ERUPT approach in Section IV. The effort will involve the mathematical formulation of an overall system effectiveness model which will include these human performance parameters along with additional equipment parameters.

c. Calculate α, β, and other human reliability parameters for ERUs of various classes of systems, based on actual equipment reliability and system operational and maintenance data. Analyze similar ERUs to develop common human reliability parameters. Classify these ERUs based on ranges of the human reliability parameters.

d. Develop relationships between various human reliability parameters and personnel characteristics. Develop sensitivity curves for sets of personnel characteristics vs human reliability parameters for which a significant relationship has been established.

5.10 Based on the results of these tasks, meaningful human reliability measures can be formulated which will be of significant value to BuPers representatives participating in weapon system effectiveness analysis. These measures can be applied to the analysis of existing systems as well as of those in various stages of early development. Further, these measures will facilitate the evaluation of such system criteria as packaging concepts, maintenance philosophy, and operating procedures in terms of manpower and personnel requirements.

5.11 Recommendation 2. The application of multivariate correlation analysis to equipment failure and personnel characteristics data showed some significant relationships based on a limited statistical sample. It is recommended that the validation of the results of the study and the extension of the techniques to other equipment be undertaken. This effort will require the following tasks:

a. Validation of the significant findings of the research conducted in this study, which will require:

   1. Additional personnel data for RD, ST, and ET ratings

   2. Additional sonar and radar equipment failure data for a larger random sample of ships

b. Application of the technique to other classes of equipment that are amenable to use of this technique

c. Formulation of large numbers of hypotheses concerning personnel and equipment failure parameters through contacts with naval personnel who are familiar with personnel requirements of those who operate and maintain the equipments

d. Determination of the availability of personnel data from Pers N needed to test the hypotheses developed

e. Finally, a multivariate correlational analysis to reveal which personnel characteristics are highly related to changes in each equipment's failure parameters. Analysis would determine whether the same personnel parameters were related to similar types of equipment.

A matrix format might be feasible for presentation and summarization of the correlations found for each of the personnel parameters with the different equipment classes.

5.12 Recommendation 3. The forms that are used to report failures constitute one of the major problems associated with existing failure reporting systems. There is no way to isolate human-initiated failures from equipment breakdown. It is recommended that a study be conducted to design a failure reporting form which would assure, with a high degree of confidence, the identification of the true causes of failures.

The study would include the investigation of the application of some form of a failure analysis tree which would take the reporter through a series of "yes" or "no" decisions to arrive at the final conclusion as to the cause of failure. The study would require the determination of information needs for equipment analyses as well as human reliability analyses to assure the inclusion on the form of only those elements that are absolutely required in support of the analyses. It is further recommended that various alternative reporting concepts be pilot tested under actual operating and maintenance conditions.

APPENDIX A

DERIVATION OF EQUATIONS FOR HUMAN RELIABILITY PARAMETER ESTIMATES AND READINESS RELIABILITY

A.1 The following terms must be defined:

α_i = probability that failure of the i^{th} ERU, if it exists, is detected and repaired during the first maintenance following the failure.

β_i = probability that maintenance does not induce failure in the i^{th} ERU given that the ERU is in nonfailed condition at the time maintenance is initiated.

π_{ij} = probability that i^{th} ERU, which is in nonfailed condition at the time the j^{th} exercise or test is initiated, survives the exercise or test.

t_i = storage time between exercises or tests of i^{th} ERU.

$1-G_i(x)$ = probability that i^{th} ERU survives a storage time x given that it was in "new" condition at beginning of storage, i.e., at zero storage time. This is determined from a theoretical distribution estimated under laboratory or test conditions.

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NK = number of different integral values of k in the sample of corrective maintenances.

k_i = number of maintenances before repair/replacement since beginning of storage or since last repair of the ERU if previous corrective maintenance has been done (including maintenance when last repair/replacement was done). A sample of k_i's is required from actual experience to derive maximum likelihood estimates of α and β.

$(i = 1, 2, \ldots NK)$.

N_i = frequency of the i^{th} value of k_i in the sample of corrective maintenances $(i = 1, 2, \ldots NK)$. Size of sample is equal to

$$\sum_{i=1}^{NK} N_i.$$

τ_i = storage time of i^{th} ERU between time when last exercised and maintained to time of operating mission.

ν_i = number of exercises or tests of ERU before operating mission.

$p_j(\nu_i)$ = probability that the i^{th} ERU survives the ν_i^{th} exercise or test and was last repaired during the $(\nu_i - j)$ maintenance period.

ESTIMATION OF HUMAN RELIABILITY MAINTENANCE PARAMETERS

A.2 Assume $\pi_{ij} = \pi_i$ for all values of j; $P_k(r)$ = probability that corrective maintenance (which assumes complete renewal) takes place on the k^{th} maintenance; and $P_x(f)$ = probability that a failure occurs before the x^{th} maintenance but not before the $(x-1)^{th}$ maintenance; i.e., the failure could have occurred during the $(x-1)^{th}$ maintenance, during storage between the $(x-1)^{th}$ and x^{th} maintenances, or during the x^{th} test.

$$p_1(f) = 1 - \left[1 - G(t)\right]\pi. \qquad (A.1)$$

$$p_x(f) = \beta^{x-2} \left[1-G\,(x-1)\,t\right] \pi^{x-1} - \beta^{x-1} \left[1-G\,(xt)\right] \pi^{x} \text{ for } x \geq 2. \qquad (A.2)$$

A.3 These formulations are obvious after inspection of input data and reexamination of the life cycle of the ERU as depicted in Figure 18.

A.4 Assuming a failure before the first maintenance, the probability that the corrective maintenance will take place on the fourth maintenance is simply:

$$p_1(f) \cdot (1-\alpha)^3 \; \alpha = 1 - \left[1-G(t)\right] \pi \; (1-\alpha^3)\,\alpha. \qquad (A.3)$$

A.5 More generally, the probability that corrective maintenance occurs on the k^{th} maintenance for a failure occurring before the x^{th} maintenance is:

$$p_x(f) \cdot (1-\alpha)^{k-x} \; \alpha.$$

Now,

$$p_k(r) = \sum_{x=1}^{k} p_x(f) \cdot (1-\alpha)^{k-x} \; \alpha. \qquad (A.4)$$

Expanding,

$$p_k(r) = \sum_{x=1}^{k} \left\{\beta^{x-2} \left[1-G\,(x-1)\,t\right] \pi^{x-1} - \beta^{x-1} \left[1-G\,(xt)\right] \pi^{x}\right\} (1-\alpha)^{k-x} \alpha$$

$$+ \left\{1 - \left[1-G\,(t)\right] \pi\right\} (1-\alpha)^{k-1} \alpha. \qquad (A.5)$$

A.6 This expression gives the probability that corrective maintenance occurred on the k^{th} maintenance regardless of when the failure occurred.

A.7 Assume now that a sample of ERU corrective maintenances shows that they have occurred on the first, third, third, second, and first preventive maintenances. Thus, under the definitions,

$NK = 3$ $K_1 = 1$ $N_1 = 2$

$K_2 = 2$ $N_2 = 1$

$K_3 = 3$ $N_3 = 2.$

A. 8 The probability that this series of corrective maintenance has occurred equals

$$\prod_{i=1}^{3} p_{k_i}(r).$$

More generally, the probability is

$$\prod_{i=1}^{NK}\left[\sum_{x=2}^{k_i}\left\{\beta^{x-2}\left[1-G\,(x-1)\,t\right]\pi^{x-1}-\beta^{\,x-1}\left[1-G\,(xt)\right]\pi^{x}\right\}(1-\alpha)^{k_i-x}\alpha + \left\{1-\left[1-G(t)\right]\pi\right\}(1-\alpha)^{k_i-1}\alpha\right]^{N_i}. \qquad (A.6)$$

A.9 The set of (α,β) desired is the set that maximizes this probability. Therefore, the desired (α,β) equals

$$\text{Max}\prod_{i=1}^{NK}\left[\sum_{x=2}^{k_i}\left\{\beta^{x-2}\left[1-G\,(x-1)t\right]\pi^{x-1}-\beta^{x-1}\left[1-G(xt)\right]\pi^{x}\right\}(1-\alpha)^{k_i-x}\alpha + \left\{1-\left[1-G(t)\right]\pi\right\}(1-\alpha)^{k_i-1}a\right]^{N_i}$$

$$\text{for}\quad\left[\alpha,\ \beta\,\middle|\,0<\alpha<1,\ 0<\beta\le 1.\right] \qquad (A.7)$$

A.10 A computer program to facilitate calculation of (α,β) is given in Appendix B.

READINESS RELIABILITY EQUATIONS

A.11 It can be shown that the readiness reliability of the i^{th} ERU is given by*

---

* Equation (A.8) for readiness reliability of the ERU can be derived by induction. The boundary condition $P_i(1) = [1-G_i(t_i)]\,\pi_i(1)$ is based on the assumption that the ERU is in operable condition with probability unity immediately following manufacture.

$$R_i(\nu_i, t_i, \tau_i, \pi_{i1}, \pi_{i2}, \ldots \pi_{i\nu_i}) = \alpha_i\left[1-\sum_{j=1}^{\nu_i} p_j(\nu_i)\right]\left[1-G_i(\tau_i)\right] + \beta_i \sum_{j=1}^{\nu_i}\left[\frac{1-G_i(j\,t_i+\tau i)}{1-G_i(j\,t_i)}\, p_j(\nu_i)\right] \qquad (A.8)$$

where the recursion equations necessary to the formulation are

$$p_1(1) = \left[1-G_i(t_i)\right]\pi_i(1),$$

$$p_1(\nu_i) = \alpha_i\left[1-\sum_{j=1}^{\nu_i} p_{ij}(\nu_i-1)\right]\left[1-G_i(t_i)\right]\pi_i(\nu_i),$$

$$p_j(\nu_i) = \beta_i \frac{1-G_i(jt_i)}{1-G_i\left[(j-1)t_i\right]}\, p_{i,j-1}(\nu_i-1)\,\pi_i(\nu_i)$$

$$p_{\nu_i}(\nu_i) = \beta_i \frac{1-G_i(\nu_i t_i)}{1-G_i\left[(\nu_i-1)t_i\right]}\, p_{i,\nu_{i-1}}(\nu_i-1)\,\pi_i(\nu_i).$$

A.12 For the case where the distribution of storage time to failure of the ERU is exponential and the probability of surviving the j^{th} exercise $\pi_{ij} = \pi_i$ for all j, it can be shown that Equation (A.8) takes on the simpler form

$$R_i = \ell^{-\lambda'_i\tau_i}\left\{\left[\pi_i(\beta_i-\alpha_i)\right]^{\nu_i}\ell^{-\lambda'_i\nu_i t_i} + \frac{\alpha i}{1-\pi_i(\beta_i-\alpha_i)\ell^{-\lambda'_i t_i}}\left(1-\left[\pi_i(\beta_i-\alpha_i)\right]^{\nu_i}\ell^{-\lambda'_i\nu_i t_i}\right)\right\}. \qquad (A.9)$$

From inspection of Equation (A.9) it can be seen that, as α_i approaches β_i, the readiness reliability of an ERU having an exponential distribution of storage time to failure will approach $\alpha_i\ell^{-\lambda'_i t_i}$, which is independent of ν_i, the number of maintenance cycles prior to operating mission. For the exponential case, note also that as ν_i becomes large, the steady-state readiness reliability approaches

$$R_i = \frac{\alpha_i \ell^{-\lambda'_i \tau_i}}{1-\pi_i\left(\beta_i-\alpha_i\right)\ell^{-\lambda'_i \tau_i}} \quad . \tag{A.10}$$

System Readiness Reliability

A.13 Taking the product of ERU readiness reliabilities defined by Equation (A.8) for ERUs required to function for a defined mission tactic yields the readiness reliability R_R. In mathematical form, this is given by

$$R_R = \prod_{i=1}^{N} R_i \quad . \tag{A.11}$$

APPENDIX B

FLOW DIAGRAM AND COMPUTER PROGRAM FOR ESTIMATING HUMAN RELIABILITY PARAMETERS

B.1 The variables and format used for the input data required for the program which estimates human reliability factors are shown in Table B.1.

TABLE B.1
INPUT DESCRIPTION

Card	Card Column	Description
1	1-10	NK, total number of k_i's or N_i's
	11-20	π_{ij}, probability of surviving test or exercise
2	1-10	AINI, initial value of alpha
	11-20	AINC, incremental value of alpha
	21-30	AFIN, terminal value of alpha
	31-40	BINI, initial value of beta
	41-50	BINC, incremental value of beta
	51-60	BFIN, terminal value of beta

TABLE B.1 (Cont)

Card	Card Column	Description
3*	1-10	k_i, number of maintenances before repair/replacement since beginning of storage
	11-20	N_i, frequency of the i^{th} value of k_i
4	1-5	G (1t) G(xt) table values
	6-10	G (2t)
	11-15	G (3t)
	.	.
	.	.
	.	.
	.	.
	46-50	G(10)

*Card 3 repeated NK times for each k_i, N_i.

B.2 The program will print all input data in Table B.1 as well as the data calculated by the program and shown in Table B.2.

TABLE B.2

OUTPUT DESCRIPTION

FORTRAN Name	Description
ALPHA	Probability of detecting a malfunction during maintenance (α)
BETA	Probability of not inducing a malfunction during maintenance (β)
PROD	Probability that this sample of corrective maintenances could have occurred given this set of alpha and beta values
PMAX	Maximum probability that this sample of corrective maintenance could have occurred.
AL	Value of alpha at which maximum (PMAX) occurs
BL	Value of beta at which maximum (PMAX) occurs

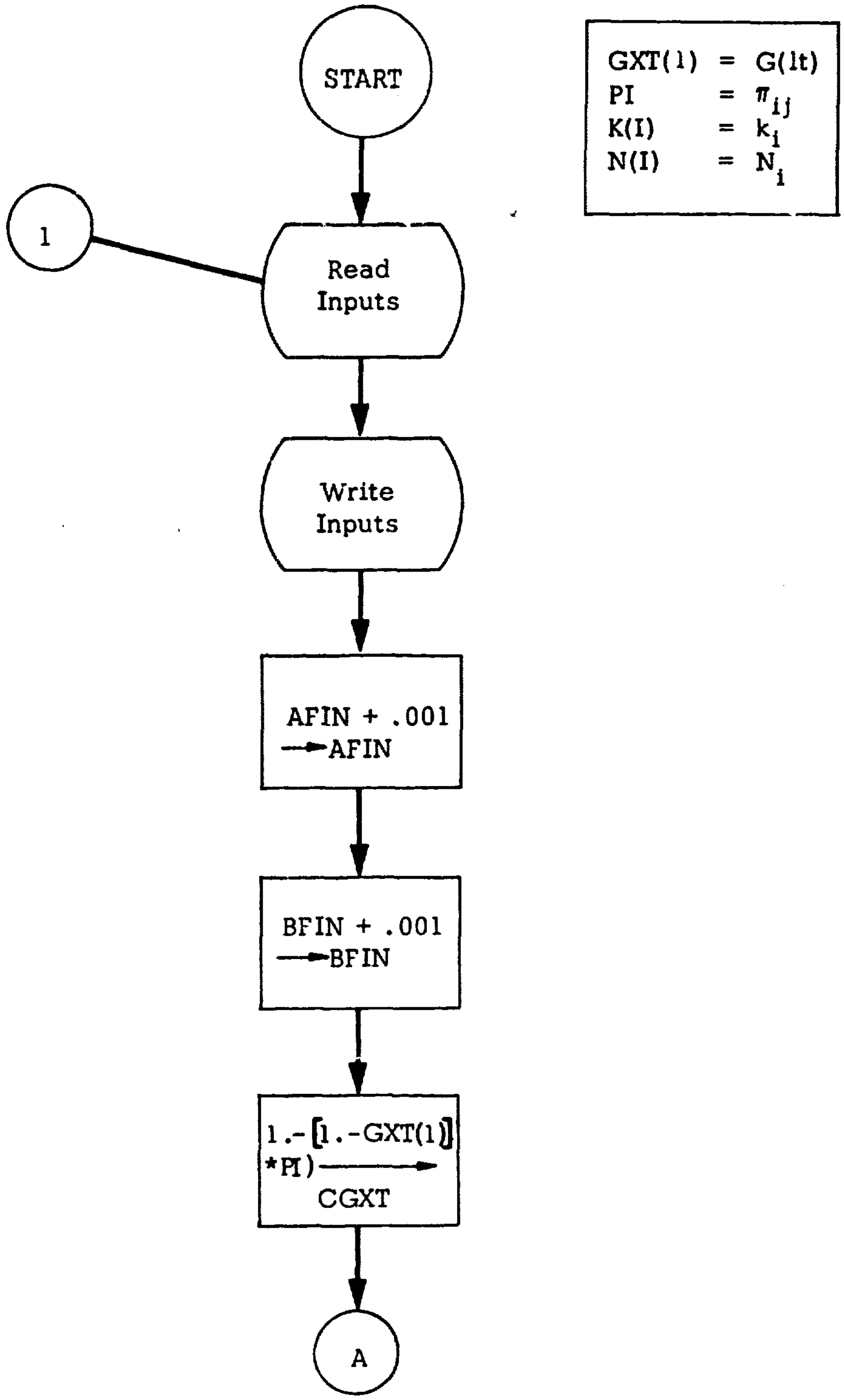

FIGURE B.1. FLOW LOGIC FOR HUMAN RELIABILITY PARAMETERS

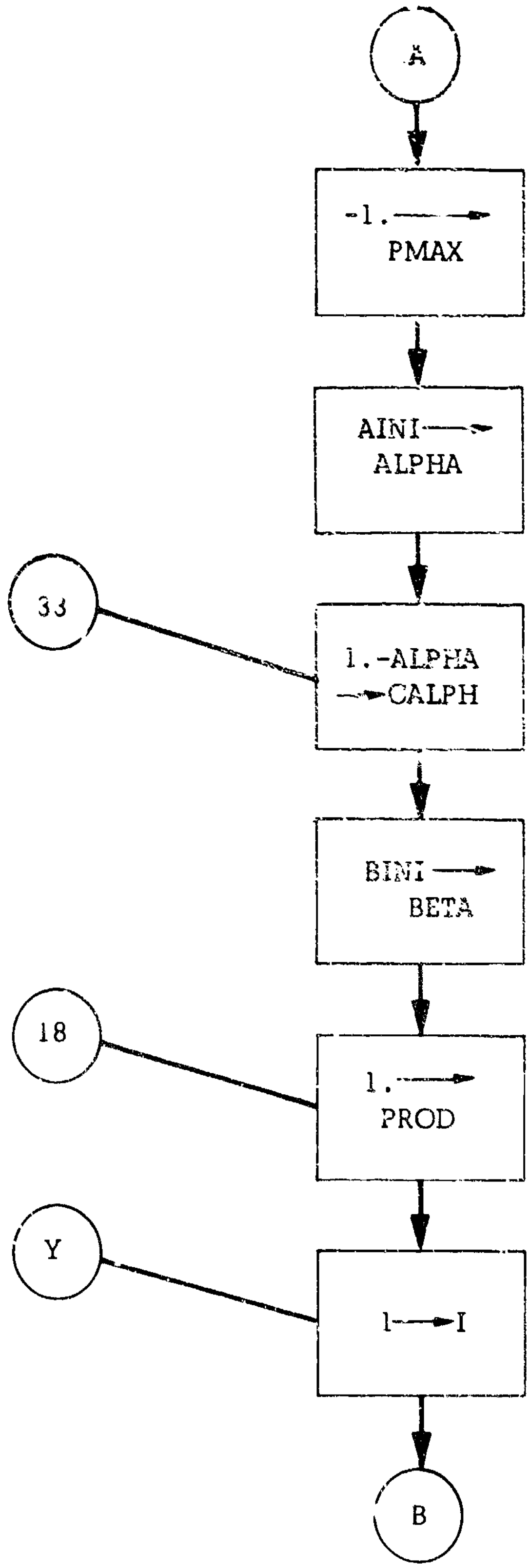

FIGURE B.1 (Cont)

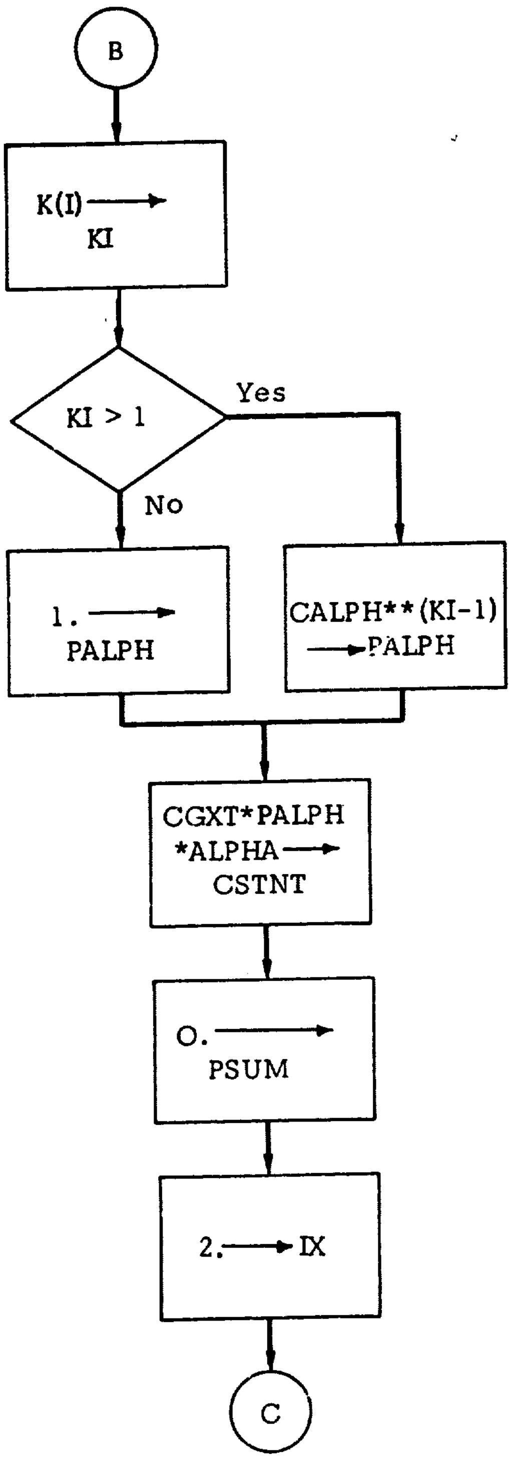

FIGURE B.1 (Cont)

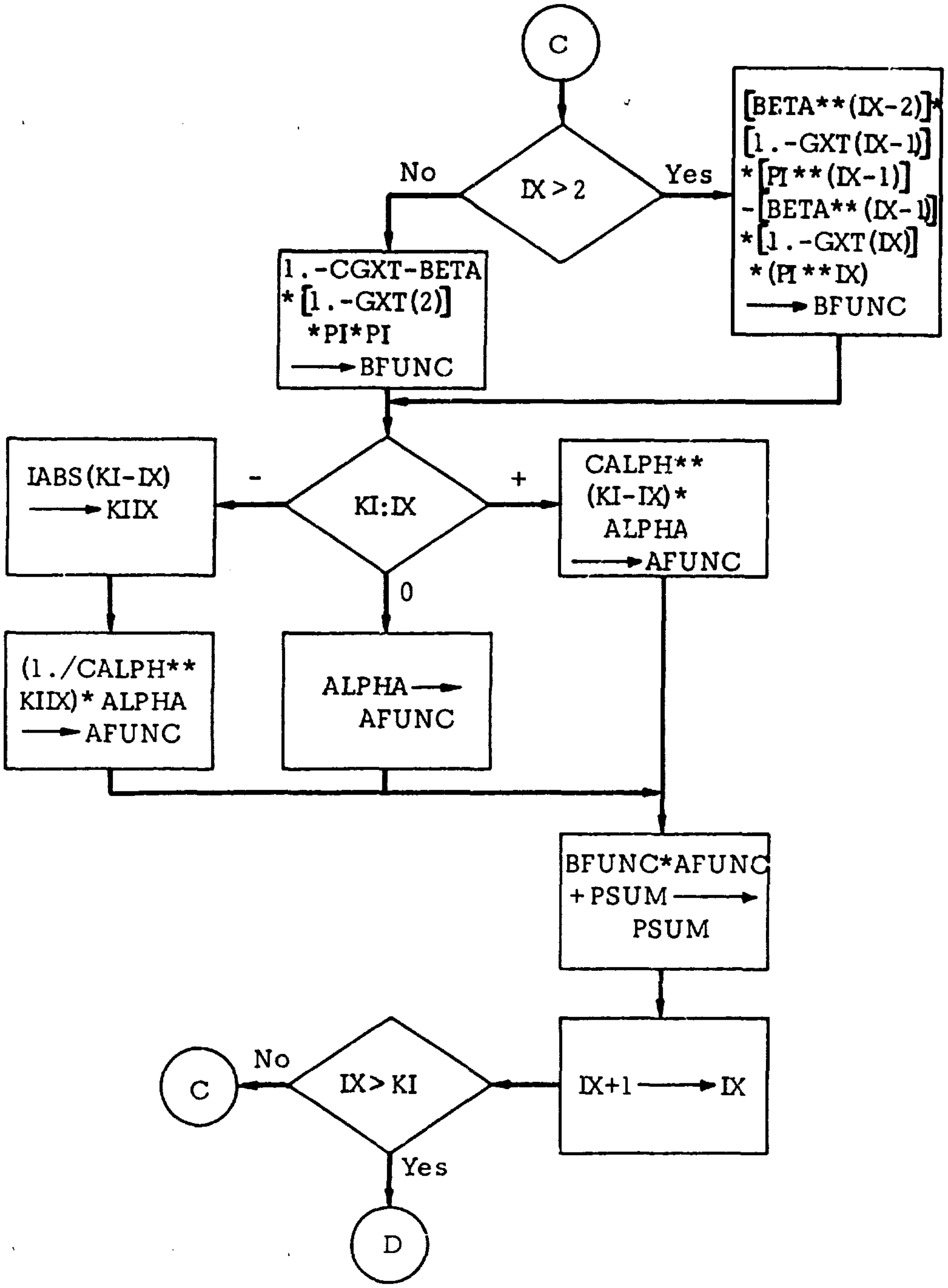

FIGURE B.1 (Cont)

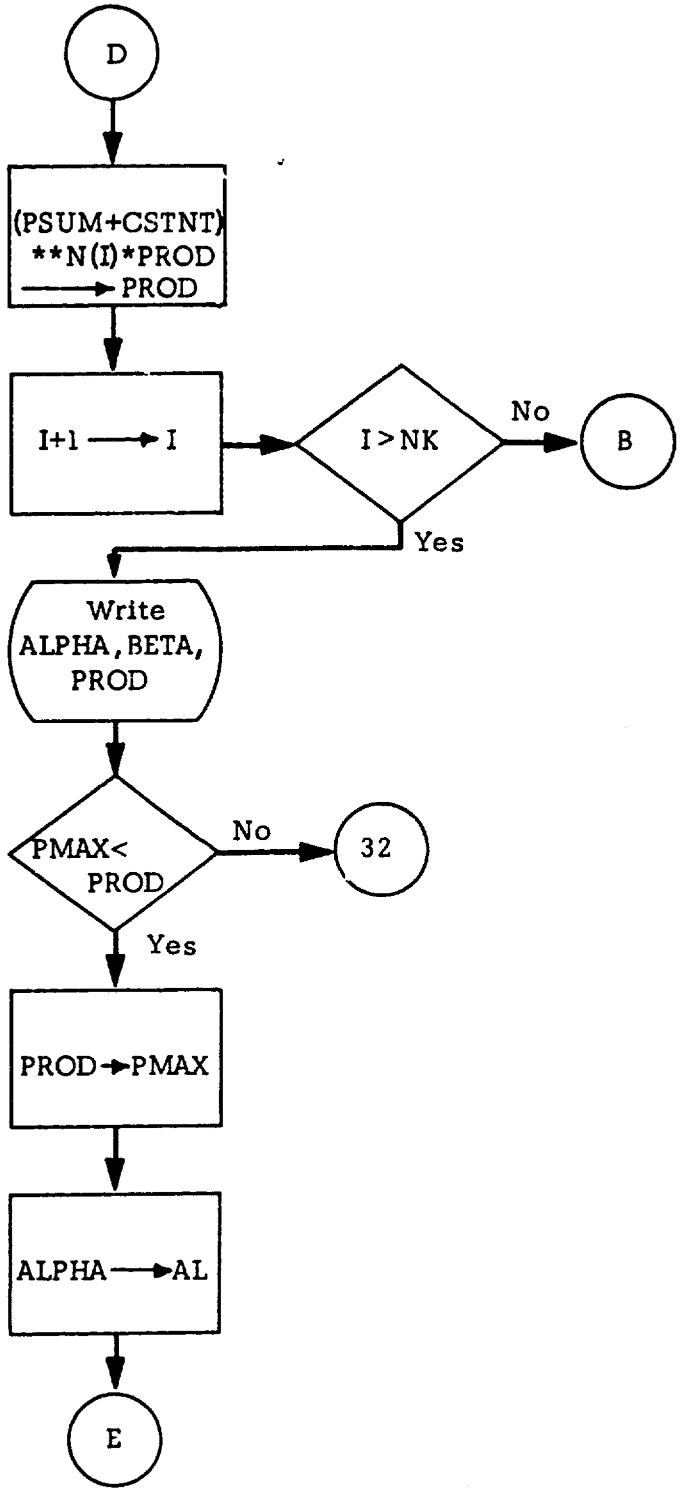

FIGURE B.1 (Cont)

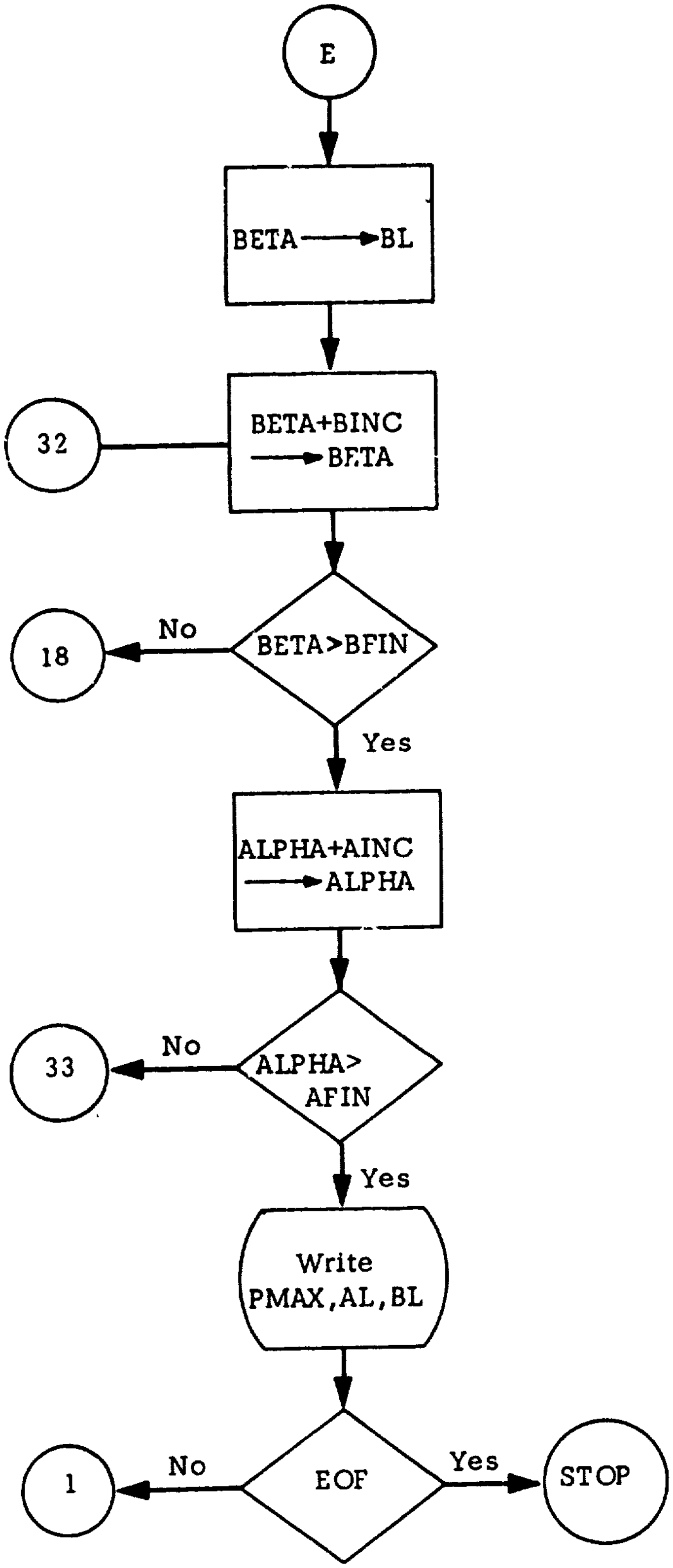

FIGURE B.1 (Cont)

```
      PROGRAM LIMMS
      DIMENSION K(10),N(10),GXT(10)
    1 READ(60,100)NK,PROB
      GO TO (40,28),EOFCKF(60)
   28 READ(60,101)AINI,AINC,AFIN,BINI,BINC,BFIN
      READ(60,102)(K(I),N(I),  I=1,NK)
      READ(60,103)(GXT(I),  I=1,10)
      WRITE(61,104)PROB,NK
      WRITE(61,110) (K(I), N(I),  I=1,NK)
      WRITE(61,105)
      WRITE(61,111) (I, GXT(I),  I=1,10)
      WRITE(61,106)AINI,AFIN,AINC
      WRITE(61,112)BINI,BFIN,BINC
      WRITE(61,107)
      AFIN= AFIN+.001
      BFIN=BFIN+.001
      PI=PROB
      CGXT=1.-((1.-GXT(1))*PI)
      PMAX=-1.
      ALPHA=AINI
   33 CALPH=1.-ALPHA
      BETA=BINI
   18 PROD=1.
      DO 2  I=1,NK
      KI=K(I)
      IF(KI-1)4,4,5
    5 PALPH=CALPH**(KI-1)
      GO TO 6
    4 PALPH=1.
    6 CSTNI=CGXT*PALPH*ALPHA
      PSUM=0.
      DO 11  IX=2,KI
      IF(IX-2)9,9,10
    9 BFUNC=1.-CGXT-BETA*(1.-GXT(2))*PI*PI
      IF(KI-IX)45,13,15
   45 KIIX=IABS(KI-IX)
      AFUNC=(1./CALPH**KIIX    )*ALPHA
      GO TO 26
   13 AFUNC=ALPHA
      GO TO 26
   15 AFUNC=CALPH**(KI-IX)   *ALPHA
      GO TO 26
   10 BFUNC=(BETA**(IX-2))*(1.-GXT(IX-1))*(PI**(IX-1))-(BETA**(IX-1))
     1*(1.-GXT(IX))*(PI**IX)
      IF(KI-IX)46,24,25
   46 KIIX=IABS(KI-IX)
      AFUNC=(1./CALPH**KIIX    )*ALPHA
      GO TO 26
```

FIGURE B.2. COMPUTER PROGRAM FOR HUMAN RELIABILITY PARAMETERS

```
 24 AFUNC=ALPHA
    GO TO 2[illegible]
 25 AFUNC=CALPH**(KI-IX)   *ALPHA
 26 PSUM=BFUNC*AFUNC+PSUM
 11 CONTINUE
 20 PROD  =(PSUM       +CSTNT)**N(I) *PROD
  2 CONTINUE
    WRITE(61,108)ALPHA,BETA,PROD
    IF(PMAX-PROD)31,32,32
 31 PMAX=PROD
    AL=ALPHA
    BL=BETA
 32 BETA=BETA+BINC
    IF(BETA-BFIN)18,18,35
 35 ALPHA=ALPHA+AINC
    IF(ALPHA-AFIN)33,33,36
 36 WRITE(61,109) PMAX,AL,BL
    GO TO 1
 40 STOP
100 FORMAT(I10,F10.2)
101 FORMAT(6F10.2)
102 FORMAT(2I10)
103 FORMAT(10F5.2)
104 FORMAT(1H1,5X,11HINPUT DATA://10X,13HPROBABILITY =,F5.2/10X,4HNK =
   1,I3//15X,13HK(I)      N(I)/)
105 FORMAT(/15X,11HG(XT) TABLE/)
106 FORMAT(/10X,F4.2,18H ≤       ALPHA    ≤ ,F4.2,5X,14HINCREMENTS OF ,
   1F4.2)
107 FORMAT(1H1,13X,26HALPHA      BETA      F VALUE/)
108 FORMAT(9X,2F9.2,F12.7)
109 FORMAT(//10X,17HMAXIMUM VALUE OF ,F10.7,11H AT ALPHA =,F5.2,8H, BE
   1TA =,[illegible]5.2)
110 FORMAT(7X,2I10)
111 FORMAT(8X,I10,F7.2)
112 FORMAT(/10X,F4.2,18H ≤       BETA     ≤ ,F4.2,5X,14HINCREMENTS OF ,
   1F4.2)
    END

      3200 FORTRAN DIAGNOSTIC RESULTS - FOR   TIMMS


                   NULL STATEMENT NUMBERS
                         20
                  LOAD,56
                  RUN,30
```

FIGURE B.2 (Cont)

APPENDIX C

COMPUTER PROGRAM FOR READINESS RELIABILITY CALCULATION

C.1 This appendix presents the flow logic and computer program developed to calculate ERU readiness reliability.

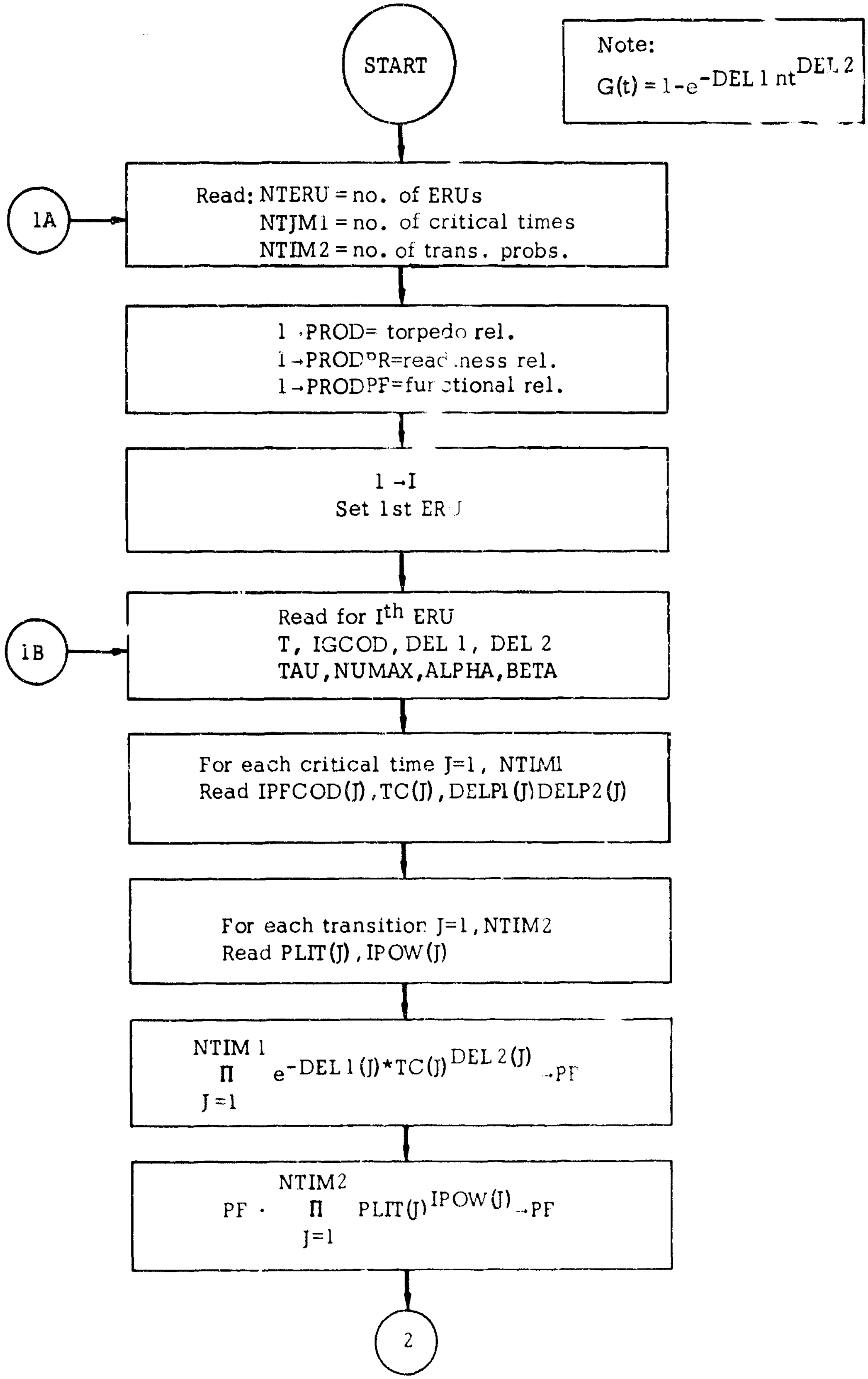

FIGURE C.1. DETAILED FLOW LOGIC FOR RELIABILITY MODEL

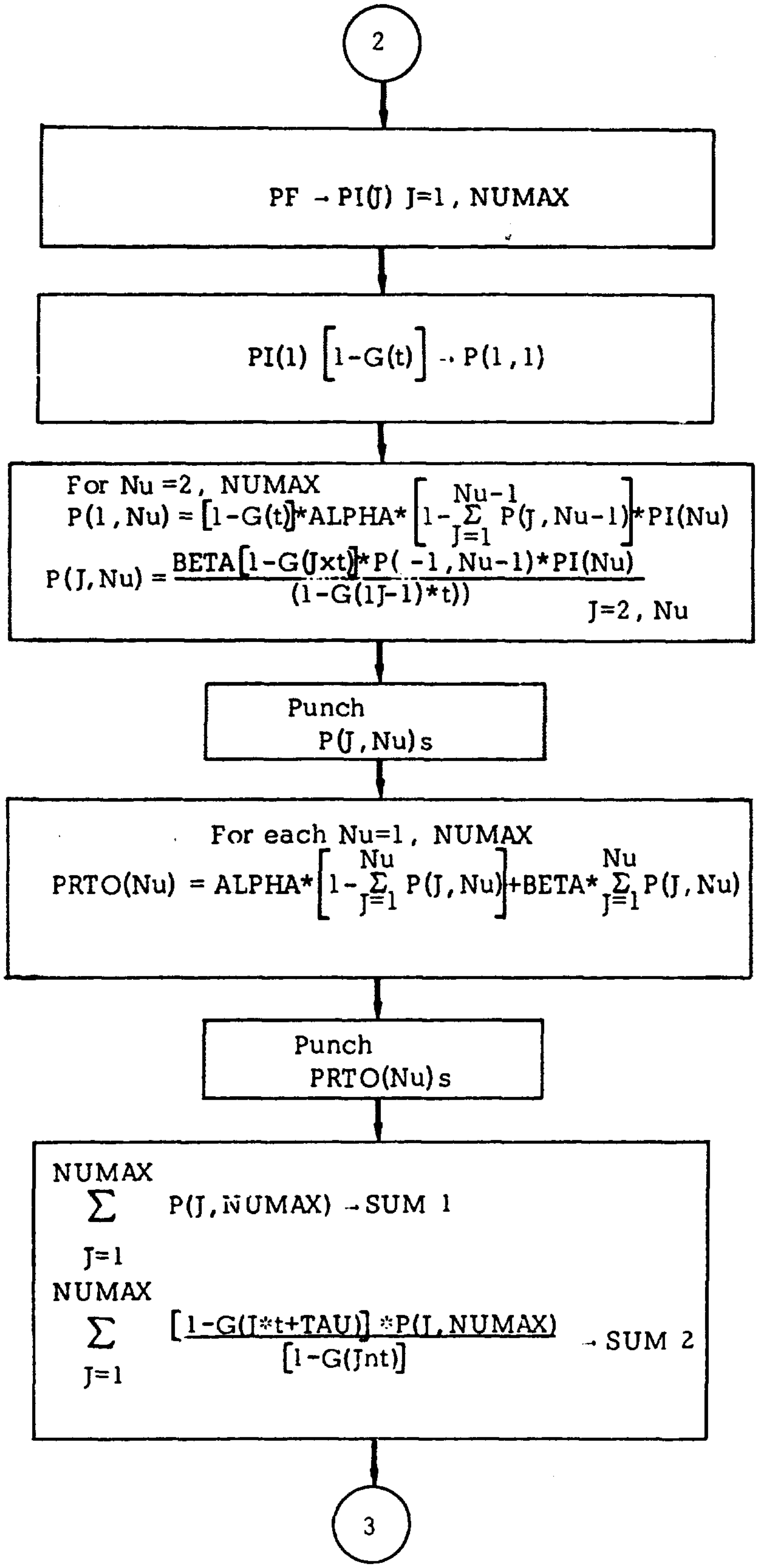

FIGURE C.1 (Cont)

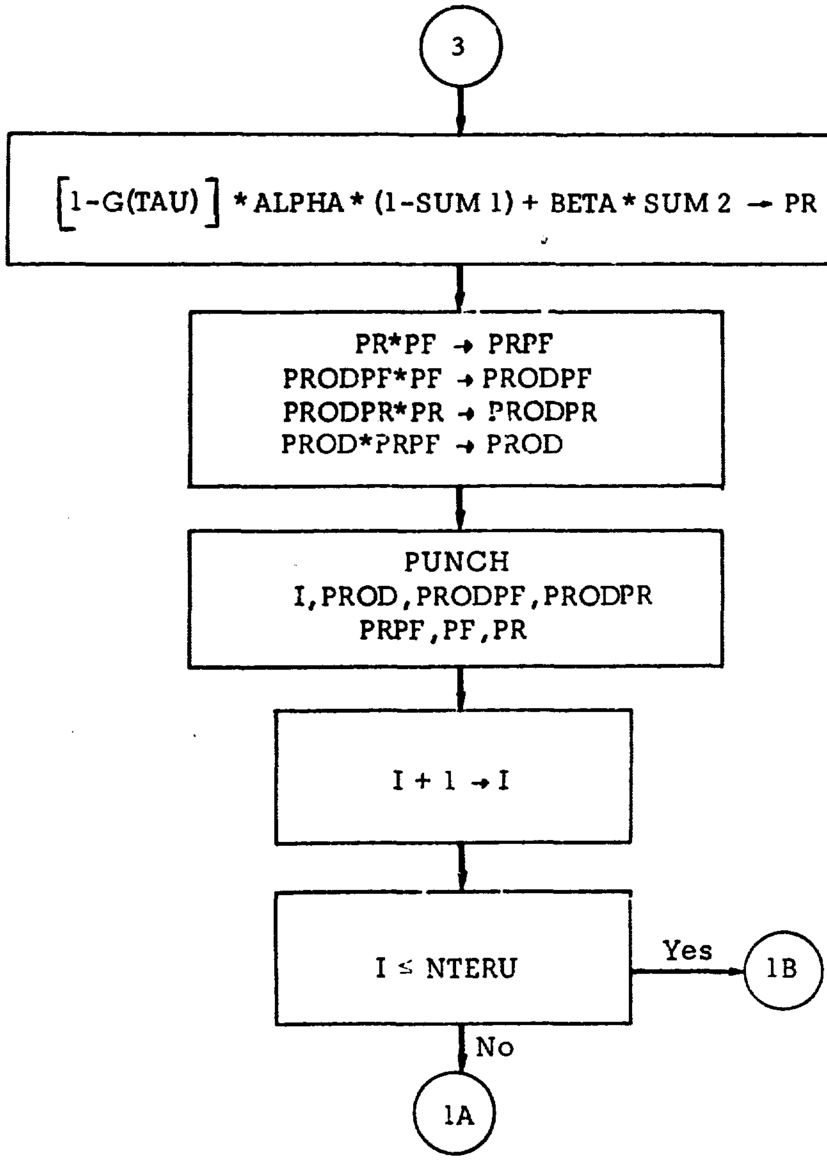

FIGURE C.1 (Cont)

```
C   RELIABILITY MARK 48 COOK-ZUSMAN    ORL-1/R  JOB NO. 280  MAY 5, 1965
      DIMENSION PLIT(20),IPOW(20),IPFCOD(20),TC(20),DELP1(20),DELP2(20),
     1PI(20),P(10,10),PRTO(10)
      G(T)=1.-EXPF(-DEL1*T**DEL2)
   11 READ 100,NTERU,NTIM1,NTIM2
      PUNCH200,NTERU,NTIM1,NTIM2
      PROD=1.
      PRODPR=1.
      PRODPF=1.
      DO 6 I=1,NTERU
      READ 101,T,IGCOD,DEL1,DEL2,TAU,NUMAX,ALPHA,BETA
      PUNCH201,T,IGCOD,DEL1,DEL2,TAU,NUMAX,ALPHA,BETA
      READ 102,(IPFCOD(J),TC(J),DELP1(J),DELP2(J),J=1,NTIM1)
      PUNCH202,(IPFCOD(J),TC(J),DELP1(J),DELP2(J),J=1,NTIM1)
      READ 103,(PLIT(J),IPOW(J),J=1,NTIM2)
      PUNCH203,(PLIT(J),IPOW(J),J=1,NTIM2)
      PF=1.
      DO 8 J=1,NTIM1
    8 PF=PF*EXPF(-DELP1(J)*TC(J)**DELP2(J))
      DO 9 J=1,NTIM2
    9 PF=PF*PLIT(J)**IPOW(J)
      DO 10 J=1,NUMAX
   10 PI(J)=PF
      P(1,1)=(1.-G(T))*PI(1)
      DO 4 NU=2,NUMAX
      SUM=0.
      NUM1=NU-1
      DO 3 J=1,NUM1
    3 SUM=SUM+P(J,NUM1)
      P(1,NU)=(1.-G(T))*ALPHA*(1.-SUM)*PI(NU)
      DO 4 J=2,NU
      XJ=J
    4 P(J,NU)=(BETA*(1.-G(XJ*T))*P(J-1,NU-1)*PI(NU))/(1.-G((XJ-1.)*T))
      PUNCH 305
      DO 53 NU=1,NUMAX
   53 PUNCH 302,I,NU,(P(J,NU),J=1,NU)
      DO 12 NU=1,NUMAX
      SUM=0.
      DO 13 J=1,NU
   13 SUM=SUM+P(J,NU)
   12 PRTO(NU)=ALPHA*(1.-SUM)+BETA*SUM
      PUNCH 304,(PRTO(NU),NU=1,NUMAX)
      SUM1=0.
      SUM2=0.
      DO 2 J=1,NUMAX
      SUM1=SUM1+P(J,NUMAX)
      XJ=J
      XJT=XJ*T
```

FIGURE C.2. COMPUTER PROGRAM FOR
ERU READINESS RELIABILITY

```
  2 SUM2=(1.-G(XJT+TAU))*P(J,NUMAX)/(1.-G(XJT))+SUM2
    PR =(1.-G(TAU))*ALPHA*(1.-SUM1)+BETA*SUM2
    TERM=PR*PF
    PRODPF=PRODPF*PF
    PRODPR=PRODPR*PR
    PROD=PROD*TERM
  6 PUNCH 303,I,PROD,PRODPF,PRODPR,TERM,PF,PR
    GO TO 11
100 FORMAT(3I10)
101 FORMAT(E10.0,I10,3E10.0,       I10,2E10.0)
102 FORMAT(I10,3E10.0)
103 FORMAT(3(E10.0,I10))
200 FORMAT(13H1RELCOMP MK48/
   1 7HONTERU=,I5, 7H NTIM1=,I5, 7H NTIM2=,I5//)
201 FORMAT(F16.8,I3,2E16.8,F16.8/10X,I5,2E16.8)
202 FORMAT(I3,F16.8,2F16.8)
203 FORMAT(3(F16.8,I3))
302 FORMAT( 4H ERU,I4,4H NU=,I4,4E16.8/(16X,4E16.8))
303 FORMAT( 4HOERU,I4,6H PROD=,F11.8,8H PRODPF=,F11.8,8H PRODPR=,F11.8
   1/8X,6H PFPR=,F11.8,4H PF=,F15.8,4H PR=,F15.8//)
304 FORMAT(10HOPRTO(NU)=,4E16.8/(10X,4E16.8))
305 FORMAT( 1H0,15X,8HP(I,NU)=/)
    END
```

FIGURE C.2 (Cont)

APPENDIX D

PILOT TEST RESULTS OF CALCULATION OF ESTIMATES OF HUMAN RELIABILITY PARAMETERS

D.1 The input symbols used in this appendix are defined in Appendix A.

D.2 Common to all test cases is the following failure distribution and value for π:

$$\pi = 0.95 .$$

D.3 The data shown in Table D.1 has been used as input for each of the four cases shown in Table D.2.

TABLE D.1

ASSUMED EQUIPMENT FAILURE DISTRIBUTION

No. of Preventive Maintenance + 1	Probability of Equipment Failure Before That Maintenance, G(xt)
1	0.26
2	0.45
3	0.59
4	0.70
5	0.77
6	0.84
7	0.88
8	0.91
9	0.94
10	0.95

TABLE D.2

INPUT DATA AND RESULTS FOR PILOT TEST CASES

Case	NK	k_i	N_i	ΣN_i	Estimate of α	Estimate of β
1	3	1,2,3	2,2,1	5	0.98	0.33
2	5	1,2,3,4,5	1,1,1,1,1	5	0.57	0.63
3	5	3,4,5,6,7	1,1,1,1,1	5	0.31	0.78
4	3	8,9,10	1,2,2	5	0.16	1.00

D.4 The computer printout of the input data and results for the mathematical formulation of the human reliability maintenance parameter estimates are presented as Figure D.1 on the following pages. The program computes a probability (F value) that a set of α and β values will produce the corrective maintenance experience reflected in the rest of the input data. It is more likely that the sample of corrective maintenance resulted from that set of α and β values with the highest probability than from any other set. The maximum likelihood estimate of α and β is therefore the set of α and β which has the highest probability calculated for it.

INPUT DATA:

PROBABILITY = .95
NK = 3

K(I)	N(I)
1	2
2	2
3	1

G(XT) TABLE

1	.26
2	.45
3	.59
4	.70
5	.77
6	.84
7	.88
8	.91
9	.94
10	.95

.90 ≤ ALPHA ≤ 1.00 INCREMENTS OF .01

.30 ≤ BETA ≤ .50 INCREMENTS OF .01

ALPHA	BETA	F VALUE	ALPHA	BETA	F VALUE
.90	.30	.0031181	.91	.30	.0031484
.90	.31	.0031059	.91	.31	.0031382
.90	.32	.0030915	.91	.32	.0031256
.90	.33	.0030750	.91	.33	.0031108
.90	.34	.0030566	.91	.34	.0030939
.90	.35	.0030362	.91	.35	.0030750
.90	.36	.0030141	.91	.36	.0030541
.90	.37	.0029901	.91	.37	.0030314
.90	.38	.0029646	.91	.38	.0030068
.90	.39	.0029374	.91	.39	.0029806
.90	.40	.0029086	.91	.40	.0029527
.90	.41	.0028785	.91	.41	.0029232
.90	.42	.0028469	.91	.42	.0028922
.90	.43	.0028140	.91	.43	.0028598
.90	.44	.0027799	.91	.44	.0028261
.90	.45	.0027446	.91	.45	.0027911
.90	.46	.0027081	.91	.46	.0027549
.90	.47	.0026707	.91	.47	.0027175
.90	.48	.0026322	.91	.48	.0026791
.90	.49	.0025928	.91	.49	.0026397
.90	.50	.0025526	.91	.50	.0025993

FIGURE D.1. SAMPLE OUTPUT

ALPHA	BETA	F VALUE	ALPHA	BETA	F VALUE
.92	.30	.0031740	.94	.41	.0030397
.92	.31	.0031659	.94	.42	.0030113
.92	.32	.0031554	.94	.43	.0029812
.92	.33	.0031425	.94	.44	.0029495
.92	.34	.0031274	.94	.45	.0029161
.92	.35	.0031100	.94	.46	.0028812
.92	.36	.0030906	.94	.47	.0028449
.92	.37	.0030692	.94	.48	.0028073
.92	.38	.0030459	.94	.49	.0027684
.92	.39	.0030207	.94	.50	.0027283
.92	.40	.0029937	.95	.30	.0032195
.92	.41	.0029651	.95	.31	.0032194
.92	.42	.0029348	.95	.32	.0032163
.92	.43	.0029031	.95	.33	.0032104
.92	.44	.0028699	.95	.34	.0032017
.92	.45	.0028353	.95	.35	.0031903
.92	.46	.0027994	.95	.36	.0031764
.92	.47	.0027623	.95	.37	.0031601
.92	.48	.0027240	.95	.38	.0031413
.92	.49	.0026847	.95	.39	.0031204
.92	.50	.0026443	.95	.40	.0030973
.93	.30	.0031945	.95	.41	.0030721
.93	.31	.0031889	.95	.42	.0030449
.93	.32	.0031806	.95	.43	.0030158
.93	.33	.0031698	.95	.44	.0029850
.93	.34	.0031566	.95	.45	.0029524
.93	.35	.0031411	.95	.46	.0029183
.93	.36	.0031233	.95	.47	.0028826
.93	.37	.0031034	.95	.48	.0028454
.93	.38	.0030814	.95	.49	.0028069
.93	.39	.0030575	.95	.50	.0027671
.93	.40	.0030316	.96	.30	.0032234
.93	.41	.0030040	.96	.31	.0032264
.93	.42	.0029746	.96	.32	.0032263
.93	.43	.0029436	.96	.33	.0032231
.93	.44	.0029110	.96	.34	.0032170
.93	.45	.0028770	.96	.35	.0032081
.93	.46	.0028416	.96	.36	.0031964
.93	.47	.0028048	.96	.37	.0031822
.93	.48	.0027668	.96	.38	.0031654
.93	.49	.0027276	.96	.39	.0031462
.93	.50	.0026873	.96	.40	.0031247
.94	.30	.0032098	.96	.41	.0031009
.94	.31	.0032068	.96	.42	.0030751
.94	.32	.0032010	.96	.43	.0030473
.94	.33	.0031925	.96	.44	.0030175
.94	.34	.0031814	.96	.45	.0029859
.94	.35	.0031679	.96	.46	.0029526
.94	.36	.0031520	.96	.47	.0029176
.94	.37	.0031337	.96	.48	.0028810
.94	.38	.0031133	.96	.49	.0028430
.94	.39	.0030908	.96	.50	.0028036
.94	.40	.0030662	.97	.30	.0032213

FIGURE D.1 (Cont)

ALPHA	BETA	F VALUE	ALPHA	BETA	F VALUE
.97	.31	.0032277	.99	.30	.0031978
.97	.32	.0032308	.99	.31	.0032119
.97	.33	.0032306	.99	.32	.0032222
.97	.34	.0032273	.99	.33	.0032288
.97	.35	.0032210	.99	.34	.0032319
.97	.36	.0032118	.99	.35	.0032316
.97	.37	.0031998	.99	.36	.0032280
.97	.38	.0031852	.99	.37	.0032212
.97	.39	.0031679	.99	.38	.0032114
.97	.40	.0031482	.99	.39	.0031987
.97	.41	.0031262	.99	.40	.0031832
.97	.42	.0031018	.99	.41	.0031650
.97	.43	.0030754	.99	.42	.0031442
.97	.44	.0030468	.99	.43	.0031210
.97	.45	.0030163	.99	.44	.0030954
.97	.46	.0029840	.99	.45	.0030676
.97	.47	.0029498	.99	.46	.0030376
.97	.48	.0029140	.99	.47	.0030057
.97	.49	.0028767	.99	.48	.0029718
.97	.50	.0028378	.99	.49	.0029360
.98	.30	.0032128	.99	.50	.0028986
.98	.31	.0032229	1.00	.30	.0031760
.98	.32	.0032295	1.00	.31	.0031943
.98	.33	.0032326	1.00	.32	.0032086
.98	.34	.0032324	1.00	.33	.0032191
.98	.35	.0032289	1.00	.34	.0032257
.98	.36	.0032224	1.00	.35	.0032288
.98	.37	.0032129	1.00	.36	.0032284
.98	.38	.0032006	1.00	.37	.0032246
.98	.39	.0031855	1.00	.38	.0032175
.98	.40	.0031678	1.00	.39	.0032074
.98	.41	.0031476	1.00	.40	.0031943
.98	.42	.0031249	1.00	.41	.0031783
.98	.43	.0031000	1.00	.42	.0031596
.98	.44	.0030728	1.00	.43	.0031382
.98	.45	.0030436	1.00	.44	.0031144
.98	.46	.0030124	1.00	.45	.0030882
.98	.47	.0029792	1.00	.46	.0030597
.98	.48	.0029443	1.00	.47	.0030290
.98	.49	.0029077	1.00	.48	.0029962
.98	.50	.0028695	1.00	.49	.0029616
			1.00	.50	.0029250

MAXIMUM VALUE OF .0032326 AT ALPHA = .98, BETA = .33

FIGURE D.1 (Cont)

APPENDIX E

METHODOLOGY USED TO EVALUATE HYPOTHESES

E. 1 The primary study objective is to identify one or a combination of personnel characteristics which, when optimally weighted under the least-squares criterion for best fit, will produce significant gross and multiple correlations with the equipment parameters.

E. 2 Special runs E952A and E987A furnished by Pers 19 for this research task contained personnel characteristics for each of the men on aboard the selected ships for each 3-month interval. Averages of the personnel characteristics for the men in ratings ET, RD, and ST were obtained.

E. 3 Special reports entitled "Maintenance History Records" (MDC-5) were obtained from the Maintenance Support Office, Mechanicsburg, Pennsylvania, which contained a chronological history of the malfunctions and repairs by ship for each equipment. From these reports, a manual tabulation of the total number of malfunctions and maintenance (repair) times was completed by ship and by 3-month period.

E. 4 At this point, frequency distributions of the variables provided rough histograms so that the normality of the variables could be checked. In many cases, the distributions were badly skewed; consequently, all raw data were normally transformed[18] so that correlations would not be spuriously inflated.

E.5 Selected scatter diagrams of the transformed data for each of the equipment parameters with each of the personnel parameters failed to disprove the assumption of linearity on which multiple correlation theory is based.

E.6 After computer calculations were made for all cases, gross (zero order) correlations and the highest multiple correlation coefficients for each number of predictor variables included in an analysis were tabulated.

E.7 Adjustments were made in these coefficients in order to avoid consistently overestimating the closeness of the relationship because of small sample size. Formulas[17] used were

$$\bar{r}^2_{xy} = 1 - \left(1 - r^2_{xy}\right) \frac{n-1}{n-2} , \qquad \text{(E.1)}$$

where n = sample size

$\bar{r}_{xy}$ = adjusted value of r_{xy} ;

and

$$\bar{R}^2_{1.23...k} = 1 - \left(1 - R^2_{1.23...k}\right) \left(\frac{n-1}{n-m}\right) \qquad \text{(E.2)}$$

where k = number of independent variables

n = sample size

m = degrees of freedom $(k + 1)$

$\bar{R}^2_{1.23...k}$ = adjusted value of $R^2_{1.23...k}$.

E.8 The adjusted gross correlations which are significantly different from zero were identified by use of a table of critical values of the correlation coefficient at the 0.05 level of significance. Such a a table is found in many standard texts. To determine if adjusted multiple correlations were significantly different from zero, the following F ratio was calculated.

$$F_{test} = \frac{\bar{R}^2}{1 - \bar{R}^2} \left(\frac{n-k-1}{k}\right) \qquad \text{(E.3)}$$

where $\bar{R}$ = adjusted multiple correlation

n = sample size

k = number of predictors .

If $F_{test} > F_{.05,\, k,\, n-k-1}$, the correlation is significant.

E.9 To test whether or not the addition of another personnel variable would increase the multiple correlation significantly, another F ratio was used.

$$F_{test} = \left(\frac{\bar{R}_1^{\,2} - \bar{R}_2^{\,2}}{1-\bar{R}_1^{\,2}}\right) \left(\frac{n-k_1-1}{k-k_2}\right), \quad \text{(E.4)}$$

where $\bar{R}_1$ = adjusted multiple correlation with larger number of personnel variables

$\bar{R}_2$ = adjusted multiple correlation with smaller number of personnel variables

k_1 = larger number of personnel variables

k_2 = smaller number of personnel variables

n = sample size .

If $F_{test} > F_{0.05,\, m_1-m_2,\, n-m-1}$, the additional personnel variable has increased the correlation significantly.

E.10 In practice, when one of the multiple correlations with two predictor variables was significantly different from zero, Formula (E.4) was used to see if an additional variable would increase the correlation significantly.

E.11 When it is known that a multiple correlation is significantly different from zero, it is possible to calculate a correlation for which it is 95 percent certain that the true correlation is greater than the calculated correlation.

E.12 Ezekiel[17/] provides convenient graphs from which this value can be estimated at the 95 percent confidence level. For example, if for 50 observations a multiple correlation of 0.62 is obtained using three personnel variables, from the graph it can be stated that there is a certainty of 95 percent that 0.42 is the probable minimum correlation in the universe.

E. 13 When multiple correlation coefficients are significantly different from zero, knowledge of the relative importance of the personnel characteristics is desirable. To obtain this, the β coefficient is calculated.[17] Thus, the most influential personnel variable is indicated by the largest absolute β value.

APPENDIX F

BIBLIOGRAPHY

F.1 This bibliography is divided into two parts. The first entries, numbered 1 through 18, have been quoted in the text and are referred to in the text by the numbers at the left. The unnumbered list contains works that were used for background information but were not referred to in the text.

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14. Commanding Officer (2)
Office of Naval Research
Branch Office
Department of the Navy
London, England

15. Chief Code 03H
Naval Ship System Command
Department of the Navy
Washington, D.C. 20360

16. Director
U.S. Naval Training Development
Center (Main Services Branch)
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17. Operations Research Incorporated (25)
1400 Spring Street
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UNCLASSIFIED
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DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Operations Research Incorporated 1400 Spring Street Silver Spring, Maryland 20910	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Human Reliability Research

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report — May 1966-August 1967

5. AUTHOR(S) (Last name, first name, initial)

Beek, C., Haynam, K., Markisohn, G.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1967	137	18

8a. CONTRACT OR GRANT NO. Nonr 4451(00) b. PROJECT NO. PF0160201H03 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TR430 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) None

10. AVAILABILITY/LIMITATION NOTICES

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Personnel Research Division Bureau of Naval Personnel Washington, D.C. 20370

13. ABSTRACT

The research effort focused on two major areas, a survey and analysis of existing failure reporting systems, and the investigation of alternative indirect approaches to determining human performance and quantifying the human reliability contribution to weapon system effectiveness.

It was found that existing failure reporting systems do not yield meaningful data on human-initiated malfunctions. In most cases, a strong reluctance to report all failures was noted, particularly human errors.

In attempting to develop an indirect approach to human reliability analysis, two techniques were investigated, both of which rely on equipment failure reporting rather than human error reporting. One technique is ERUPT. This approach, by grouping the components of a weapon system into elementary reliability units, provides a means of inferring two human performance parameters from available equipment reliability and maintenance data. The second approach relates certain personnel characteristics of individuals operating and maintaining the equipment to number of failures and equipment repair times by the application of multivariate correlation analysis techniques.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
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human reliability human factors failure reporting systems weapon system effectiveness multivariate analysis model, weapon system readiness reliability human performance readiness reliability						

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