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July 1978

MAINTAINABILITY PREDICTION AND ANALYSIS STUDY

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Hughes Aircraft Company

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Existing maintainability prediction techniques are not accurate estimators of current electronic equipment/system characteristics. A new time synthesis prediction technique is developed which directly relates diagnostic/isolation/test subsystem characteristics and other design characteristics to equipment/system maintainability parameters. The developed methodology includes a detailed prediction procedure for use when final design data is available, and an early prediction procedure for use when preliminary design data is (Cont'd)

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available. Predicted parameters include mean time to repair, maximum (percentile) time to repair, maintenance man-hours per repair, and fault isolation resolution. Also included is a comprehensive set of time standards applicable to physical maintenance actions associated with current construction and packaging techniques.

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MAINTAINABILITY PREDICTION AND ANALYSIS STUDY

T. F. Pliska, et al

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Fullerton, California

July 1978

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EVALUATION

1. The results of this report represent a joint effort sponsored by the Naval Electronics Systems Command and the Rome Air Development Center.

2. The objective of this study was to investigate and develop maintainability prediction and analysis techniques. Such techniques were to be based on the engineering characteristics of the fault detection/isolation/test capabilities of the equipment or system and be applicable to modern state-of-the-art design factors.

3. The maintainability prediction procedure which was developed satisfactorily achieves the objectives for which it was intended. Two prediction procedures were developed:

a. A detailed procedure that can produce very accurate predictions that are limited only by the quality of the input data.

b. An early procedure that yields less accurate predictions due to its use of estimated rather than actual equipment data. Both of the procedures can be applied at any equipment or system level.

4. The analysis and modelling methodology developed provides the tools necessary for assessing and evaluating the maintainability of modern equipments and systems, including direct accountability of the diagnosis/isolation/test capabilities, packaging, replaceable item make up and component failure rates.

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5. The prediction and analysis methodologies can be applied at any level of maintenance, for any maintenance concept and for avionics, ground electronics, and shipboard electronics.

6. The implementation of the methodologies developed allows the user to track the overall system maintainability parameters throughout the design and development of a system. Using the techniques and procedures, the user can evaluate whether or not the maintainability design requirements that have been specified will be met before the system is fully developed. If it appears that maintainability requirements will not be met, then the designers can be informed. Thus, time and money can be conserved by carefully tracking the maintainability parameters through a system's development.

7. These techniques will be used to update MIL-HDBK-472, "Maintainability Prediction", 24 May 66.

JERRY F. LIPA, Jr
Project Engineer

SECTION 0.0 EXECUTIVE SUMMARY

The maintainability of modern electronic equipments is directly related to diagnostic/isolation/test capabilities, system packaging, and replaceable item makeup and failure rates. The maintainability prediction techniques presently in use do not allow direct accountability of these factors, particularly as related to diagnostic/isolation/test characteristics. The methodology developed under this study provides a maintainability analysis approach which can be applied at any hardware level and which directly relates maintainability parameters (e.g. MTTR) to the noted factors which influence maintainability.

Selection of the methodology developed under this study was based on a review of state of the art equipment/system characteristics, current maintainability analysis techniques, and the requirements of the maintainability community relative to prediction and analysis application. Conclusions drawn from the review indicated that the developed methodology should:

1. Be based on a time synthesis approach,
2. Be applicable to any and all hardware levels.
3. Be symptom oriented rather than failure oriented, and
4. Be developed for two stages of equipment development:
    a. When detailed design data is available, and
    b. When preliminary (early) design data is available.

A number of existing prediction techniques are failure oriented; that is, an assessment of repair time is made based on the fact that a certain replaceable item has failed. Real world maintenance is not failure oriented but rather symptom oriented; that is, the maintenance which is performed is based on the failure symptom, or on the results obtained from the fault detection/isolation process. This is the way that the developed prediction procedure is structured. A list is constructed which identifies all possible failure symptoms or results of the fault detection/isolation process (FD&I outputs). The equipment is analyzed and the replaceable items, or portions thereof, which could fail and result in each of the FD&I outputs are identified. The failure rate associated with each possible occurrence is noted. A maintenance flow diagram is constructed which defines the maintenance actions that are performed and decisions made for each FD&I output. Times are synthesized for each maintenance action and combined by a failure rate weighted technique to yield mean time to repair estimates. This prediction technique requires detailed design data and is not applicable during early design phases.

A modified version of the detailed procedure was developed for early predictions. The early prediction technique estimates maintenance times synthesized from the average times to perform the nine elemental maintenance activities (i.e. preparation, fault isolation, spare retrieval, disassembly, interchange, reassembly, alignment, checkout, startup). For each of the nine maintenance elements, a submodel is selected based on the equipment maintenance characteristics (i.e., fault isolation resolution, iterative versus group Replaceable Item (RI) replacement, and distribution of RI groups). Elemental activity times are synthesized based on the general approach(es) to each activity. The time for each approach type is estimated and the average time for each activity estimated using failure rate weighted techniques. The average time for the nine elemental activities are then combined to estimate MTTR. Diagnostic/isolation/test capabilities are accounted for in the early prediction technique by defining the general approaches to fault isolation to be implemented, establishing which approach will be used for each replaceable item or grouping of replaceable items, estimating the average resolution provided by each of the fault isolation types for each grouping of replaceable items, and estimating the time to perform fault isolation for each fault isolation type.

Within the detailed and early prediction procedures, times for each activity are computed using time line techniques. Standard times for physical maintenance actions (e.g., removing a screw, soldering a lead, opening a cabinet door) have been established and are tabulated for use in time line analyses.

TECHNICAL REPORT SUMMARY

INTRODUCTION

This summary presents an overview of the final report prepared for the Maintainability Prediction and Analysis Study conducted under RADC Contract F30602-76-C-0242.

SUMMARY

Current maintainability prediction techniques are relatively ineffective as predictors for state of the art electronic equipments/systems. This document summarizes the study conducted to develop a more effective and accurate method of predicting maintainability parameters.

The basic objective of the study program was to investigate and develop maintainability prediction and analysis techniques applicable to state of the art electronic equipments/systems. The procedures are to be capable of directly relating diagnostic/isolation/test subsystem characteristics and other design characteristics to equipment and system maintainability. Additionally, the developed techniques are to be applicable to avionics, ground, and shipboard electronics at the organizational, intermediate, and depot levels of maintenance.

Specific objectives include:

1. Development of a maintainability prediction methodology which allows direct relationships to be drawn between effectiveness measures of diagnostic/isolation/test capability and the resulting maintainability of an equipment or system; Provisions of relating diagnostic/isolation/test routines (test circuits, software, failure indicators – automatic, semi-automatic or manual) to the replaceable items they serve; Provisions for assessing those replaceable items or portions thereof not capable of fault detection/isolation with the diagnostic/isolation/test subsystem.

2. Development of a set of procedures for performing a prediction of mean-time-to-repair, or maintenance man-hours per maintenance action, which reflects the equipment/system diagnostic/isolation/test capabilities, packaging, replaceable item make up, failure rates of individual replaceable items, and fault isolation ambiguity.

3. Development of a set of time standards (appropriate to measures of physical actions required to correct an equipment malfunction) applicable to modern era designs and packaging concepts; Investigation of time standard differences for avionics, ground electronics and shipboard electronics.

4. Development of items 1, 2, and 3 directly and not through the use of multiple regression or structured checklist techniques.

The approach to satisfying the study objectives was threefold: 1) perform a literature survey to define and evaluate the existing maintainability prediction techniques (and maintenance time standards) and their applicability to current electronic equipments/systems, 2) review the characteristics of current equipments/systems and the prediction needs of the maintainability community to define the maintainability parameters to be predicted and the general approach to the prediction methodology, and 3) review the maintenance policies in current use and develop prediction techniques consistent with the way maintenance is accomplished.

Selection of the methodology developed under this study was based on a review of state of the art equipment/system characteristics, current maintainability analysis techniques, and the requirements of the maintainability community relative to prediction and analysis application.

A number of existing prediction techniques are failure oriented; that is, an assessment of repair time is made based on the fact that a certain replaceable item has failed. Real world maintenance is not failure oriented but rather symptom oriented; that is, the maintenance which is performed is based on the failure symptoms, or on the results obtained from the fault detection/isolation process. This is the way that the developed prediction procedures are structured.

The maintainability prediction methodology is divided into two seperate procedures: 1) a detailed procedure for use when detailed design and support data is available, and 2) an early procedure for use when preliminary design data is available. Both procedures are time synthesis techniques and both use the same general model for predicting MTTR. When a combination of detailed and preliminary data is available, the two procedures can be used together to yield a composite estimate of MTTR.

For the detailed prediction, a list is constructed which identifies all possible failure symptoms or results of fault detection/isolation procedures (FD&I outputs). These failure symptoms or FD&I outputs include all the possible indications that an operator/technician may experience in identifying the fault correction actions to be performed.

The next step of the procedure is to correlate the replaceable items (RI) of the system with the identified failure symptom or FD&I output. This is usually accomplished with a failure mode and effects analysis (FMEA) or similar analysis. After the correlation has been completed a Maintenance Correlation Matrix similar to the one shown in figure 1 is prepared. The matrix provides: 1) the failure rate (λ_{nj}) of each RI (n) associated with each failure symptom/FD&I output (j), (2) the repair time (R_{nj}) for a replaceable item given that a specific FD&I output occurs, and 3) the replacement order (K_{nj}) of a replaceable item given that a specific FD&I output occurs and the maintenance concept is iterative replacement.

The repair times entered in the Maintenance Correlation Matrix are established with the aid of a maintenance flow diagram (MFD). The maintenance flow diagram identifies the step by step procedure that is followed for each FD&I output. Figure 2 is an example of an MFD. The times for each activity are synthesized using a time line analysis in conjunction with the updated set of maintenance time standards included in section 4 of the report. The times (R_{nj}) for each failure symptom/FD&I output are entered in the Maintenance Correlation Matrix of figure 1 next to the associated failure rates.

The average repair time of each RI (R_n) and the MTTR of the equipment/system are computed as:

$$R_n = \frac{\sum_{j=1}^{J} \lambda_{nj} R_{nj}}{\sum_{j=1}^{J} \lambda_{nj}}$$

$$MTTR = \frac{\sum_{m=1}^{N} \lambda_n R_n}{\sum_{m=1}^{N} \lambda_n}$$

In addition to the replaceable item repair times and MTTR, the Maintenance Correlation Matrix can also be used to determine fault isolation resolution.

82590-1P

EQUIPMENT	001			011			022			031		
$\lambda_{EQUIP.}$	79.720			226.957			40.779			233.571		
i	K_{1i}	λ_{1i}	R_{1i}	K_{2i}	λ_{2i}	R_{2i}	K_{3i}	λ_{3i}	R_{3i}	K_{4i}	λ_{4i}	R_{4i}
1	1	22.103	9.2									
2				1	10.920	39.4						
3							1	7.778	8.6			
4										1	192.388	39.4
5												
6												
7												
8												
9												
10				1	3.456	40.4				2	1.944	80.8
11	1	49.362	9.2							2	4.310	49.6
12				1	198.645	39.4				2	4.310	78.8
13							1	2.132	8.6	2	0.119	50.5
14				3	1.171	59.7	1	16.997	8.6			
15							3	0.327	29.8			
16												
17	1	0.059	9.2									
18				1	0.059	47.9						
19							1	0.059	16.1			
20												

EQUIPMENT	039			041			081			541			610		
$\lambda_{EQUIP.}$	126.923			663.127			161.636			9.961			27.476		
i	K_{5i}	λ_{5i}	R_{5i}	K_{6i}	λ_{6i}	R_{6i}	K_{7i}	λ_{7i}	R_{7i}	K_{8i}	λ_{8i}	R_{8i}	K_{9i}	λ_{9i}	R_{9i}
1															
2															
3															
4															
5	1	71.061	9.2												
6				1	599.541	11.0									
7							1	168.879	11.0						
8							2	0.088	20.2	1	8.276	9.2			
9													1	25.560	9.2
10															
11															
12															
13															
14	2	3.079	20.3												
15				1	43.761	11.0				2	1.429	20.2			
16															
17															
18															
19															
20	1	0.059	16.7												

FAILURE RATES (λ) IN FAILURES/10^6 HOURS
REPAIR TIMES (R) IN MINUTES

Figure 1. Sample Maintenance Correlation Matrix

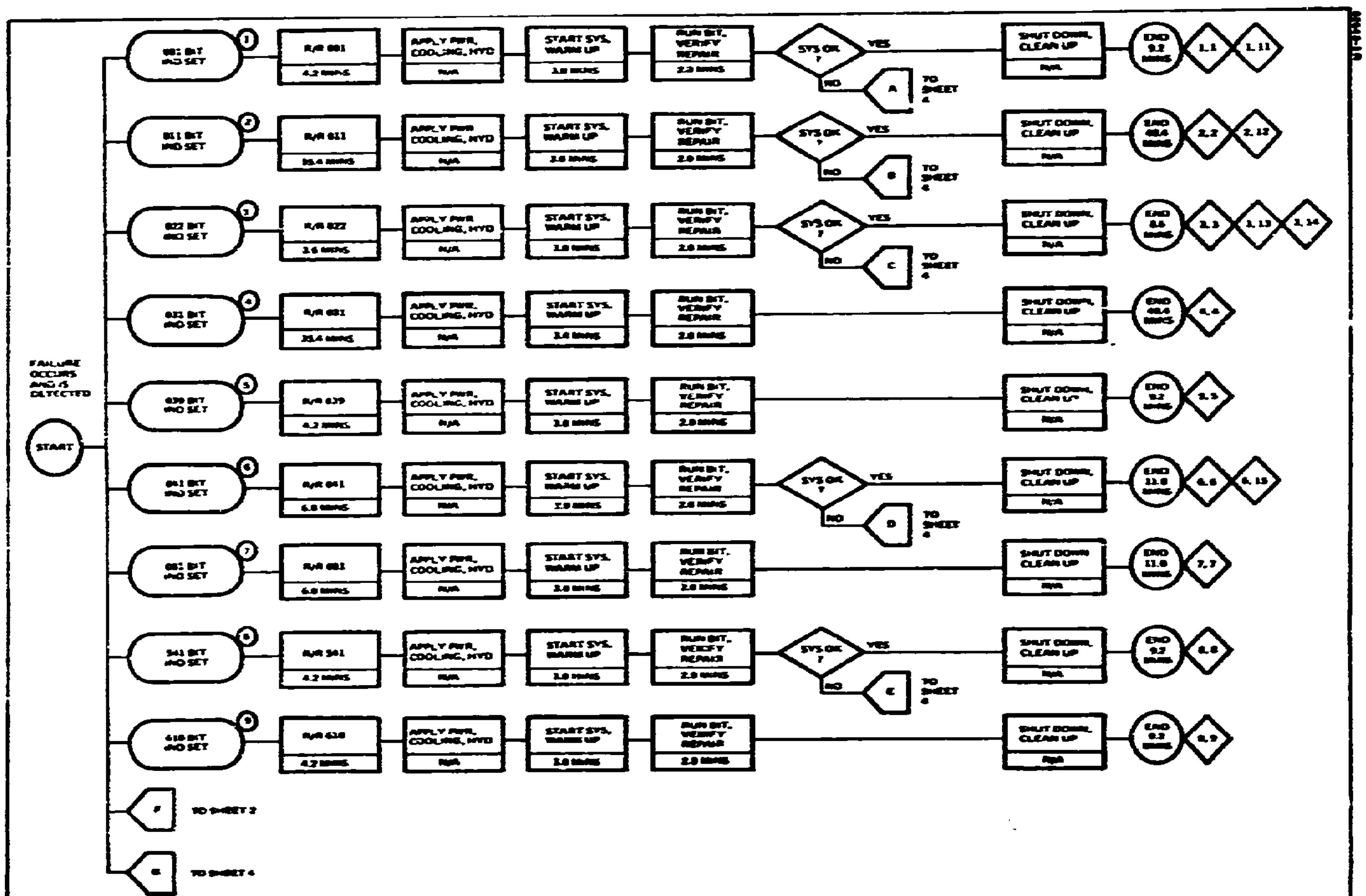


Figure 2. Sample Maintenance Flow Diagram

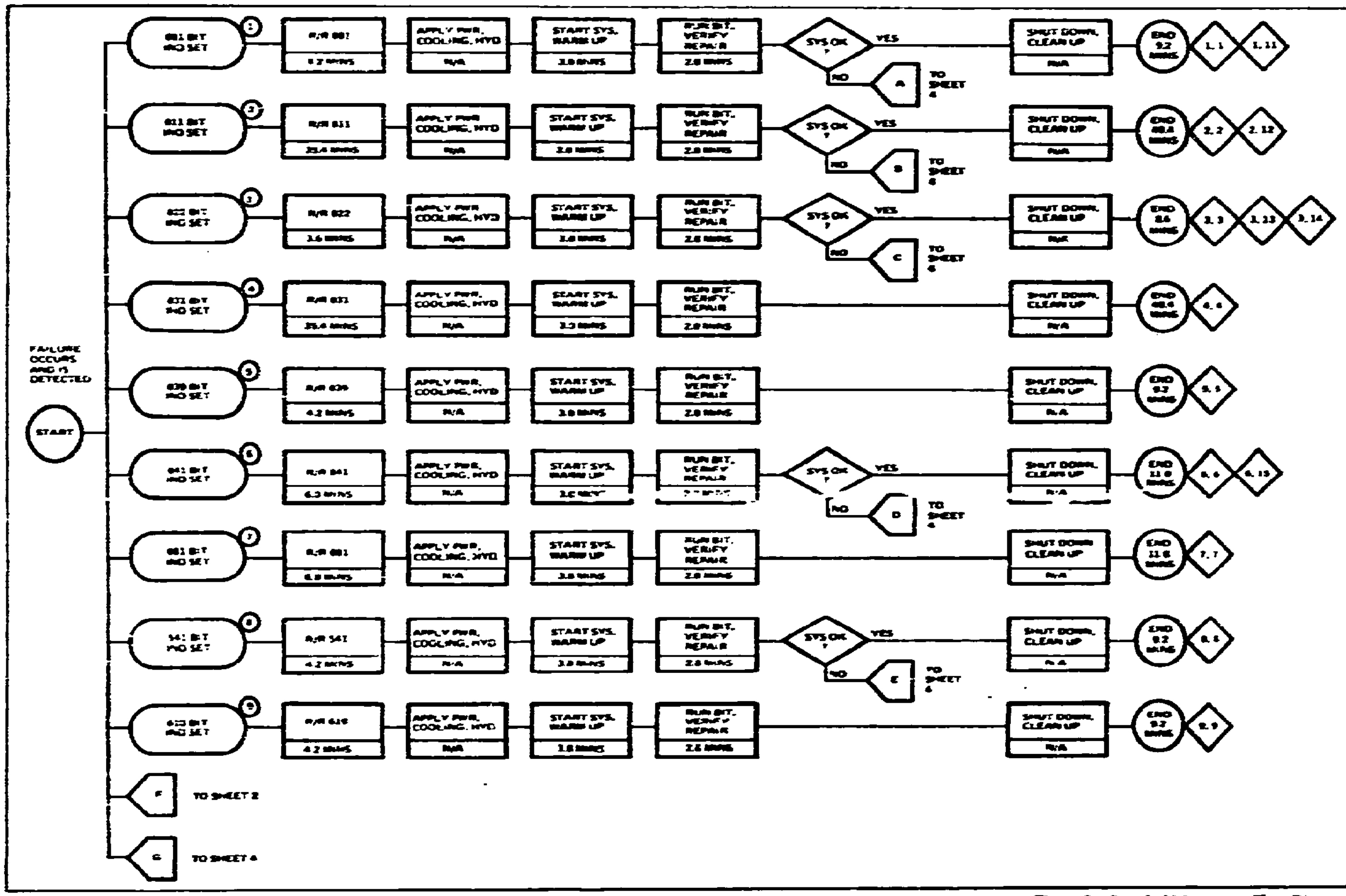


Figure 2. Sample Maintenance Flow Diagram

5-6

Maintenance Philosophy			Preparation $\bar{T}_P$	Fault Isolation $\bar{T}_{FI}$	Spare Retrieval – $\bar{T}_{SR}$: Obtain All at Once	Spare Retrieval – $\bar{T}_{SR}$: Obtain When Needed	Disassembly/Reassembly $\bar{T}_D/\bar{T}_R$	Interchange $\bar{T}_I$	Alignment $\bar{T}_A$	Check Out $\bar{T}_C$	Startup $\bar{T}_{ST}$
Isolation to a Single RI			↕	↕	↕	↕	$\bar{T}_m = \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$, m = D, R	$\bar{T}_I = \frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_I} \lambda_{I_v}}$	↕	↕	↕
Isolation to a Group of RIs	Group Replacement	Multiple Access	↕	↕	↕	$\bar{T}_{SR} = \frac{\sum_{v=1}^{V_{SR}} \lambda_{SR_v} T_{SR_v}}{\sum_{v=1}^{V_{SR}} \lambda_{SR_v}}$	$\bar{T}_m = \sum_{i=1}^{A} \left[1 + \left(\frac{\lambda_T - \lambda_i}{\lambda_T} \right)^{\bar{K}_C} \right] \bar{T}_{m_i}$, m = D, R	$\bar{T}_I = \bar{K}_C \frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_I} \lambda_{I_v}}$	↕	$\bar{T}_C = \frac{\sum_{v=1}^{V_C} \lambda_{C_v} T_{C_v}}{\sum_{v=1}^{V_C} \lambda_{C_v}}$	↕
	Group Replacement	Single Access	↕	↕	↕	↕	$\bar{T}_m = \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$, m = D, R	↕	↕	↕	↕
	Iterative Replacement, Multiple Access	Reassembly Not Required for Checkout	$\bar{T}_P = \frac{\sum_{v=1}^{V_P} \lambda_{P_v} T_{P_v}}{\sum_{v=1}^{V_P} \lambda_{P_v}}$	$\bar{T}_{FI} = \frac{\sum_{v=1}^{V_{FI}} \lambda_{FI_v} T_{FI_v}}{\sum_{v=1}^{V_{FI}} \lambda_{FI_v}}$	$\bar{T}_{SR} = \frac{\sum_{v=1}^{V_{SR}} \lambda_{SR_v} T_{SR_v}}{\sum_{v=1}^{V_{SR}} \lambda_{SR_v}}$	↕	$\bar{T}_m = \left(\frac{\bar{A}+1}{2} \right) \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$, m = D, R	↕	$\bar{T}_A = \frac{\sum_{v=1}^{V_A} \lambda_{A_v} T_{A_v}}{\sum_{v=1}^{V_A} \lambda_{A_v}}$	↕	$\bar{T}_{ST} = \frac{\sum_{v=1}^{V_{ST}} \lambda_{ST_v} T_{ST_v}}{\sum_{v=1}^{V_{ST}} \lambda_{ST_v}}$
	Iterative Replacement, Multiple Access	Reassembly Required for Checkout	↕	↕	↕	$\bar{T}_{SR} = (\bar{A}) \frac{\sum_{v=1}^{V_{SR}} \lambda_{SR_v} T_{SR_v}}{\sum_{v=1}^{V_{SR}} \lambda_{SR_v}}$	$\bar{T}_m = (\bar{A}) \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$, m = D, R	$\bar{T}_I = (\bar{A}) \frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_I} \lambda_{I_v}}$	↕	$\bar{T}_C = (\bar{A}) \frac{\sum_{v=1}^{V_C} \lambda_{C_v} T_{C_v}}{\sum_{v=1}^{V_C} \lambda_{C_v}}$	↕
	Iterative Replacement, Single Access	Reassembly Not Required for Checkout	↕	↕	↕	↕	$\bar{T}_m = \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$, m = D, R	↕	↕	↕	↕
	Iterative Replacement, Single Access	Reassembly Required for Checkout	↕	↕	↕	↕	$\bar{T}_m = (\bar{A}) \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$, m = D, R	↕	↕	↕	↕

Figure 3. Early Prediction Sub-Models

The early prediction procedure is a modified version of the detailed prediction model. This technique estimates the average time to perform each elemental maintenance activity (i.e., preparation, fault isolation, spare retrieval, disassembly, interchange, reassembly, alignment, checkout and start-up), and combines these values to determine the MTTR. For each of the nine maintenance activities, a submodel is selected based on the maintenance characteristics of the system (i.e., fault isolation resolution, iterative versus group RI replacement, and distribution of RI groups). Times are synthesized for each unique method of performing each elemental activity, and the average time for each activity is completed by using the appropriate submodel. A summary of the different applicable submodels appears in figure 3.

The most important step in the early prediction procedure is the estimation of the fault isolation resolution parameter ($\overline{S}$) that is used within some of the submodels. Since detailed information pertaining to the system fault isolation capabilities is not usually available at an early stage, an estimate of the systems capabilities must be made. The accuracy at which this estimate of $\overline{S}$ is made governs the accuracy of the prediction being made. The early prediction procedure basically computes MTTR at the level at which $\overline{S}$ is estimated. Higher level MTTRs can be calculated with a failure rate weighted model. Lower level MTTRs can be estimated but are limited in accuracy to the higher level estimates of $\overline{S}$.

In conclusion, the maintainability prediction methodology developed achieves the objectives for which it was intended. It provides a technique for analyzing the maintainability of modern equipments/systems including direct accountability of diagnostic/isolation/test capabilities, packaging, replaceable item make up and failure rates. The methodology can be applied at any maintenance level, for any maintenance concept, and for avionics, ground electronics and shipboard electronics. The detailed procedure can produce very accurate predictions (limited only by the quality of the input data) and can be applied at any hardware level. The early prediction procedure yields less accurate predictions (limited by the quality and quantity of input data) and again can be applied at any equipment level.

The implementation of the model presented here allows the user to keep track of the overall system maintainability parameters throughout the design and development of a system. By using this technique the user can detect whether or not the maintainability design requirements specified will be met before the system is complete. If the maintainability requirements appear that they will not be met, then the designers can be informed to the necessary changes before it is too late. Thus time and money can be saved by carefully tracking the maintainability parameters throughout a system's development.

SECTION 1.0 INTRODUCTION

This document presents the results of a study to develop and document an improved maintainability prediction and analysis methodology. The study was performed under Contract F30602-76-C-0242 with Rome Air Development Center. This report is prepared in accordance with CDRL item A002 and data item description DI-S-3591A/M.

1.1 PROGRAM OBJECTIVE

The basic objective of this study program was to investigate and develop maintainability prediction and analysis techniques applicable to state of the art electronic equipments/systems. The procedures are to be capable of directly relating diagnostic/isolation/test subsystem characteristics and other design characteristics to equipment and system maintainability parameters. Additionally, the developed techniques are to be applicable to ground, shipboard and avionics electronics at the organizational, intermediate, and depot levels of maintenance. Specific objectives include:

1. Development of a maintainability prediction methodology which allows direct relationships to be drawn between effectiveness measures of diagnostic/isolation/test capability and the resulting maintainability of an equipment or system; provisions for relating diagnostic/isolation/test routines (test circuits, software, failure indicators - automatic, semiautomatic or manual) to the replaceable items they serve; provisions for assessing those replaceable items or portions thereof not capable of fault detection/isolation with the diagnostic/isolation/test subsystem.
2. Development of a set of procedures for performing a prediction of mean-time-to-repair, or maintenance manhours per maintenance action, which characterizes the equipment/system diagnostic/isolation/test capabilities, packaging, replaceable item makeup, failure rates of individual replaceable items, and fault isolation ambiguity.
3. Development of a set of time standards (appropriate to measures of physical actions required to correct an equipment malfunction) applicable to current designs and packaging concepts; investigation of time standard differences for avionics, ground electronics and shipboard electronics.
4. Development of items 1, 2 or 3 directly and not through the use of multiple regression or structured checklist techniques.

1.2 APPROACH

The approach to satisfying the study objective was threefold: 1) perform a literature survey to define and evaluate the existing maintainability prediction techniques (and maintenance time standards) and their applicability to current electronic equipments/systems, 2) review the characteristics of current equipments/systems and the prediction needs of the maintainability community to define the maintainability parameters to be predicted and the general approach to the prediction methodology, and 3) review the maintenance policies in current use and develop prediction techniques consistent with the way maintenance is accomplished.

1.3 ORGANIZATION OF REPORT

This document is divided into six major sections plus appendices. A review of existing techniques, selection of the predicted parameters and general prediction approach, and development of the models for the detailed prediction and early prediction methodologies is presented in Section 2. Section 3 describes the equipment/system data collection effort including data on physical attributes, fault isolation characteristics, maintainability parameters, and maintenance philosophies. Section 4 describes the development of the maintenance time standards and provides a composite list of standards. Section 5 provides step by step procedures for both the detailed prediction and early prediction techniques. Conclusions and recommendations are presented in Section 6. Supporting data and analyses are provided in the attached appendices, including the derivation of M_{max} (Φ) for a lognormal distribution (Appendix B), tables for estimating M_{max} (Φ) for lognormal repair distribution (Appendix C), a sample prediction using the detailed procedure (Appendix F), and two sample predictions using the early procedure (Appendix G).

SECTION 2.0 MODEL DEVELOPMENT

This section presents the developed maintainability prediction methodology. A survey of the current maintainability prediction techniques was conducted and a summary of their characteristics and shortcomings prepared. Based on the survey results, and driven by the needs of today's maintainability community, a time synthesis approach to predicting mean time to repair (MTTR) was selected.

Recognizing the various stages of design and development to which a maintainability prediction methodology must be applied, two basic models were developed (i.e. detailed and early). The detailed model provides the capability for an in-depth prediction when the equipment being predicted is in the final development stage and detailed data is available on fault detection and isolation capability, packaging, and maintenance policy. The early model provides a technique for predicting maintainability characteristics during early and intermediate design stages when prediction data is preliminary and/or incomplete.

The detailed prediction procedure can produce very accurate predictions for any maintenance concept at any hardware level. The early prediction procedure produces less accurate predictions (limited by the quality and quantity of input data), for any equipment level, within the confines of seven defined maintenance concepts.

2.1 BACKGROUND

During the past decade a steadily declining effectiveness of the available standard maintainability prediction methodologies has been recognized. As a prelude to selecting/developing a state-of-the-art maintainability prediction and analysis methodology, a survey of existing techniques was conducted. Each method was reviewed to define the basic prediction hypothesis, data base, detailed procedure, and short comings. Table 1 presents a summary of the more prominent methods reviewed, including the existing military standards.

The prediction methods which were reviewed can be generally segregated into time synthesis models and correlation models. Time synthesis models are those in which: (1) the maintenance activity is broken down into elemental maintenance tasks, (2) each elemental task is assigned a fixed time or time function, and (3) the elemental task time elements are combined or synthesized to form an overall maintainability parameter such as mean time to repair (MTTR). Correlation methods are those in which a checklist or other vehicle is used to score maintenance related attributes of a system and the score(s) of the checklist(s) are inserted into a regression equation to yield the estimated maintainability parameter. The ARINC Fault/Symptom Model (RADC-TR-70-89) is a combined time synthesis and correlation methodology; fault isolation and checkout attributes are evaluated by checklists and regression equations, and physical elements of access and interchange are evaluated by combining elemental task times.

All of the methods reviewed have substantial drawbacks with respect to adequately evaluating complex modern systems. Principally lacking is a meaningful correlation between quantitative maintainability parameters such as MTTR and system fault detection/isolation/test (FDIT) features such as computer controlled diagnostics, and built-in test capabilities. Also lacking is a sensitivity to state-of-the-art packaging and construction techniques, and to the system maintenance concept or detailed maintenance plan.

MIL-HDBK-472, Procedure 1 and Procedure 2A have provided useful estimators in the past but the data base on which these procedures were developed is no longer representative of modern systems and techniques. MIL-HDBK-472, Procedures 2B and 4, and the Dunlop and Associates Distribution Model present viable general approaches but the inputs are dependent on "expert judgment" time estimates. There are no procedures for relating the capabilities of the FDIT features to expert

TABLE 1. SUMMARY OF CURRENT MAINTAINABILITY PREDICTION MODELS

Model	Prediction Concept	Method Shortcomings
ARINC Time Synthesis Model; MIL-HDBK-472 Procedure 1	• Similar systems have similar repair activities • Repair can be broken down into known activities • Repair time distribution derived from probability of occurrence of each activity	• Requires extensive data on similar systems • Requires extensive and complex computations • Insensitive to some equipment design features • Not applicable during early design
Federal Electric Corp Time Synthesis Model; MIL-HDBK-472, Procedure 2	• Repair consists of 7 maintenance tasks • Time for each task based on functional level • System repair time is failure weighted mean of average LRU repair times	• Elemental task times not compatible with current maintenance techniques and features • Insensitive to maintenance concept and LRU failure modes
RCA Checklist Model; MIL-HDBK-472, Procedure 3	• Repair time dependent on equipment, personnel and support attributes • Scoring of 3 checklists evaluates maintenance attributes • Regression equation converts checklist scores to mean repair time	• Checklists based on non-current design techniques • Insufficient coverage of fault isolation characteristics • Equal weighting of items within each checklist
Republic Aviation Corp Time Synthesis Model; MIL-HDBK-472, Procedure 4	• Provides accountability of maintenance under all expected operational & maintenance environment • Repair time estimates by expert judgment • System repair time based on failure rate weighting and environment applicability	• Repair time estimates are subjective, i.e., based on expert judgment • Procedure is maintenance environment oriented, not design oriented

TABLE 1. SUMMARY OF CURRENT MAINTAINABILITY PREDICTION MODELS (Continued)

Model	Prediction Concept	Method Shortcomings
Dunlop & Associates Distribution Model; AD 890 199L	• System defined in terms of all maintenance subtasks and probability of each • Subtask probabilities, times and distribution based on expert judgment	• Distribution of repair times and time estimates are subjective • Procedure not directly sensitive to maintenance features
Federal Electric Corp Functional Model; AD 847 065V	• Early design prediction based on equipment functions • Checklist of design & support features compiled for each function • Multiple repression equation used to evaluate scores	• Concluded to be infeasible by Federal Electric Corp. investigators
ARINC Functional Model; RADC-TR-65-467	• Checklist evaluation of 15 maintenance parameters • Checklist scores correlated & used in one of 8 regression equations determined by equipment function	• Regression equation very limited in features evaluated (particularly trouble-shooting) and equipment (i.e., functions) covered
ARINC Fault/Symptom Model; RADC-TR-70-89	• System defined in terms of faults and resulting symptoms • Multiple checklists used to score LRU design characteristics • Regression equations used to determine mean repair times	• Does not provide evaluation of lower level items • Fault isolation & checkout time estimates are combined • Inherent inaccuracies of checklist & regression analysis approach

judgment estimates. There are also no estimators for physical tasks consistent with modern packaging and construction techniques. MIL-HDBK-472, Procedure 3 is a correlation type model in which three (3) checklists are scored. The checklists are based on non-current design techniques and very insensitive to modern FDIT features.

The ARINC Fault/Symptom Model appears to be a good start on a new predictive technique but it still has some basic problems. Some of these problems, such as no lower indenture capability, and a combined estimator of fault isolation and checkout times are described in RADC-TR-74-112. Additional problems include: (1) the basic failure of checklist type approaches to cover all FDIT capabilities and combinations thereof, (2) the failure to cover all maintenance concept alternatives such as group Replaceable item (RI) replacement, iterative RI replacement, and replacement based on highest failure probability, and (3) the lack of time standards which cover modern packaging techniques.

2.2 MODEL SELECTION

The previous section defines the more widely known of the maintainability prediction models and the shortcomings of each. A review of the models indicates the most powerful of the models in terms of flexibility, applicability and accuracy are the time synthesis versions. Therefore, the time synthesis approach is the basis for the methodology presented herein.

The time synthesis approach implies that the maintenance time estimate for a given maintenance action is found by simple addition of the time (or estimate of the average there of) that it takes to perform each maintenance element (e.g., preparation, fault isolation, etc. - Refer to section 2.3.2.3). Likewise, the individual maintenance element time estimates are found by simple addition of the time required to perform each subtask of the maintenance element. If more refinement is desired, subtasks could be broken down into sub-subtasks, etc. This process soon reaches a point of diminishing returns, however, and as a rule of thumb, maintenance actions should not be broken down into lower than .1 minute segments. The only recommended exception to this is the use of standard maintenance times (i.e., the times provided in section 4.5.5). For purposes of this procedure, its models, and the application examples shown in this document, maintenance actions only at the subtask and higher levels are addressed. Subtasks are defined as discrete physical actions such as loading a diagnostic program, removing a slotted head screw, or examining a waveform on an oscilloscope.

Time estimates for subtasks, maintenance elements, and complete maintenance actions are the fundamental portion of a time synthesis prediction and there is little difference in the way in which time estimates are computed for this procedure from previous procedures. The key, however, in performing an accurate maintainability prediction of a given equipment is the definition of the full spectrum of probable maintenance actions and the frequency of occurrence of each of those actions.

Most previous time synthesis prediction techniques have concentrated on the supposition that: given a certain item has failed, what is the time required to effect repair by replacement of that item. The basic pitfall in this approach is that most replaceable items exhibit more than one failure mode and/or associated failure effect. Depending on the particular failure mode, the corrective maintenance time can be significantly different due to the methodology required for fault isolation, or due to the resolution/ambiguity of the fault isolation procedure for different failure symptoms.

Fault isolation has notoriously been the biggest unknown in corrective maintenance time estimation. It typically exhibits the largest variance of the maintenance elements, and is the predicted element that typically shows the lowest correlation with field experience. The lack of success in predicting fault isolation times is due to the insufficient handling of failure modes, as described above, and to the differences in the way different technicians approach the same failure condition.

With an appreciation of the problems associated with previous prediction procedures, the approach to developing a procedure which accurately predicts maintainability becomes straight forward. To accurately predict maintainability, the prediction methodology must account for the way maintenance is actually performed. Primarily this ground rule implies:

1) Fault isolation time estimation must be based on the way in which the failure manifests itself in terms of external failure effects and the results of the fault isolation procedure(s) as available to the maintenance technician.
2) Variability due to different failure modes and effects of each replaceable item must be accounted for. These variations are principally in the areas of fault isolation time and fault correction time.
3) Ambiguity must be accounted for. This includes all ambiguity as discussed in section 2.2.1.2 including consideration of secondary maintenance which must be performed when the primary fault correction procedure does not correct the problem.
4) The prediction methodology should not be susceptible to technician variance (other than perhaps skill level), i.e., the prediction must be based on an established procedure for each corrective maintenance action.

Within the ground rules stated above, the prediction model developed herein will allow systematic estimation of fault isolation times through the following procedure:

1. Identify replaceable items (RIs) - refer to definition in section 2.2.1.1.
2. Identify the fault detection and isolation outputs. These are the results of the BIT/Diagnostic capabilities of the system or the outputs from manual/semi-automatic testing by the maintenance personnel.
3. Relate the fault detection and isolation outputs to the RIs or portions thereof which are associated with each output.
4. Develop a maintenance flow diagram (step-by-step man/machine process in fault isolation) and a time line analysis for each RI/fault isolation output combination.

5. Assign times to each subtask in the time lines and compute the elapsed time for each unique fault isolation process.
6. Enter the fault isolation times into the appropriate maintainability prediction model.

A somewhat similar approach to this technique was proposed in RADC-TR-70-89. The shortcoming of this approach was in the use of regression equations to assess time for LRU/fault symptom relationship. The proposed methodology presented herein expands this basic approach by defining all replaceable item/fault isolation result relationships, and by establishing a maintenance time estimate for each combination based on a well defined set of fault correction procedures.

2.2.1 Definitions

Among the different services, and different organizations within each service, different terms are used to mean the same thing and/or the same term is used to mean different things. For example a replaceable circuit card can be called an LRU, SRU, SRA, LRI, WRA, etc. depending on the organization involved. To ensure a common understanding of the presented methodology, a set of definitions has been developed to define the most common ambiguous terms.

2.2.1.1 Replaceable Items

One of the problems with some previous maintainability prediction techniques (particularly regression or check list type) is their limitation in being applied to different levels of maintenance (e.g., organizational, intermediate, depot). These different levels normally address different types of maintenance actions such as unit replacement, module replacement and piece part replacement.

A significant advantage to this present procedure is its universal applicability to any level or type of maintenance. The problem associated with this expanded capability is that the typical definitions of LRU, SRU, WRU, etc., do not consistently apply. To resolve this problem the prediction procedure is presented in generic terms of replaceable items as defined below.

REPLACEABLE ITEM (RI) = THOSE PHYSICAL ENTITIES NORMALLY REMOVED AND REPLACED TO EFFECT REPAIR AT THE MAINTENANCE LEVEL FOR WHICH THE PREDICTION IS BEING MADE (LRU, PRU, SRU, WRA, PART, ETC.).

2.2.1.2 Ambiguity

Ambiguity is a term which has been used interchangeability to mean several things. For purposes of this procedure, three types of ambiguity have been defined and will be referenced in succeeding sections of this document as ambiguity Type 1, Type 2, and Type 3. These three types are defined as:

1) Fault isolation to a group of RIs
2) Fault isolation results indicate a particular RI or RI group and fault is actually in another RI
3) Fault is indicated when there is no fault (i.e., false alarm)

2.2.1.3 False Alarm Rate (FAR)

This is another term which has been used interchangeably to denote several different things. For purposes of this procedure FAR will be limited to the following definitions:

1) Ambiguity Type No. 3 - Fault is indicated when there is no hard fault
2) Fault is detected and can not be repeated or, fault is detected in one environment or under one set of operating conditions and cannot be duplicated under maintenance conditions (e.g., Airborne radar fault detected in flight but cannot be duplicated on the flight line).

2.3 DETAILED PREDICTION MODEL DEVELOPMENT

2.3.1 Maintainability Parameter Selection

The maintainability parameter most often specified in DOD contract requirements is Mean Time To Repair (MTTR). Equivalent parameters are Mean Repair Time (MRT) and Mean Corrective Maintenance Time (Mct). MTTR has been the primary measure of maintainability for the past two decades and has no apparent successor in the foreseeable future. MTTR is also the parameter which most previous prediction methodologies have addressed (in one form or another), and is the parameter most easily definable and understandable to non-maintainability oriented personnel. For these reasons, MTTR has been selected as the primary maintainability parameter to be predicted with the methodology presented herein.

Aside from MTTR, various other maintainability and maintainability related parameters have been defined and evaluated. Among these are Median Time to Repair, Maximum Time to Repair (at various percentiles), Mean Preventive Maintenance Time, Maintainability Index, Maintenance Man-hours per Operating Hour, False Alarm Rate, and Fault Isolation Resolution. The parameters which are specifically addressed in this document are:

- MTTR - Mean Time to Repair
- $M_{max}(\Phi)$ - Maximum Corrective Maintenance Time at the Φ Percentile
- I_1 - Fault Isolation Resolution to a single RI
- I_N - Fault Isolation Resolution to $\leq$ N RIs
- $\overline{MMH}$/Repair - Mean Maintenance Man-hours per Repair
- $\overline{MMH}$/MA - Mean Maintenance Man-hours per Maintenance Action (including false alarm)
- $\overline{MMH}$/OH - Mean Maintenance Man-hours per Operating Hour
- MTTR with Periodic Adjustments

Additional parameters, or variations of the above parameters, can be predicted with minor modifications to the presented procedure.

2.3.2 Prediction of MTTR

2.3.2.1 Definition of MTTR

As noted in section 2.3.1, the primary maintainability parameter to be predicted with the methodology presented herein is MTTR. The definition of MTTR per MIL-STD-721B is:

"The total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time"

This definition is easily applied to operational maintenance data or formal maintainability demonstration tests, however, it is not as easily applied to predictions. A prediction cannot confidently account for times associated with operational or logistic constraints, nor can it accurately account for non predictable failure occurrences such as intermittent failures or induced failures. Additionally it cannot account for maintenance occurring during a set period of time since the repairs occurring during that time cannot be accurately predicted. For purposes of the prediction methodology presented herein, the following definition of MTTR is provided:

MTTR — THE MEAN VALUE OF THE PROBABILITY DISTRIBUTION OF TIMES TO COMPLETE ACTIVE CORRECTIVE MAINTENANCE OVER ALL PREDICTABLE UNSCHEDULED MAINTENANCE ACTIONS WEIGHTED BY THE RELATIVE FREQUENCIES OF OCCURRENCE OF THESE ACTIONS.

2.3.2.2 MTTR Prediction Ground Rules

The ground rules associated with a specific prediction will depend on the operational requirements and customer specified requirements for a particular equipment application. For example, one contract may require that spare retrieval time be included in the prediction whereas another contract would not; or, one contract might require that a system be reinitialized and returned to an operating state before repair is considered complete, whereas another contract might consider repair completion concurrent with completion of repair verification (i.e. checkout).

In general the following ground rules will apply to all predictions:

- Failures occur at the predicted failure rate
- Hard failures only
- Single failures only
- Randomly occurring failures only

- Maintenance is performed in accordance with established maintenance procedures (i.e., documentation, tools, test equipment)
- Maintenance is performed by technicians with appropriate skills and training
- Active maintenance time only - excludes administrative and logistic delays, fault detection, clean up

2.3.2.3 MTTR Elements

The methodology presented herein is a typical time synthesis technique. The times associated with each portion of a maintenance action are summed together to yield the total maintenance time for that action. It should be noted that for each individual maintenance action, the predicted/estimated maintenance time is the expected average time to complete that maintenance action. For all but the most basic or automated maintenance tasks (e.g., load time for a fixed length computer controlled diagnostic program), there is some variability to maintenance time. In the presented methodology variability is addressed only for predicting maximum corrective maintenance time as presented in section 2.5.

Previous time synthesis prediction techniques have broken down MTTR into various maintenance elements as shown in Table 2. The time elements are basically the same for all techniques. Minor differences occur in the nomenclature of the various elements and in the quantity of elements which are included. For example, all the breakdowns include some form of fault location/isolation time, while only 3 include preparation time, and only one includes clean up time. For all of the techniques shown, the repair time is the algebraic sum of the times associated with the elements. Elements such as preparation time, excluded in some techniques, can be included simply by adding the associated time to the previously computed repair time.

Two advantages of the presented methodology, over other time synthesis techniques, are its flexibility and its capability of treating ambiguous maintenance actions. MTTR predictions using this procedure can include any or all of the elements addressed in other techniques. They normally address the broad categories shown in Table 3. A definition of each of the maintenance elements is provided in Table 4. The methods applicable to estimating each of the maintenance element times are presented in Table 5.

TABLE 2. ELEMENTS OF MTTR AS DEFINED IN THE NOTED DOCUMENTS.

MIL-HDBK-472 (Procedure 2)	MIL-STD-721B	AMCP-706-134	AD 727 014	RADC TR-70-89
	Preparation	Preparation		Preparation
Localization	Fault Location	Fault Location	Localization	Fault Location - Checkout
Isolation			Isolation	
	Obtain Item	Obtain Item		Obtain Item
Disassembly	Fault Correction	Item Replacement	Disassembly	Fault Correction - Adjustment
Interchange			Interchange	
Reassembly			Reassembly	
Alignment	Adjustment	Adjustment		
Checkout	Checkout	Final Test	Checkout	
	Clean Up			

TABLE 3. MTTR ELEMENTS FOR NEW PREDICTION METHODOLOGY

Proposed Breakdown (Basic)	Isolation to Single RI	Isolation to Group with Group Replacement	Isolation to Group with Iterative Replacement	Isolation with Ambiguity	
Preparation	Preparation	Preparation	Preparation	Preparation	Secondary Preparation
Isolation	Isolation	Isolation	Isolation	Isolation	Secondary Isolation
Fault Correction	Spare Retrieval	Spare Retrieval	Fault Correction	Fault Correction	Secondary Fault Correction
	Disassembly	Disassembly			
	Interchange	Interchange			
	Reassembly	Reassembly			
	Alignment	Alignment			
	Checkout	Checkout			
Start Up	Start Up	Start Up	Start Up	Continue	Start-Up

TABLE 4. DEFINITION OF MAINTENANCE TASK TIMES

Maintenance Element Time	Abbreviation*	Definition
Preparation	$T_{P_{nj}}$	Time associated with those tasks required to be performed before fault isolation can be executed. Examples: Obtain, set-up and warm up test equipment; Apply power and cooling to system, warm up and stabilize; Input system initialization parameters.
Fault Isolation	$T_{FI_{nj}}$	Time associated with those tasks required to isolate the fault to the level at which fault correction begins. Examples: Load, run, and interpret results of a diagnostic program; Examine fault isolation symptoms, locate symptoms in maintenance manual, follow manual procedures to point where replaceable item or group of replaceable items is identified.
Fault Correction		
• Spare Retrieval	$T_{SR_{nj}}$	Time associated with obtaining a spare replaceable item or group of replaceable items from the designated spares area.
• Disassembly	$T_{D_{nj}}$	Time associated with gaining access to the replaceable item(s) identified during the fault isolation process. Examples Opening cabinet doors, pulling out equipment drawers, removing CCA retaining bars; Technician transit time to a remote equipment.
• Interchange	$T_{I_{nj}}$	Time associated with the removal and replacement of a faulty replaceable item or suspected faulty items. Examples: Removing screws, connectors, solder joints; Extracting and inserting the replaceable item; Application of conformal coating, heat transfer paste.
• Reassembly	$T_{R_{nj}}$	Time associated with closing up the equipment after interchange is performed, i.e., the opposite process of disassembly.

*Abbreviations used in the prediction math models; Time to perform the m^{th} elemental task (P, FI, SR, D, I, R, A, C, ST) for the n^{th} RI given the j^{th} fault isolation result.

TABLE 4. DEFINITION OF MAINTENANCE TASK TIMES (Continued)

Maintenance Time	Abbreviation*	Definition
• Alignment	$T_{A_{nj}}$	Time associated with aligning or calibrating the system or RI after a fault has been corrected.
• Checkout	$T_{C_{nj}}$	Time associated with the verification that a fault has been corrected and the system is operational.
Start-up	$T_{ST_{nj}}$	Time associated bringing a system up to the operational state it was in prior to failure, once a fault has been corrected and verified.

*Abbreviation used in the prediction math models.

TABLE 5. CORRECTIVE MAINTENANCE TIME ELEMENTS AND METHODS OF ESTIMATION

	Time Standards	Fixed Time	Field History	Engineering Judgement
PREPARATION - $T_{P_{nj}}$		X	X	X
FAULT ISOLATION - $T_{FI_{nj}}$		X	X	X
SPARE RETRIEVAL - $T_{SR_{nj}}$			X	X
DISASSEMBLY - $T_{D_{nj}}$	X			X
INTERCHANGE - $T_{I_{nj}}$	X			X
REASSEMBLY - $T_{R_{nj}}$	X			X
ALIGNMENT - $T_{A_{nj}}$		X	X	X
CHECKOUT - $T_{C_{nj}}$		X	X	X
START UP - $T_{ST_{nj}}$		X	X	X

2.3.2.4 Generalized Model

The generalized equation for computing MTTR is

$$MTTR = \frac{\sum_{n=1}^{N} \lambda_n R_n}{\sum_{n=1}^{N} \lambda_n}$$

where:

N = Number of replaceable items (RI)

λ_n = Failure rate of the nth RI excluding any undetected failure rate

R_n = Mean repair time of the nth RI as computed below

$$R_n = \frac{\sum_{j=1}^{J} \lambda_{nj} R_{nj}}{\sum_{j=1}^{J} \lambda_{nj}}$$

where:

J = Number of unique fault isolation results (refer to section 5.1.3)

λ_{nj} = Failure rate of those parts of the nth RI which would cause the nth RI to be called out in the jth fault isolation result (note that this can be zero)

R_{nj} = Average repair time of the nth RI when called out in the jth fault isolation result as computed below:

$$R_{nj} = \sum_{m=1}^{M_{nj}} T_{m_{nj}}$$

where:

M_{nj} = Number of steps to perform corrective maintenance when a failure occurs in the nth RI and results in the jth fault isolation results. Includes all maintenance elements - preparation, isolation, spare retrieval, et al. This may include operations on other RIs called out in the jth fault isolation result.

$T_{m_{nj}}$ = Average time to perform the mth corrective maintenance step for the nth RI given the jth fault isolation result.

2.3.2.5 Special Cases

This section defines mathematical models for computing MTTR under certain special cases of maintenance concepts. The special models are interesting in that they clearly show how the MTTR is affected by differing maintenance philosophies. However, their utility is somewhat limited. There are very few equipments or systems which encompass one and only one special case described. In general, maintenance will include several types of maintenance actions. Hence the generalized models in conjunction with the procedure of Section 5.1 must be applied.

(1) Nonambiguous: Maintenance is accomplished by performing fault isolation to a single RI and replacing that RI. (Refer to Figure 1.)

$$R_{nj} = T_{P_{nj}} + T_{FI_{nj}} + T_{SR_{nj}} + T_{D_{nj}} + T_{I_{nj}} + T_{R_{nj}} + T_{A_{nj}} + T_{C_{nj}} + T_{ST_{nj}}$$

(2) Ambiguity (Type 1) - Group Replacement:
Maintenance is accomplished by performing fault isolation to a group of RIs and replacing all the RIs in the group.

(a) Generalized (N_j = RI group size) - Refer to Figure 2.

$$R_{nj} = T_{P_{nj}} + T_{FI_{nj}} + T_{SR_{nj}} + \sum_{s=1}^{N_j'} \left(T_{D_{nj}} + T_{R_{nj}}\right)_s + \sum_{s=1}^{N_j} \left(T_{I_{nj}} + T_{A_{nj}}\right)_s + T_{CO_{nj}} + T_{ST_{nj}}$$

where N_j = number of RIs that must be replaced as a result of the jth fault isolation result

N_j' = number of disassembly/reassembly actions required for the jth fault isolation result

= N_j, if separate disassembly and reassembly required for each interchange

(b) Reduced (Single access & spare retrieval) -- Refer to Figure 3.

$$R_{nj} = T_{P_{nj}} + T_{FI_{nj}} + T_{SR_{nj}} + T_{D_{nj}} + \sum_{s=1}^{N_j} \left(T_{I_{nj}} + T_{A_{nj}}\right)_s + T_{R_{nj}} + T_{C_{nj}} + T_{ST_{nj}}$$

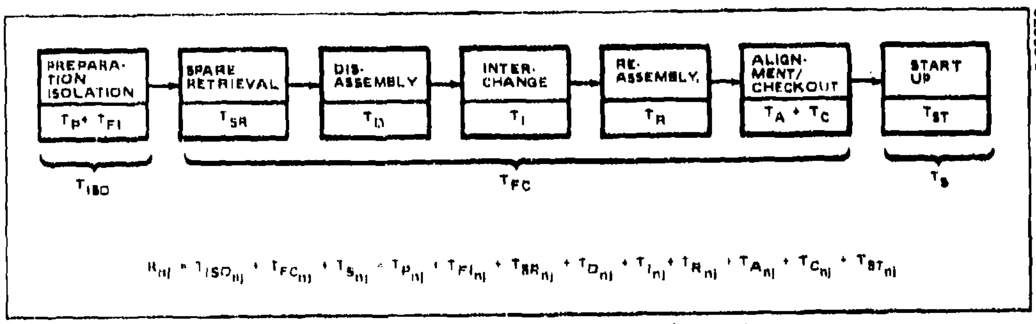


Figure 1. Fault Isolation to a Single LRU

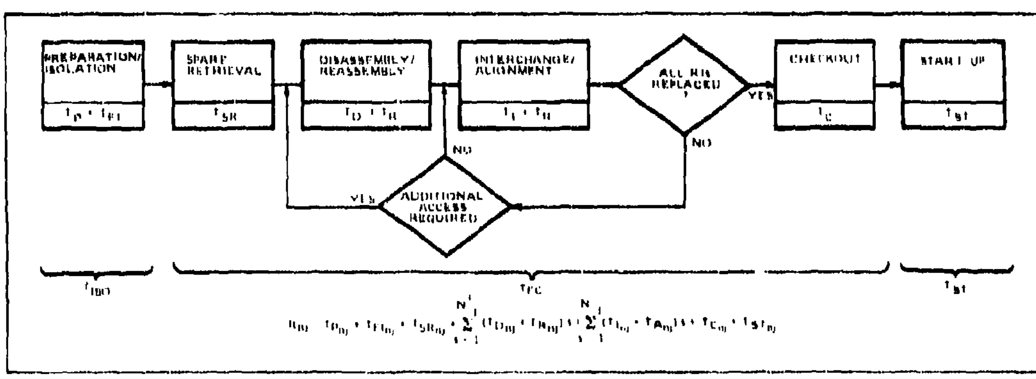


Figure 2. Group Replacement (Generalized)

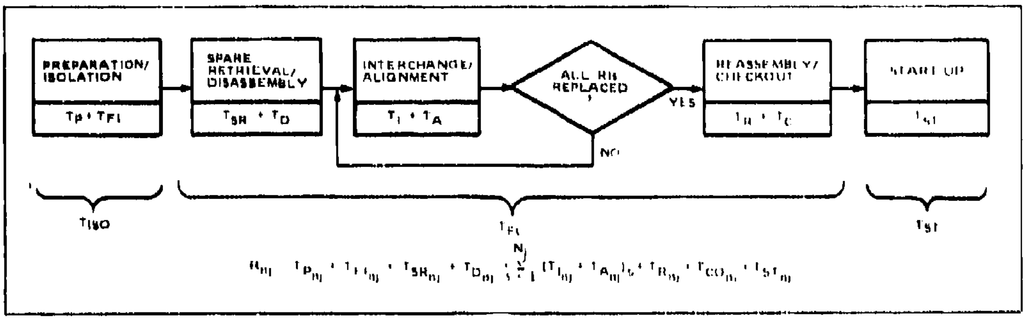


Figure 3. Group Replacement/Single Access and Spare Retrieval

(3) **Ambiguity (Type-1) - Iterative Replacement:**

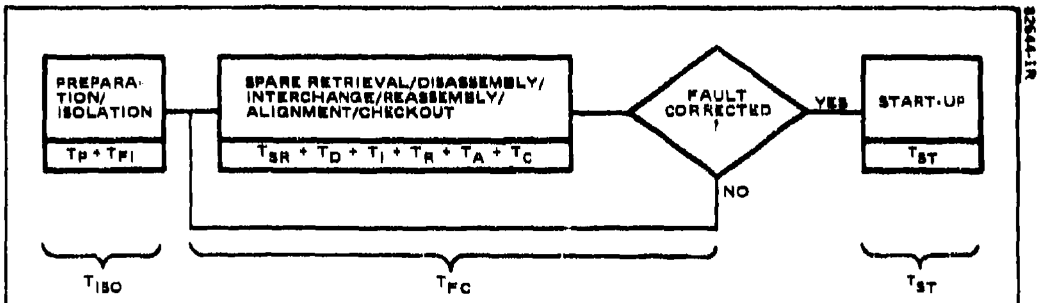
Maintenance is accomplished by performing fault isolation to a group of RIs and then replacing the suspect RIs one at a time until the fault has been corrected. (Refer to Figure 4)

$$R_{nj} = T_{P_{nj}} + T_{FI_{nj}} + \sum_{k=1}^{K_{nj}} \left(T_{SR_{nj}} + T_{D_{nj}} + T_{I_{nj}} + T_{R_{nj}} + T_{A_{nj}} + T_{C_{nj}} \right)_k + T_{ST_{nj}}$$

where:

K_{nj} = replacement order of nth RI given the jth FI result.

$T_{D_{nj}}$ and $T_{R_{nj}}$ included as many times as required.



$$R_{nj} = TP_{nj} + TFI_{nj} + \sum_{k=1}^{K_{nj}} (TSR_{nj} + TD_{nj} + TI_{nj} + TR_{nj} + TA_{nj} + TC_{nj})k + TST_{nj}$$

Figure 4. Iterative Replacement

2.4 EARLY PREDICTION MODEL DEVELOPMENT

The maintainability prediction methodology presented in section 2.3 can not be easily implemented during the early stages of a program. The major reason for this limitation is the requirement of detailed information about the fault isolation characteristics. The early prediction model presented herein requires less detailed fault isolation data and therefore is capable of implementation during the early stages of a program.

Two approaches were taken to develop an early prediction model. The first approach was to develop prediction models using correlation equations generated from regression analyses of the physical, fault isolation, and maintainability characteristics of existing systems. The second approach was to simplify the detailed model into a general form where less information would be required to implement it.

The findings and results of these two approaches are presented in the following sections.

2.4.1 Correlation Analysis Approach

The objective of this analysis was to derive an equation or set of equations which define the correlation between design characteristics and inherent maintainability parameters. The approach followed was to: 1) define the prediction parameters to be predicted, 2) define the design characteristics believed to be related to each of the maintainability parameters, 3) collect data on the defined design characteristics and maintainability parameters from existing systems, and 4) perform a stepwise regression analysis to generate and evaluate the regression equations.

2.4.1.1 Selection of Maintainability Parameters

In consonance with establishing MTTR as the primary maintainability parameter to be predicted with the detailed procedure, MTTR was also selected as the primary parameter for the regression analysis. Additionally, within MTTR, it was felt that a further distinction between various aspects of MTTR might produce more meaningful correlations. As a starting point, three equations defining MTTR were hypothesized:

1) $MTTR = K_A \, MTTR_A + K_S \, MTTR_S + (1-K_A-K_S) \, MTTR_M$

2) $MTTR = P_D \, MTTR_D + P_A \, MTTR_{ANA} + P_{PS} \, MTTR_{PS} + P_{RF} \, MTTR_{RF} + P_{PP} MTTR_{PP} + P_C MTTR_C$

3) $MTTR = MTTR_{ISO} + MTTR_{RR} + MTTR_{CO}$

where:

- K_A = percent automatic fault isolation
- K_S = percent semi-automatic fault isolation
- $MTTR_A$ = MTTR associated with automatic fault isolation
- $MTTR_S$ = MTTR associated with semi-automatic fault isolation
- $MTTR_M$ = MTTR associated with manual fault isolation
- P_D = Percentage of equipment which is digital
- P_A = Percentage of equipment which is analog
- P_{PS} = Percentage of equipment which is power supplies
- P_{RF} = Percentage of equipment which is RF
- P_{PP} = Percentage of equipment which is pieceparts
- P_C = Percentage of equipment which is chassis associated components
- $MTTR_D$ = MTTR of digital portion of equipment
- $MTTR_{ANA}$ = MTTR of analog portion of equipment
- $MTTR_{PS}$ = MTTR of power supply portion of equipment
- $MTTR_{RF}$ = MTTR of RF portion of equipment
- $MTTR_{PP}$ = MTTR of pieceparts portion of equipment
- $MTTR_C$ = MTTR of equipment chassis
- $MTTR_{ISO}$ = average fault isolation time
- $MTTR_{RR}$ = average fault correction time
- $MTTR_{CO}$ = average checkout time
- MTTR = mean time to repair

It was proposed that regression equations be established for the above parameters, values be determined for the equipment being predicted, and the values entered into one of the three hypothesized equations to yield MTTR. Exception to this would be values for $MTTR_A$, $MTTR_S$ and $MTTR_M$ which would be derived by time synthesis methods.

2.4.1.2 Selection of Design Characteristics

In establishing the regression equation for the maintainability parameters defined in the preceding section, the following linear model was selected

$$Y = B_0 + B_1 X_1 + B_2 X_2 \ldots B_P X_P$$

where:

Y = the dependent variable being predicted (e.g., K_A, K_S, $MTTR_A$)

Xp = The P^{th} predicting parameter (independent variable)

Bp = the coefficients computed by the regression program for the P^{th} parameter

The dependent variables, or design characteristics to be correlated with the maintainability parameters were selected based on their expected influence on equipment maintainability. The selected design characteristics are defined in Table 6. The selected design characteristics were compared against the list of dependent variables to determine which characteristics should be correlated with each parameter. The resulting relationship matrix is shown in Table 7.

2.4.1.3 Data Collection

The data collected on each of the dependent and independent variables which was used to conduct the regression analysis and establish the regression equations is provided in section 3. Also included in section 3 is a more detailed definition of each of the dependent and independent variables evaluated.

In the process of data collection it was found that data could not be segregated for the variables $MTTR_D$, $MTTR_{ANA}$, $MTTR_{PS}$, $MTTR_{RF}$, $MTTR_{PP}$ or $MTTR_C$. Therefore, the second hypothesized equation

$$(MTTR = P_D\, MTTR_D + P_A\, MTTR_{ANA} + P_{PS}\, MTTR_{PS} + P_{RF}\, MTTR_{RF} + P_{PP}\, MTTR_{PP} + P_C\, MTTR_C)$$

could not be evaluated and was dropped from the analysis.

2.4.1.4 Regression Analysis

2.4.1.4.1 Regression Analysis Program

The regression analysis was performed using the computerized stepwise regression analysis program (SRAP) contained in the UCLA Biomedical Computer Program library. This program takes a multiple number of independent variables and one dependent variable and computes a series of multiple linear regression equations. The first regression equation contains the one independent variable that has the highest correlation with the dependent variable. At each step an additional independent variable is inserted and a new multiple linear regression equation is computed. The variable added is the one which makes the greatest reduction in the error sum of squares. Variables can also be removed after they have been inserted, if their F values fall below a tolerance value set by the user. The result of the stepwise regression analysis program is a multiple linear regression equation that estimates the dependent variable using those independent variable(s) that have the highest combined multiple correlation.

TABLE 6. DEFINITION OF VARIABLES

VAR #	Variables	Definition
1	RIQ	quantity of replaceable RIs
2	MRIQ	quantity of replaceable modular (plug-in) RIs
3	ACT	quantity of active components
4	PAS	quantity of passive components
5	FR	failure rate (failures per 10^6 hours)
6	ISO	predicted fault isolation time
7	RR	predicted removal/replacement time
8	CO	predicted checkout time
9	MTTR	predicted MTTR
10	DISO	demonstrated fault isolation time
11	DRR	demonstrated removal/replacement time
12	DCO	demonstrated checkout time
13	DMTTR	demonstrated MTTR
14	QFIR	quantity of unique fault isolation results
15	KA	fraction of faults isolated automatically
16	TYPA	type of automatic fault isolation
17	KS	fraction of faults isolated semi-automatically
18	TYPS	type of semi-automatic fault isolation
19	KM	fraction of faults isolated manually
20	DIAG	size of the computer diagnostic program
21	RES1	fraction resolution to one RI
22	RES3	fraction resolution to less than or equal to 3 RIs
23	MAXRI	maximum number of RIs in a FI group
24	AVG	average FI group size
25	ANA	fraction of analog parts
26	DIG	fraction of digital parts
27	RF	fraction of RF parts
28	PS	fraction of power supply parts
29	PP	fraction pieceparts
30	CHASS	fraction chassis parts
31	ALI	fraction of RIs that require alignment
32	PLG	fraction of plug-in RIs

Notes: 1) All fractions are based on failure rates
2) All times are in minutes

TABLE 7. ASSUMED RELATIONSHIPS BETWEEN MAINTAINABILITY PARAMETERS (DEPENDENT VARIABLES) AND EQUIPMENT CHARACTERISTICS (INDEPENDENT VARIABLES)

		Independent Variables																															
		RIQ	MRIQ	ACT	PAS	FR	ISO	RR	CO	MTTR	DISO	DRR	DCO	MTTR	QFIR	KA	TYPA	KS	TYPS	KM	DIAG	RES1	RESS	MAXRI	AVG	ANA	DIG	RF	PS	PP	CHASS	ALI	PLG
No.	Dependent Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
15	K_A	X	X	X	X	X											X				X					X	X	X	X	X	X	X	
17	K_S	X	X	X	X	X												X			X					X	X	X	X	X	X	X	
19	K_M	X	X	X	X	X																				X	X	X	X	X	X	X	
	$MTTR_A$	X	X	X	X	X									X		X				X	X	X	X	X	X	X	X	X	X	X	X	X
	$MTTR_S$	X	X	X	X	X									X				X		X	X	X	X	X	X	X	X	X	X	X	X	X
	$MTTR_M$	X	X	X	X	X															X	X	X	X	X	X	X	X	X	X	X	X	X
	$MTTR_D$	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X							X	X
	$MTTR_{ANA}$	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X							X	X
	$MTTR_{PS}$	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X							X	X
	$MTTR_{RF}$	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X							X	X
	$MTTR_{PP}$	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X							X	X
	$MTTR_C$	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X							X	X
6	$MTTR_{ISO}$ (pred.)	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
7	$MTTR_{RR}$ (pred.)	X	X																			X	X	X	X	X	X	X	X	X	X		X
8	$MTTR_{CO}$ (pred.)	X	X	X	X	X									X	X	X	X	X	X	X					X	X	X	X	X	X	X	
9	MTTR (pred.)	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
10	$MTTR_I$ (demo.)	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
11	$MTTR_{RR}$ (demo.)	X	X	X	X	X																X	X	X	X	X	X	X	X	X	X		X
12	$MTTR_{CO}$ (demo.)	X	X	X	X	X					X															X	X	X	X	X	X	X	
13	MTTR (demo.)	X	X	X	X	X									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

2.4.1.4.2 Regression Analysis Procedure and Results

The first approach to running the regression program was to segregate the data by equipment type and create unique regression equations for each type. The original concept conceived types to be easily defined by equipment function (i.e., computer, transmitter, receiver, signal processor, display, etc.), however, it was soon recognized that function did not uniquely identify types. Types had to be further categorized by circuit type (analog, digital, RF, etc.), circuit implementation type (tube, transistor, microelectronics, etc.), fault isolation implementation type (BIT, BITE, Diagnostics, Manual), fault isolation use type (automatic, semi-automatic, manual), voltage/power levels, etc. To accurately and uniquely define types, almost each piece of data collected would be a separate data set and insufficient data would be available to conduct the regression analyses.

In the final analysis all the data collected was combined into one data set. This was considered a reasonable approach since 1) the independent variables do in fact characterize the equipment by type, and 2) ideally, a single model to predict maintainability parameters for all equipment types is desired.

At first each dependent variable was run individually against the corresponding independent variables identified in Table 7. This was done to see if any single predictor could produce a good prediction model. Table 8 shows the best predictors found for each dependent variable regressed upon.

TABLE 8. PRELIMINARY CORRELATION RESULTS BASED ON A SINGLE INDEPENDENT VARIABLE

Dependent Variable	Best Independent Variable Predictor	Correlation Coefficient
K_A	PAS	+0.382
K_S	PP	-0.467
K_M	PP	+0.530
$MTTR_{ISO}$ (P)	KA	-0.450
$MTTR_{RR}$ (P)	ANA	-0.210
$MTTR_{CO}$ (P)	KA	-0.637
MTTR (P)	KA	-0.385
$MTTR_{ISO}$ (D)	KS	+0.570
$MTTR_{RR}$ (D)	RES 1	+0.243
$MTTR_{CO}$ (D)	DISO	+0.597
MTTR (D)	KS	+0.437

P = predicted; D = demonstrated

As expected the results were negative. In some cases the correlation was good (>0.5), but the predicted values versus the actual values were very erratic.

Next the SRAP program was implemented using the maximum number of independent variables available for each dependent variable. The results are summarized in Table 9.

In an attempt to increase the multiple correlation some new independent variables were created. They were:

- PARTS - total number of parts (equal to ACT + PAS)
- DRES - fraction of resolution ≤3 RIs, but >1 RI (equal to RES3 - RES1)
- TANAL - fraction of failure rate of all analog type RIs (equal to ANA + PS + RF)
- QFIR/RIQ - quantity of fault isolation results per RI (equal to QFIR/RIQ)
- QFIR/MRIQ - quantity of fault isolation results per modular RI (equal to QFIR/MRIQ)
- NMRIQ - quantity of non-modular RIs (equal to RIQ-MRIQ)

The SRAP program was rerun using the new independent variables. The results showed only a slight improvement in the multiple correlation.

At this point the following changes were implemented.

1. The data containing 1's and 0's for KA and KM was removed since realistically it is impossible to have 100% for KA, or 0% for KM.

TABLE 9. FIRST MULTIPLE CORRELATION RESULTS

DV	Sample Size	Qty of IVs Available	Qty of IVs Used	Multiple R
K_A	80	12	11	0.565
K_S	80	12	12	0.584
K_M	80	11	11	0.659
$MTTR_{ISO}$ (P)	80	19	18	0.666
$MTTR_{RR}$ (P)	80	11	10	0.470
$MTTR_{CO}$ (P)	80	17	16	0.753
MTTR (P)	80	20	19	0.692
$MTTR_{ISO}$ (D)	52	19	18	0.840
$MTTR_{RR}$ (D)	52	11	10	0.496
$MTTR_{CO}$ (D)	52	17	17	0.918
MTTR (D)	52	20	20	0.816

P = predicted; D = demonstrated
DV = Dependent Variable
IV = Independent Variable

2. KS was removed as a possible independent variable. Semi-automatic isolation is a non definitive entity which indicates a capability somewhere between automatic and manual isolation. As more positive indicators, K_A and K_M were used. The analysis was not weakened by this change since KS = 1 - KA - KM.
3. $MTTR_{RR}$ was removed as a possible dependent variable. The regression analysis indicated very low correlation with all independent variables. Instead $MTTR_{RR}$ will be time synthesized.
4. Predicted repair times ($MTTR_{ISO}$ (P), $MTTR_{RR}$ (P), $MTTR_{CO}$ (P)) were excluded as possible dependent variables. The predicted values were based on old prediction methodologies and the validity of the data was therefore questionable.
5. The failure rate for each equipment was normalized to a ground fixed environment.

2.4.1.4.2.1 Correlation and Regression Analysis for K_A, K_S and K_M

After making the changes mentioned above the SRAP was rerun for K_A and K_M. The results are shown in Table 10.

TABLE 10. SECOND CORRELATION RESULTS FOR K_A AND K_M

DV	Sample Size	Qty of IVs Available	Qty of IVs Used	Multiple R
K_A	18	15	11	0.822
K_M	31	14	9	0.840

This time the correlation was very good and the predicted values were close to the actual values. The next step was to minimize the quantity of IVs and still maintain a good correlation. The results of this effort are shown in table 11.

TABLE 11. THIRD CORRELATION RESULTS FOR K_A AND K_M

DV	Sample Size	Qty of IVs Available	Qty of IVs Used	Multiple R	Reduction Number
K_A	18	9	6	0.676	1
K_M	31	8	8	0.840	1
K_A	18	5	5	0.652	2
K_M	31	6	6	0.739	2

The linear models used in the correlation analysis of K_A and K_M showed good correlation as indicated above but they had two major drawbacks. It was possible using the linear models that $K_A + K_M$ could be greater than or equal to one and it was also possible that K_A and/or K_M could be less than zero. Since K_A and K_M must be positive and $K_A + K_M + K_S$ must be equal to 1.0, the regression model was changed to an exponential equation. Two forms of the exponential equation were used as indicated below:

$$Y = e^{-X}$$

and

$$\hat{Y} = 1 - e^{-X}$$

where

$$X = B_0 + B_1X_1 + B_2X_2 \ldots B_P X_P$$

and

$$\hat{Y} = \hat{K}_A \text{ or } \hat{K}_M$$

The above scheme guaranteed that $\hat{K}_A$ and $\hat{K}_M$ were greater than or equal to zero and less than or equal to one, but it did not guarantee that the sum of $\hat{K}_A$ and $\hat{K}_S$ were less than or equal to one. This was then solved by using the following:

$$\hat{K} = K_A + K_M = 1 - e^{-X} \quad \text{where } X = B_0 + B_1X_1 + B_2X_2 \ldots B_PX_P \qquad (1A)$$

$$\text{or} \quad = e^{-X} \qquad (1B)$$

then

$$\hat{K}_A = \hat{K}\,(1 - e^{-X}) \quad \text{where } X = B_0 + B_1X_1 + B_2X_2 + \ldots B_PX_P \qquad (2A)$$

$$\text{or} = \hat{K}\,(e^{-X}) \qquad (2B)$$

The results using equations 1A and 1B showed low correlation for $K = K_A + K_M$, so it was rerun using $K = K_A + K_S = 1 - K_M$. This time the correlation and predicted values were very good. Next equations 2A and 2B were run using the results obtained for K in the previous run (i.e., $K = K_A + K_S$). The results showed very good correlation. The summary of the results are shown in Table 12.

TABLE 12. FOURTH CORRELATION RESULTS FOR K_A AND K

DV	Sample Size	Qty of IVs Available	Qty of IVs Used	Multiple R	Model Used
$K=K_A+K_S$	31	18	15	0.861	1A
$K=K_A+K_S$	31	18	12	0.848	1B
K_A	12	10	8	0.951	2A
K_A	14	12	10	0.814	2B

Once the model forms were established, they were reduced to minimize the quantity of IVs while maintaining a good predicting model. The criteria used for the removal of an IV was:

1. how easy is it to obtain the data during the preliminary design phase
2. how much effect does the IV have on the model (weighting)
3. engineering judgment

The results for the final model are shown in Table 13.

TABLE 13. FINAL CORRELATION RESULTS FOR K_A AND K

Appendix A Reference Number	DV	Sample	IVs Available	IVs Used	Multiple R	Model
1	$K=K_A+K_S$	31	11	11	0.800	1A
2	K_A	12	7	6	0.935	2A

The final prediction models for K_A, K_S, and K_M are:

A. $\hat{K} = \hat{K}_A + \hat{K}_S = 1 - e^{-X_1}$

where

$$X_1 = 0.418 + 0.0016\ MRIQ - 0.0002\ ACT + 0.0018\ FR + 0.21\ DIAG + 0.73\ DIG - 0.30\ PP - 3.60\ ALI + 0.00007\ PARTS + 0.98\ TANAL - 0.001\ QFIR + 0.058\ QFIR/MRIQ$$

B. $\hat{K}_A = \hat{K}\,(1 - e^{-X_2})$

where

$$X_2 = -0.5[illegible] - 0.003\ MRIQ + 0.0003\ ACT + 0.0006\ FR + 0.11\ DIAG - 0.27\ TANAL + 0.18\ QFIR/MRIQ$$

C. $\hat{R}_S = \hat{R} - \hat{R}_A$

D. $\hat{R}_M = 1 - \hat{R}$

2.4.1.4.2.2 Correlation and Regression Analysis for $MTTR_{ISO}$ and $MTTR_{CO}$

Using the modified data sets described in 2.4.1.4.2, the SRAP program was rerun for $MTTR_{ISO}$ and $MTTR_{CO}$. The results showed very good correlation. A summary of the results is shown in Table 14.

TABLE 14. SECOND CORRELATION RESULTS FOR $MTTR_{ISO}$ AND $MTTR_{CO}$

DV	Sample Size	Qty of IVs Available	Qty of IVs Used	Multiple R
$MTTR_{ISO}$	26	25	20	0.967
$MTTR_{CO}$	26	19	19	0.899

The next step was to reduce the quantity of IVs in each model. The criteria for removing an IV was the same as described in section 2.4.1.4.2.1. A summary of these runs is provided in Table 15.

TABLE 15. FINAL CORRELATION RESULTS FOR $MTTR_{ISO}$ AND $MTTR_{CO}$

Appendix A Reference Number	DV	Sample Size	Qty of IVs Available	Qty of IVs Used	R
3	$MTTR_{ISO}$	26	10	10	0.651
4	$MTTR_{CO}$	26	10	10	0.687

The final prediction models of $MTTR_{ISO}$ and $MTTR_{CO}$ are:

$$MTTR_{ISO} = 7.94 - 0.01\ MRIQ + 0.00033\ FR - 1.88\ KA + 0.77\ KS - 0.17\ DIAG - 4.38\ RESI - 0.24\ AVG + 5.5\ PP + 0.13\ QFIR/MRIQ + 0.68\ DIG$$

$$MTTR_{CO} = 0.344 - 0.006\ MRIQ + 0.0016\ FR - 0.125\ KA + 0.064\ KS + 0.12\ DIAG + 0.70\ DIG + 0.67\ PP + 1.59\ ALI + 3.70\ TANAL + 0.06\ QFIR/MRIQ$$

2.4.1.5 Conclusions/Recommendations

The regression equations developed in the previous section show high correlation with the sample data, however, they are not recommended for use as maintainability parameter predictors. There are two major reasons that this recommendation is made.

First, the regression models showed little sensitivity to the obviously dominant maintainability characteristics related to that model. For example, the model established for fault isolation time ($MTTR_{ISO}$) was very insensitive to changes in the percentage of automatic fault isolation (KA). Fault isolation automaticity is definitely a factor in fault isolation time but the regression equation indicates only a small reduction in time with 100% automatic fault isolation (as compared with zero automatic isolation).

Second, as in all regression type analysis, the resulting models are only as valid as the data base from which the models were developed. Additionally, the models are only valid for application to systems with characteristics similar to the data base systems. Assuming there were no errors in data collection, data interpretation, or data entering, use of the developed models should be restricted to systems approximating the data base systems.

2.4.2 Simplified Version of the Detailed Prediction Model

2.4.2.1 Prediction Model Basis

The detailed prediction model developed in section 2.3.2 does not enable MTTR predictions to be easily made early in the design phase of a program. This section involves the development of a prediction model, similar to the detailed model, that can be incorporated without the extensive data required for the previous method.

For an early prediction it is assumed that the following data is available, at least in preliminary form:

1. A configuration index from which a definition of the primary replaceable items can be derived
2. The failure rate of each of the primary replaceable items
3. The overall fault isolation concept (i.e. fault isolation to a single RI or group of RIs)
4. The replacement concept when fault isolation is to a group of RIs. (i.e. group or iterative replacement)
5. The basic packaging philosophy including preliminary access and interchange characteristics of each RI
6. The primary fault isolation technique to be implemented for each primary RI
7. The fault isolation resolution which is defined in one of two ways:
   a) average RI group size

b) X_1 % isolation to a single RI

X_2 % isolation to >1RI, $\leq N_1$ RIs

X_3 % isolation to $>N_1$RIs, $\leq N_2$ RIs

where

$X_1 + X_2 + X_3 = 100\%$

2.4.2.2 Early Prediction Model Development

The prediction model developed in this section is based on the generalized version of the detailed model. That is:

$$MTTR = \overline{T}_P + \overline{T}_{FI} + \overline{T}_{SR} + \overline{T}_D + \overline{T}_I + \overline{T}_R + \overline{T}_A + \overline{T}_C + \overline{T}_{ST}$$

or

$$MTTR = \sum_{m=1}^{9} \overline{T}_m$$

where

$\overline{T}_m$ = average time of the m^{th} element

m = the elemental maintenance tasks (P, FI, SR, D, I, R, A, C, ST) as defined in Table 4.

The detailed prediction model assesses MTTR by defining all possible unique maintenance actions, determining the frequency of each occurring (i.e. failure rate), determining the time to accomplish each task, and computing a failure rate weighted average to determine MTTR. The early prediction model developed herein is a simplified version of this technique. It defines the major ways in which elemental maintenance tasks are performed, assigns failure rates and times to each of the different elemental task types, determines a failure rate weighted average for each maintenance element, and finds the MTTR by adding the average times of each element.

2.4.2.3 Submodels for Elemental Maintenance Activities

Two methods are available for determining the time associated with each maintenance element.

The first method is summarized by the following model:

$$\overline{T}_m = \frac{\sum_{n=1}^{N} \lambda_n T_{m_n}}{\sum_{n=1}^{N} \lambda_n}$$

where

N = the quantity of primary RIs

λ_n = the failure rate of the n^{th} RI

T_{m_n} = the synthesized time for the m^{th} elemental task of the n^{th} RI

This model assumes that T_{m_n} is available for each maintenance element of each RI. If this were true for all elements, the detailed prediction model could possibly be used. For those maintenance elements where this is not true, the second method determines an average value for the elemental times by using the following model:

$$\overline{T}_m = \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$$

where:

V_m = the number of major unique methods of performing the m^{th} elemental task.

λ_{m_v} = the failure rate associated with the set of faults involving the v^{th} method of performing the m^{th} elemental task.

T_{m_v} = the time required to perform the m^{th} elemental task using the v^{th} method.

The number of ways of performing each of the maintenance elements (i.e. V_m) should be kept at a minimum consistent with the system being evaluated and the data available. For example, the ways of performing fault isolation on a display console might be test pattern interpretation for the majority of display circuitry, maintenance panel readings for power supplies, computer controlled loop testing for I/O circuits, and manual isolation of miscellaneous cabinet electronics. A time would be assigned to each of these methods of fault isolation, and an average fault isolation time would be computed based on the estimated failure rate of the circuitry associated with each method. A similar procedure would be followed for each maintenance element and the MTTR computed by adding all the element times.

The $\bar{\bar{T}}_m$ computed in the above models is only good for the most general case, where fault isolation is to a single RI. The following sub-sections present how the computation for each elemental times should be modified for the different maintenance concepts and repair policies that exist.

2.4.2.3.1 Computation of $\bar{\bar{T}}_P$, and $\bar{\bar{T}}_{ST}$

Preparation time ($\bar{\bar{T}}_P$) and start-up time (T_{ST}) are not normally affected by the maintenance concepts and policies under consideration. Also, these times are typically independent of the failure mode, and weighting by failure rate is not required for these elemental tasks. However, if the information necessary to determine $\bar{\bar{T}}_P$, or $\bar{\bar{T}}_{ST}$ using a failure rate weighting model is available at the time of the prediction then the appropriate submodels should be used since they will result in more accurate estimates.

2.4.2.3.2 Computation of $\bar{\bar{T}}_{FI}$

Fault isolation is typically performed differently for different equipments or functions and the time associated with each fault isolation time is also different. Fault isolation time, as defined for the early model, is independent of the repair policy therefore, the average fault isolation time can be computed using one of the two models presented in section 2.4.2.3. During the preliminary design phases the second method for determining $\bar{\bar{T}}_{FI}$ would normally be used and the model for $\bar{\bar{T}}_{FI}$ would be:

$$\bar{\bar{T}}_{FI} = \frac{\sum_{v=1}^{V_{FI}} \lambda_{FI_v} T_{FI_v}}{\sum_{v=1}^{V_{FI}} \lambda_{FI_v}}$$

where

V_{FI} = number of unique fault isolation methods

λ_{FI_v} = failure rate of the set of RIs involving the v^{th} FI method

T_{FI_v} = time required to perform the v^{th} FI method.

2.4.2.3.3 Computation of $\overline{T}_{FC} = \overline{T}_D + \overline{T}_I + \overline{T}_R$

The fault correction time is the sum of the disassembly, interchange, and reassembly times. These times were lumped together since the various maintenance concepts affected these elemental tasks equally. The computation of the fault correction time is dependent upon the following:

1. fault isolation concept (i.e. isolation to a single RI or group of RIs)
2. replacement concept (i.e. group or iterative replacement)
3. access (i.e. single or multiple access)
4. packaging (i.e. reassembly required or not required for checkout)

The form of the model for $\overline{T}_{FC}$ is greatly affected by the above concepts. Figure 5 illustrates the different combinations of concepts that can occur. The following subsections develop the models for each particular case of figure 5.

2.4.2.3.3.1 Case 1 – Isolation to a Single RI

For this case no changes to the models presented in section 2.4.2.3 are necessary. Therefore, the models for $\overline{T}_{FC}$ for this case are:

$$\overline{T}_{FC} = \frac{\sum_{n=1}^{N} \lambda_n (T_D+T_I+T_R)_n}{\sum_{n=1}^{N} \lambda_n} \quad \text{(if details about each RI are known)}$$

or

$$\overline{T}_{FC} = \frac{\sum_{v=1}^{V_{FC}} \lambda_{FC_v} (T_D + T_I + T_R)_v}{\sum_{v=1}^{V_{FC}} \lambda_{FC_v}} \quad \text{(if only preliminary data is available)}$$

2.4.2.3.3.2 Case 2 – Isolation to a Group/Single Access/Group Replacement

Since group replacement is required for this case the average interchange time must be multiplied by the quantity of RIs in the isolated group. Since the fault isolation groups of the diagnostic program are not known at this phase of a

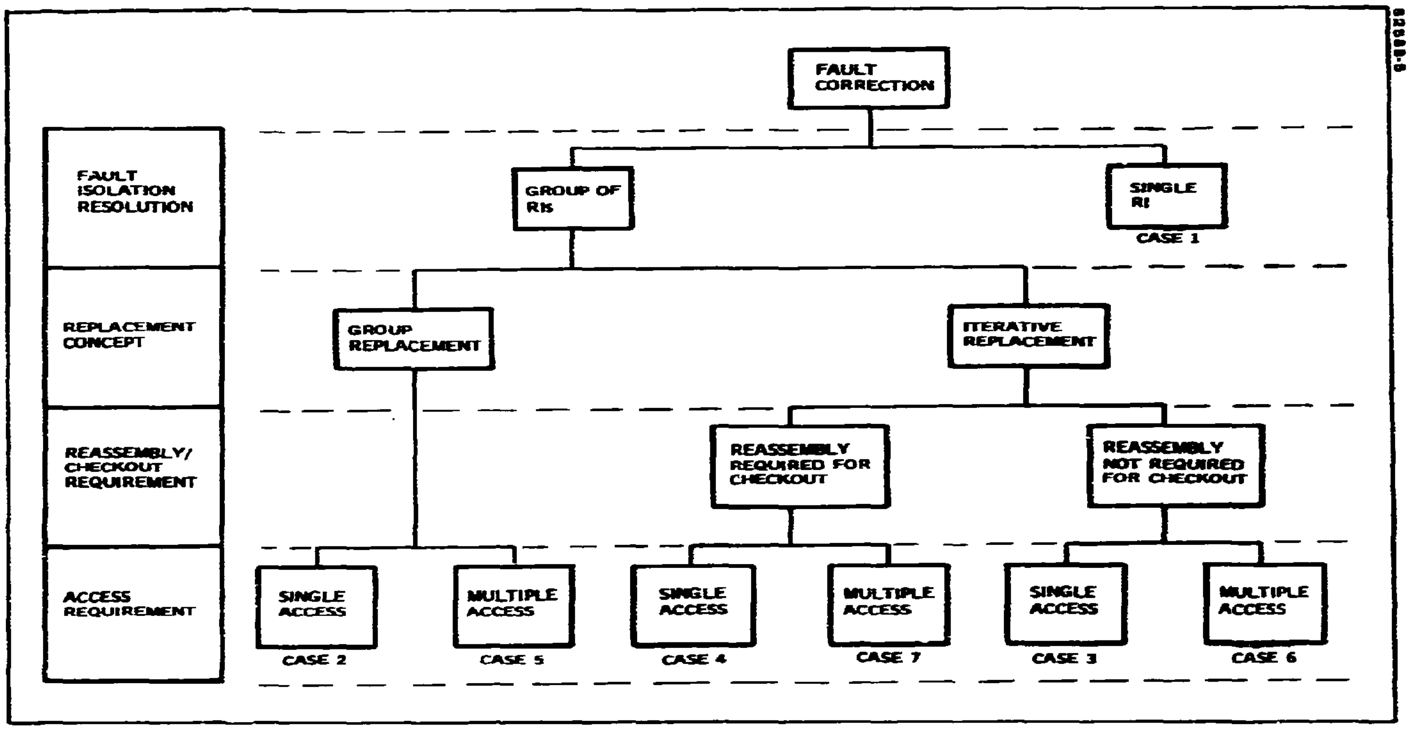


Figure 5. Categorization of Fault Correction

program, it is difficult to determine the quantity of interchanges required for each failure. Instead, the interchange time is multiplied by the average quantity of RIs ($\overline{S}_G$) per fault isolation group. This value is determined by either estimates of the diagnostic capabilities or by using the specified requirements. The fault correction time is then computed as follows:

$$\overline{T}_{FC} = \overline{T}_D + \overline{S}_G T_I + \overline{T}_R$$

where:

$\overline{S}_G$ = average fault isolation group size(see section 2.4.2.3.3.2.1)

$\overline{T}_D$, $\overline{T}_I$, $\overline{T}_R$, are determined using the models presented in 2.4.2.3 and repeated here.

$$\overline{T}_m = \frac{\sum_{n=1}^{N} \lambda_n T_{m_n}}{\sum_{n=1}^{N} \lambda_n} \quad \text{(if details of each RI are known)}$$

where m = D, I, R

or

$$\overline{T}_m = \frac{\sum_{v=1}^{Vm} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{Vm} \lambda_{m_v}} \quad \text{(if only preliminary data is available)}$$

2.4.2.3.3.2.1 Definition of $\overline{S}$

When the maintenance philosophy is fault isolation to a group of RIs the technician has two options. Depending on the replacement concept the RIs can be replaced as a group or one by one until the fault is corrected. In order to account for the additional time required to replace more than one RI the average replacement times are multiplied by $\overline{S}$. $\overline{S}$ is defined two ways:

$\overline{S}_G$ = when a suspected group of RIs are replaced all at once, this value of $\overline{S}$ is defined as the average number of RIs that appear in a fault isolation result.

$\overline{S}_I$ = when a suspected group of RIs are replaced one by one until the fault is corrected, the value of $\overline{S}$ is defined as the average number iterations required to correct a fault, also known as the fault isolation resolution. The methodology for computing $\overline{S}$ (I or G) is presented in section 5.2.5.1.

2.4.2.3.3.3 Case 3 – Isolation to a Group of RIs/Single Access/Iterative Replacement/Reassembly Not Required for Checkout

For this case RIs are replaced one by one with checkout performed after each replacement until the fault is corrected. Assuming that the average number of iterations required for fault correction is $\overline{S}_I$ then, the form of the fault correction time model is:

$$\overline{T}_{FC} = \overline{T}_D + (\overline{S}_I)\,\overline{T}_I + \overline{T}_R$$

where $\overline{S}_I$ is the average number of iterations required to correct a fault and $\overline{T}_D$, $\overline{T}_I$, and $\overline{T}_R$ are computed as in section 2.4.2.3.

2.4.2.3.3.4 Case 4 – Isolation to a Group of RIs/Single Access/Iterative Replacement/Reassembly Required for Checkout

For this case reassembly is required for checkout after each replacement. Therefore the average disassembly and reassembly time (as well as the interchange time) must be multiplied by the number of iterations required for fault correction (as in 2.4.2.3.3.3, $\overline{S}_I$).

Therefore:

$$\overline{T}_{FC} = \overline{S}_I\,(\overline{T}_D + \overline{T}_I + \overline{T}_R)$$

2.4.2.3.3.5 Case 5 – Isolation to a Group of RIs/Multiple Access/Group Replacement

This case is similar to case 2 but the isolated RIs are not necessarily located in the same unit. Therefore, the disassembly and reassembly time must be adjusted to account for more than one access required. The form of the model in this case is:

$$\overline{T}_{FC} = \overline{T}_D' + \overline{S}_G\overline{T}_I + \overline{T}_R'$$

T_D' and T_R' are the adjusted disassembly and reassembly times that account for multiple access. This is approximately equal to the average disassembly or reassembly time multiplied by the average number of accesses required per fault isolation in group. The details on how $\overline{T}_D'$ and $\overline{T}_R'$ are computed is developed in 2.4.2.3.3.5.1.

2.4.2.3.3.5.1 Development of Models for $\overline{T}_D'$ and $\overline{T}_R'$

The computation of $\overline{T}_D'$ and $\overline{T}_R'$ are based on the following assumptions:

- the maintenance concept is fault isolation to a group of RIs and group replacement with multiple access
- the RIs can be grouped into "G" RI sets with an estimated $\overline{S}_g$ (average number of RIs in a fault isolation result) for each set as is done in section 5.2.5.1

With the above assumptions the disassembly and reassembly time can be computed as follows:

$$\overline{T}'_{D/R} = \frac{\sum_{g=1}^{G} \lambda_g \overline{T}'_{D/R_g}}{\sum_{g=1}^{G} \lambda_g}$$

or

$$\overline{T}'_D = \frac{\sum_{g=1}^{G} \lambda_g \overline{T}'_{D_g}}{\sum_{g=1}^{G} \lambda_g}$$

$$\overline{T}'_R = \frac{\sum_{g=1}^{G} \lambda_g \overline{T}'_{R_g}}{\sum_{g=1}^{G} \lambda_g}$$

where the total expected disassembly or reassembly time for the g^{th} RI set can be computed by:

$$\overline{T}'_{D/R_g} = \sum_{a=1}^{A_g} P_{ga}(T_{D_{ga}} + T_{R_{ga}}) = \sum_{a=1}^{A_g} P_{ga} T_{D_{ga}} + \sum_{a=1}^{A_g} P_{ga} T_{R_{ga}}$$

where:

A_g = the total number of unique accesses contained in the g^{th} RI set

$T_{D_{ga}}$ = the estimated time required to disassemble the a^{th} access

$T_{R_{ga}}$ = the estimated time required to reassemble the a^{th} access

P_{ga} = the probability that an RI from assembly "a" will be contained in the fault isolation call out

The above equation can be modified to determine the average number of accesses required per fault isolation result.

$$\overline{A}_g = \sum_{a=1}^{A_g} P_{ga}$$

where $\overline{A_g}$ = the average number of accesses required per fault isolation result for the gth RI set.

From the assumptions stated previously.

$$p^0_{ga} = \frac{\lambda_{ga}}{\lambda_g}$$

where:

p^0_{ga} = the probability of accessing the a^{th} assembly of the g^{th} RI set,

λ_{ga} = the failure rate of RIs in the g^{th} RI set with the a^{th} type assembly

λ_g = the failure rate of RIs located in the g^{th} RI set

Also, the probability that an RI is not located in assembly "a"

$$q^0_{ga} = 1 - p^0_{ga} = \frac{\lambda_g - \lambda_{ga}}{\lambda_g}$$

The above probabilities are valid for: 1) when only one RI appears in the fault isolation callout, or 2) the first RI in a fault isolation callout containing more than one RI. For a system where the average number of RIs in a fault isolation callout is $\bar{S}_g$, the probability that the $\bar{S}_g^{\,th}$ RI (i.e. the last RI in fault isolation callout) will be in the ath access, given that the first $\bar{S}_g - 1$ RIs in the fault isolation callout are not in the ath access is:

$$p_{ga}^{\bar{S}_g - 1} = \frac{\lambda_{ga}}{\lambda_g - (\bar{S}_g - 1)\,\bar{\lambda}_{ga}} \quad \text{and} \quad q_{ga}^{\bar{S}_g - 1} = \frac{\lambda_g - (\bar{S}_g - 1)\,\bar{\lambda}_{ga} - \lambda_{ga}}{\lambda_g - (\bar{S}_g - 1)\,\bar{\lambda}_{ga}}$$

where $\bar{\lambda}_{ga} = \lambda_{ga}/N_{ga}$

and N_{ga} = the number of RIs in the ath assembly of the gth RI set

Hence the probability that none of the $\bar{S}_g$ RIs called out by the fault isolation result will be in the ath assembly is:

$$Q_{ga} = \prod_{s=1}^{\bar{S}_g} \frac{\lambda_g - (s-1)\,\bar{\lambda}_{ga} - \lambda_{ga}}{\lambda_g - (s-1)\,\bar{\lambda}_{ga}}$$

and the probability that at least one RI called out by the fault isolation program is in assembly is:

$$P_{ga} = 1 - Q_{ga}$$

Note, that if N_g (i.e., quantity of RIs in the gth set) is large compared to $\bar{S}_g$, then the equation for Q_{ga} reduces to

$$Q_{ga} \approx \prod_{s=1}^{\bar{S}_g} \left(\frac{\lambda_g - \lambda_{ga}}{\lambda_g}\right)_s$$

$$\approx \left(\frac{\lambda_g - \lambda_{ga}}{N_g}\right)^{\bar{S}_g}$$

therefore:

$$P_{ga} \approx 1 - \left(\frac{\lambda_g - \lambda_{ga}}{\lambda_g}\right)^{\bar{S}_g}$$

Substituting P_{ga} into the first two equations presented for $\bar{T}'_{D/R_g}$ results in

$$\bar{T}'_{D/R_g} = \sum_{a=1}^{A_g} \left[1 - \left(\frac{\lambda_g - \lambda_{ga}}{\lambda_g}\right)^{\bar{S}_g}\right] \left[T_{D_{ga}} + T_{R_{ga}}\right]$$

and which can be broken up into

$$\overline{T}'_{D_g} = \sum_{a=1}^{A_g} \left[1 - \left(\frac{\lambda_g - \lambda_{ga}}{\lambda_g}\right)^{\overline{S}_g}\right] T_{D_{ga}}$$

and

$$\overline{T}'_{R_g} = \sum_{a=1}^{A_g} \left[1 - \left(\frac{\lambda_g - \lambda_{ga}}{\lambda_g}\right)^{\overline{S}_g}\right] T_{R_{ga}}$$

2.4.2.3.3.6 Case 6 — Isolation to a Group of RIs/Multiple Access/Iterative Replacement/Reassembly not Required for Checkout

This case is very similar to the previous case. Since reassembly is not required for checkout it is uncertain how many different disassembly and reassembly times will exist. The average disassembly and reassembly times must be multiplied by the average number of accesses that will occur for this case ($\frac{\overline{A}+1}{2}$, the average of the maximum and the minimum number of unique accesses). The interchange time must also be multiplied by the average number of iterations required to correct a fault ($\overline{S}_I$). The resultant model is

$$\overline{T}_{FC} = \frac{\overline{A}+1}{2}\left(\overline{T}_D + \overline{T}_R\right) + \overline{S}_I\left(\overline{T}_I\right)$$

where:

$\overline{A}$ = the average number of unique accesses per fault isolation result. (determined per section 2.4.2.3.3.5.1)

$\overline{T}_D$, $\overline{T}_R$, $\overline{T}_I$ the average time required to perform those mth elemental tasks. (determined per section 2.4.2.3)

2.4.2.3.3.7 Case 7 — Isolation to a Group of RIs/Multiple Access/Iterative Replacement/Reassembly Required for Checkout

This case involves a disassembly and reassembly time for each interchange. Therefore, the fault correction time is

$$\overline{T}_{FC} = \overline{S}_I\left(\overline{T}_D + \overline{T}_I + \overline{T}_R\right)$$

where:

$\overline{T}_D$, $\overline{T}_I$, $\overline{T}_R$ are the average times computed for each elemental task by the equations of 2.4.2.3

2.4.2.3.4 Computation of T_A

The average alignment time is determined by using the second model of 2.4.2.3. The different types of alignment are identified and the failure rate associated with each type is estimated. Note that the average alignment time ($\overline{T}_A$) is taken over the total system failure rate and not over just the failure rate requiring alignment. The resulting model is:

$$\overline{T}_A = \frac{\sum_{v=1}^{V_A} \lambda_{A_v} T_{A_v}}{\sum_{v=1}^{V_A} \lambda_{A_v}}$$

where:

V_A = the number of different alignment methods (including the case of no alignment required)

λ_v = failure rate associated with the set of RIs requiring v^{th} alignment method

T_{A_v} = estimated time for the v^{th} alignment method.

2.4.2.3.5 Computation of $\overline{T}_C$

The computation of the average check-out time ($\overline{T}_C$) is dependent upon the replacement concept.

For group replacement only one check-out would be required. Thus the models presented in section 2.4.2.3 would be directly applicable:

$$\overline{T}_C = \frac{\sum_{n=1}^{N} \lambda_n T_{C_n}}{\sum_{n=1}^{N} \lambda_n} \qquad \text{(if information is available for each RI)}$$

or

$$\overline{T}_C = \frac{\sum_{v=1}^{V_C} \lambda_{C_v} T_{C_v}}{\sum_{v=1}^{V_C} \lambda_{C_v}} \qquad \text{(if only preliminary data is available)}$$

For iterative replacement there is one check-out for each interchange. Since the average number of interchanges is $(\overline{S}_I)$:

$$\overline{T}_C' = \overline{S}_I \overline{T}_C$$

where $\overline{T}_C$ is computed like it was for group replacement.

2.4.2.3.6 Computation of $\overline{T}_{SR}$

The model for the spare retrieval time is dependent upon the spare retrieval philosophy. Figure 6 depicts the breakdown of the various concepts that can occur.

The resulting spare retrieval submodels for cases SR-1, SR-2, and SR-3 are:

$$\overline{T}_{SR} = \frac{\sum_{n=1}^{N} \lambda_n T_{SR_n}}{\sum_{n=1}^{N} \lambda_n} \qquad \text{(if information is available for each RI)}$$

or

$$\overline{T}_{SR} = \frac{\sum_{v=1}^{V_{SR}} \lambda_{SR_v} T_{SR_v}}{\sum_{v=1}^{V_{SR}} \lambda_{SR_v}} \qquad \text{(if only preliminary data is available)}$$

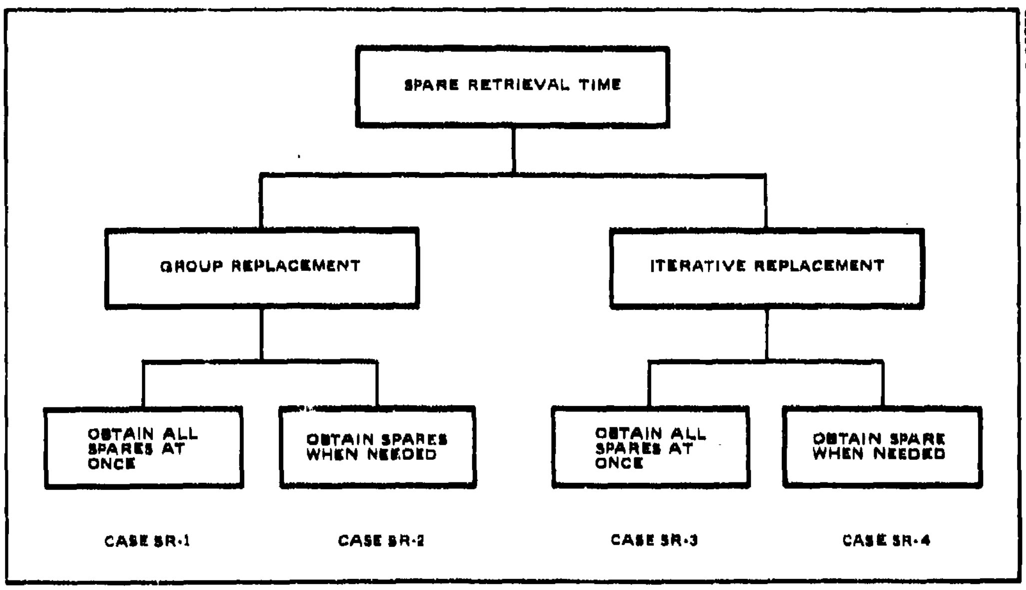


Figure 6. Possible Space Retrieval Philosophies

The model of case SR-4 is:

$$\overline{T}_{SR}' = \overline{S}_I \overline{T}_{SR}$$

where $\overline{T}_{SR}$ is computed as in model 1.

2.4.2.4 Computation of MTTR

Once the average time for each element has been computed, the final step is just a simple summation.

$$MTTR = \sum_{m=1}^{M} \overline{T}_m$$

where $\overline{T}_m$ = average time for the m^{th} element of MTTR (preparation, fault isolation . . .)

2.4.2.5 Summary of the Early Prediction Submodels

Table 16 summarizes the early prediction models developed in this section. The appropriate models to be used can be easily determined by selecting the applicable maintenance philosophy. The resulting MTTR is found by summing the average times computed for each elemental activity.

$$MTTR = \overline{T}_P + \overline{T}_{FI} + \overline{T}_{SR} + \overline{T}_D + \overline{T}_I + \overline{T}_R + \overline{T}_A + \overline{T}_C + \overline{T}_{ST}$$

Definition of the terms that appear in each sub-model can be found in Table 17. Other parameters that are necessary to compute the average times for each elemental maintenance activity are the average number of RIs in a fault isolation result ($\overline{S}_G$), the average number of RI interchanges required to correct a fault ($\overline{S}_I$), and the average number of unique accesses required per fault isolation result ($\overline{A}$). Methods for computing these parameters are presented in the early prediction procedure (section 5.2.5).

TABLE 16. APPLICABLE PREDICTION MODELS FOR THE VARIOUS MAINTENANCE PHILOSOPHIES

Maintenance Philosophy	Preparation $\bar{T}_P$	Fault Isolation $\bar{T}_{FI}$	Spare Retrieval – $\bar{T}_{SR}$: Obtain All At Once	Spare Retrieval – $\bar{T}_{SR}$: Obtain When Needed	Disassembly/Reassembly $\bar{T}_D/\bar{T}_R$	Interchange $\bar{T}_I$	Alignment $\bar{T}_A$	Check Out $\bar{T}_C$	Startup $\bar{T}_{ST}$
Isolation to a Single RI	↑	↑	↑	↑	$\bar{T}_m = \frac{\sum_{v=1}^{V_m}\lambda_{m_v}T_{m_v}}{\sum_{v=1}^{V_m}\lambda_{m_v}}$, m = D, R	$\bar{T}_I = \frac{\sum_{v=1}^{V_I}\lambda_{I_v}T_{I_v}}{\sum_{v=1}^{V_I}\lambda_{I_v}}$	↑	↑	↑
Isolation to a Group of RIs – Group Replacement – Multiple Access	↕	↕	↕	$\bar{T}_{SR} = \frac{\sum_{v=1}^{V_{SR}}\lambda_{SR_v}T_{SR_v}}{\sum_{v=1}^{V_{SR}}\lambda_{SR_v}}$	$\bar{T}_m = \sum_{a=1}^{A}\left[1-\left(\frac{\lambda_T-\lambda_a}{\lambda_T}\right)^{\bar{r}_C}\right]\bar{T}_{m_a}$, m = D, R	$\bar{T}_I = \bar{r}_C\frac{\sum_{v=1}^{V_I}\lambda_{I_v}T_{I_v}}{\sum_{v=1}^{V_I}\lambda_{I_v}}$	↕	$\bar{T}_C = \frac{\sum_{v=1}^{V_C}\lambda_{C_v}T_{C_v}}{\sum_{v=1}^{V_C}\lambda_{C_v}}$	↕
Isolation to a Group of RIs – Group Replacement – Single Access	↕	↕	↕	↓	$\bar{T}_m = \frac{\sum_{v=1}^{V_m}\lambda_{m_v}T_{m_v}}{\sum_{v=1}^{V_m}\lambda_{m_v}}$, m = D, R	↓	↕	↓	↕
Isolation to a Group of RIs – Iterative Replacement – Multiple Access – Reassembly Not Required for Checkout	$\bar{T}_P = \frac{\sum_{v=1}^{V_P}\lambda_{P_v}T_{P_v}}{\sum_{v=1}^{V_P}\lambda_{P_v}}$	$\bar{T}_{FI} = \frac{\sum_{v=1}^{V_{FI}}\lambda_{FI_v}T_{FI_v}}{\sum_{v=1}^{V_{FI}}\lambda_{FI_v}}$	$\bar{T}_{SR} = \frac{\sum_{v=1}^{V_{SR}}\lambda_{SR_v}T_{SR_v}}{\sum_{v=1}^{V_{SR}}\lambda_{SR_v}}$	↕	$\bar{T}_m = \left(\frac{k+1}{2}\right)\frac{\sum_{v=1}^{V_m}\lambda_{m_v}T_{m_v}}{\sum_{v=1}^{V_m}\lambda_{m_v}}$, m = D, R	↑	$\bar{T}_A = \frac{\sum_{v=1}^{V_A}\lambda_{A_v}T_{A_v}}{\sum_{v=1}^{V_A}\lambda_{A_v}}$	↑	$\bar{T}_{ST} = \frac{\sum_{v=1}^{V_{ST}}\lambda_{ST_v}T_{ST_v}}{\sum_{v=1}^{V_{ST}}\lambda_{ST_v}}$
Isolation to a Group of RIs – Iterative Replacement – Multiple Access – Reassembly Required for Checkout	↕	↕	↕	$\bar{T}_{SR} = ([illegible])\frac{\sum_{v=1}^{V_{SR}}\lambda_{SR_v}T_{SR_v}}{\sum_{v=1}^{V_{SR}}\lambda_{SR_v}}$	$\bar{T}_m = (\bar{k})\frac{\sum_{v=1}^{V_m}\lambda_{m_v}T_{m_v}}{\sum_{v=1}^{V_m}\lambda_{m_v}}$, m = D, R	$\bar{T}_I = ([illegible])\frac{\sum_{v=1}^{V_I}\lambda_{I_v}T_{I_v}}{\sum_{v=1}^{V_I}\lambda_{I_v}}$	↕	$\bar{T}_C = ([illegible])\frac{\sum_{v=1}^{V_C}\lambda_{C_v}T_{C_v}}{\sum_{v=1}^{V_C}\lambda_{C_v}}$	↕
Isolation to a Group of RIs – Iterative Replacement – Single Access – Reassembly Not Required for Checkout	↕	↕	↕	↕	$\bar{T}_m = \frac{\sum_{v=1}^{V_m}\lambda_{m_v}T_{m_v}}{\sum_{v=1}^{V_m}\lambda_{m_v}}$, m = D, R	↕	↕	↕	↕
Isolation to a Group of RIs – Iterative Replacement – Single Access – Reassembly Required for Checkout	↓	↓	↓	↓	$\bar{T}_m = (\bar{k})\frac{\sum_{v=1}^{V_m}\lambda_{m_v}T_{m_v}}{\sum_{v=1}^{V_m}\lambda_{m_v}}$, m = D, R	↓	↓	↓	↓

TABLE 17. DEFINITION OF EARLY PREDICTION MODEL TERMS

T_{P_v}	- time required to prepare a system for fault isolation using the v^{th} method
T_{FI_v}	- time required to isolate a fault using the v^{th} method
T_{SR_v}	- time required to obtain a spare using the v^{th} method
T_{D_v}	- time required to perform disassembly using the v^{th} method
T_{R_v}	- time required to perform reassembly using the v^{th} method
T_{I_v}	- time required to interchange an RI using the v^{th} method
T_{A_v}	- time required to align or calibrate an RI using the v^{th} method
T_{C_v}	- time required to check a repair using the v^{th} method
T_{ST_v}	- time required to start up a system using the v^{th} method
λ_{P_v}	- failure rate of RIs associated with the v^{th} method of performing preparation
λ_{FI_v}	- failure rate of RIs associated with the v^{th} method of performing fault isolation
λ_{SR_v}	- failure rate of RIs associated with the v^{th} method of performing spare retrieval
λ_{D_v}	- failure rate of RIs associated with the v^{th} method of performing disassembly
λ_{R_v}	- failure rate of RIs associated with the v^{th} method of performing reassembly
λ_{I_v}	- failure rate of RIs associated with the v^{th} method of performing interchange
λ_{A_v}	- failure rate of RIs associated with the v^{th} method of performing alignment
λ_{C_v}	- failure rate of RIs associated with the v^{th} method of performing checkout
λ_{ST_v}	- failure rate of RIs associated with the v^{th} method of performing start-up
V_P	- the number of unique ways to perform preparation
V_{FI}	- the number of unique ways to perform fault isolation

TABLE 17. DEFINITION OF EARLY PREDICTION MODEL TERMS (Con't)

V_{SR}	- the number of unique ways to perform spare retrieval
V_D	- the number of unique ways to perform disassembly
V_R	- the number of unique ways to perform reassembly
V_I	- the number of unique ways to perform interchange
V_A	- the number of unique ways to perform alignment
V_C	- the number of unique ways to perform check-out
V_{ST}	- the number of unique ways to perform start-up
$\bar{S}_G$	- the average number of RIs contained in a fault isolation result
$\bar{S}_I$	- the average number of interchanges required to correct a fault
A	- the number of unique accesses ($A \le V_D$ or V_R)
$\bar{A}$	- the average number of unique accesses required per fault isolation result
λ_a	- the failure rate of the RIs that require the a^{th} type of access
λ_T	- the total system failure rate
T_{D_a}	- the time required to disassemble the a^{th} access
T_{R_a}	- the time required to reassemble the a^{th} access

2.5 PREDICTION OF MAXIMUM REPAIR TIME

2.5.1 Discussion of M_{max} (Φ)

Specification of maximum repair time (in addition to a specified mean) is a common practice. Since repair time distributions are typically lognormal, exponential, or normal (refer to figure 7), the distribution has a "tail" which asymptotically approaches zero. Therefore, repair time maximums cannot be specified as an absolute value but rather must be specified as a percentile of the total distribution (i.e., 80, 90, 95, 99%). The selected percentile represents that percentage of repairs that can be performed in a time equal to or less than the specified value and is equal to the shaded area under the curve shown in figure 8.

The maximum repair time is typically denoted by M_{max}, $M_{max_{ct}}$, $MTTR_{max}$ or Max TTR. For this report, the maximum will be denoted as M_{max} (Φ) where Φ is the associated percentile.

The concept of M_{max} (Φ) is straight forward but an accurate quantitative prediction of its value is not easily obtained. Several methodologies have been developed but each has draw-backs and inaccuracies. Two of the more common methods are MIL-HDBK-472 Procedure 1, and MIL-HDBK-472 Procedure 3. Procedure 1 results in a cumulative distribution function which can be used to predict any derived percentile. The cumulative distribution is derived by combining the time distributions of the individual tasks which make up the repair actions. The method is based entirely on task definition and individual task time distributions derived from historical data from a system(s) with similar maintenance characteristics. This data is expensive to develop and not normally available.

Procedure 3 predicts M_{max} (Φ) based on the M_{max} (Φ) equation from MIL-STD-471 Test Method 2 (MIL-STD-471A, Test Method 9). This procedure assumes that repair times follow a lognormal distribution and uses a fixed sample of repair tasks to evaluate M_{max} (Φ). This method is adequate for demonstration purposes since it is based on a random sample of repair actions (approximately failure rate weighted) and a random occurrence of each repair action in that sample. As a prediction methodology it is less accurate since it eliminates the randomness of the time associated with each trial and results in a prediction of M_{max} (Φ) based on a distribution of means rather than on an entire distribution of repair times.

As an example, consider a simple unit with 5 different maintenance actions (i.e. repair types). Further assume that the 5 repair types have an equal frequency of

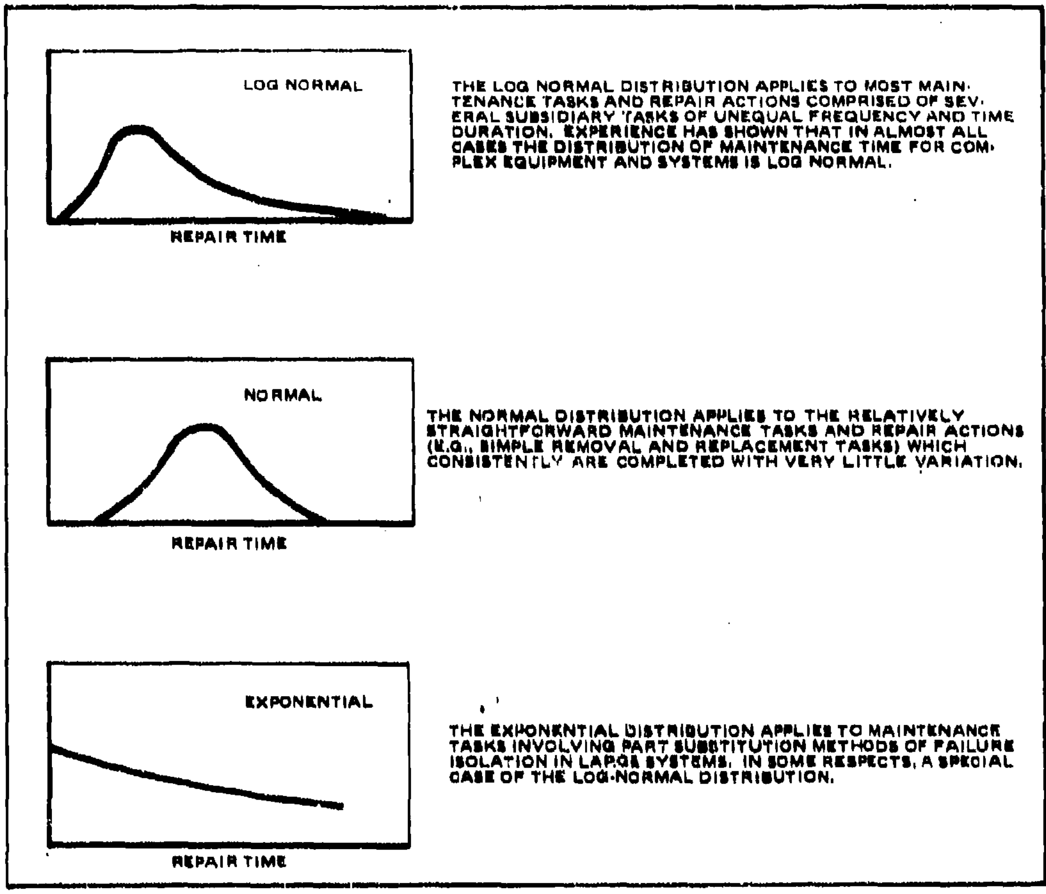


Figure 7. Typical Repair Time Distribution

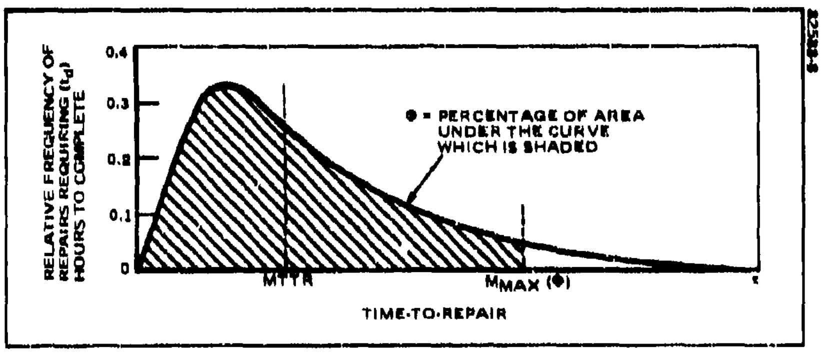


Figure 8. M_{max} (Φ) for a Log Normal Distribution

occurrence (i.e., equal failure rates). The time associated with each of these repair types and their associated maintenance elements (i.e., preparation, fault isolation, disassembly, etc.) has some variability associated with it. Assume the distribution of times for each of the five repair types is as shown in figure 9. These distributions are derived by combining the time distribution associated with each of the individual maintenance elements. Figure 9 indicates the assumed element time distribution for repair type 4. Typically, the distribution for the 9 basic maintenance elements will be as indicated in Table 18. As noted in the table, the major causes of variance in the individual distribution are technician/operator oriented (e.g., skill, dexterity, motivation).

Table 18. Typical Distribution of Times Associated with the Nine Basic Maintenance Elements

Maintenance Element	Typical Distribution	Variance Factors*
Preparation	Normal	Test equipment retrieval and warm-up time, technician skill.
Fault Isolation	Normal (automatic isolation)	Technician interpretation and understanding of results.
	Lognormal (manual isolation)	Technician skill and luck.
Spare Retrieval	Normal	Location of spares
Disassembly	Normal	Technician skill and dexterity.
Interchange	Normal	Technician skill and dexterity.
Reassembly	Normal	Technician skill and dexterity.
Alignment	Lognormal	Amount of alignment required, technician skill and dexterity.
Check-out	Normal (automatic)	Technician review of results.
	Lognormal (manual isolation)	Technician skill
Start Up	Normal	Equipment warm up, operator skill.

*The listed factors all include technician motivation.

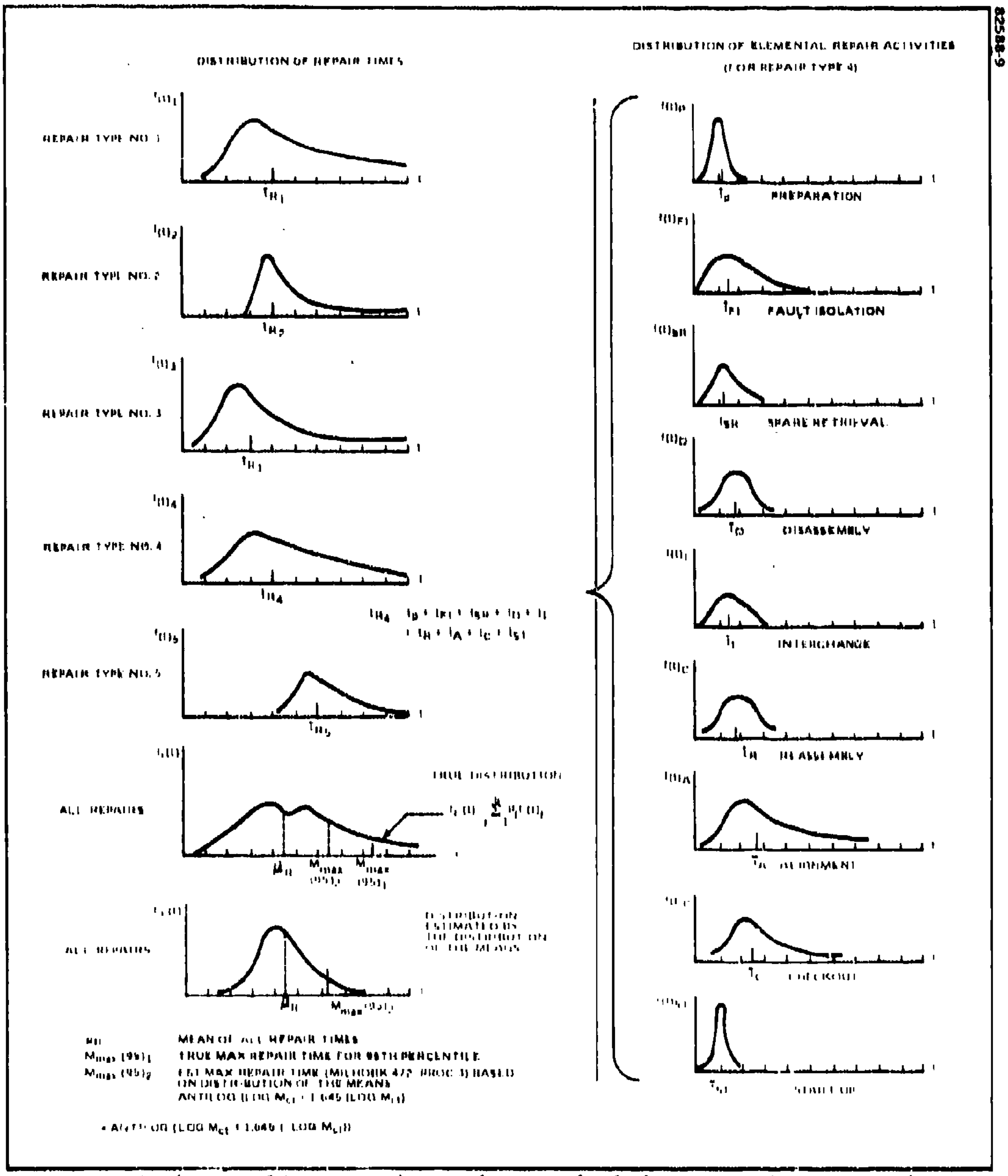


Figure 9. Prediction of M_{max} (Φ) by Combining Individual Repair Task Time Distribution

In the example, the mean ($\overline{t}_R$) for each repair type is found by adding the mean times of each element (i.e. $\overline{t}_P$, $\overline{t}_{FI}$, $\overline{t}_{SR}$, etc). The MTTR ($\bar{\mu}$) is found by computing the failure rate weighted average of the means of the 5 repair types. To find $M_{max}(\Phi)$, the distributions must be combined and the desired $M_{max}(\Phi)$ taken from this derived distribution. The procedure of "creating" a distribution of the repair type means and finding the $M_{max}(\Phi)$ of that distribution is obviously not the same as the $M_{max}(\Phi)$ of the derived true distribution (refer to Figure 9). As indicated in the example, the M_{max} (95) assumed log normal distribution based on the predicted means and variance, as derived using the equation of MIL-HDBK-472 Procedure 3, is much less than the true M_{max} (95) derived from the true combined distribution. This is the expected result and this method will always result in an optimistic prediction of $M_{max}(\Phi)$.

2.5.2 Prediction of $M_{max}(\Phi)$

Depending on the desired accuracy, two methods of predicting $M_{max}(\Phi)$ have been derived and proposed herein. The first method provides an approximation of $M_{max}(\Phi)$ to be used when the overall repair time distribution can be assumed to be lognormal, and the variance can be estimated from previous experience. The second method provides a more detailed methodology.

2.5.2.1 Approximation of $M_{max}(\Phi)$

An approximation of $M_{max}(\Phi)$ can be easily obtained, given that the overall repair time distribution is lognormally distributed, by using the following equation:

$$M_{max}(\Phi) = \frac{MTTR}{\sqrt{1+\eta^2}} \exp z_\Phi \sqrt{\ln(1+\eta^2)}$$

where

MTTR = the predicted mean time to repair

η = the coefficient of variation, either based on sample data, or historical data on similar systems. The coefficient of variation is defined as $\sigma_T/MTTR$ where σ_T is the standard deviation of the repair time distribution.

z_Φ = value obtained from the standard normal distribution tables corresponding to the desired percentile (Φ). A partial list is provided below.

Percentile (Φ)	z_{Φ}
80%	0.84
85%	1.03
90%	1.28
95%	1.64
99%	2.33

The above equation for predicting M_{max} (Φ) is derived in Appendix B.

As a further approximation, to be used for order of magnitude computations, Appendix C provides a ready compilation of M_{max} (Φ) for given values of MTTR and standard deviation. M_{max} (Φ) values are provided for combinations of MTTR values from .1 to 2.6 hours, lognormal repair time distribution standard deviations (sigma) of .1 to 2.5 hours, and percentiles (Φ) of 60, 70, 80, 90, 95 and 99.

2.5.2.1.1 Coefficient of Variation

The coefficient of variation (η) may not be known during the prediction stages of a given program. In this case η should be approximated based on previous experience on similar systems. If applicable experience is not available, the data provided in table 19 can be used. The data represents actual maintainability demonstration results from 14 formal tests conducted on modern systems/equipments. An

Table 19. Coefficient of Variation (η) from 14 Formal Maintainability Demonstration Tests

Equipment/System Type	Test Sample Size	Demonstrated MTTR	Demonstrated σ_T/MTTR
Data Processing System	70	9.93	0.69
Sonar Receiver	33	15.93	1.57
Display Equipment	51	7.77	1.63
Communications	50	10.14	1.10
Communications	40	10.57	0.53
Electronic Warfare	21	44.33	0.53
Mobile Radar	48	13.40	0.61
Signal Processing	50	13.31	0.55

Table 19. Coefficient of Variation (η) from 14 Formal Maintainability Demonstration Tests (Continued)

Equipment/System Type	Test Sample Size	Demonstrated MTTR	Demonstrated σ_T/MTTR
Display Equipment	25	17.33	1.21
Data Processing System	100	5.39	1.31
Signal Processing	50	12.10	0.56
Data Converter	50	3.42	0.42
Display	50	13.17	0.50
Display	50	14.24	0.64
Average	688	-----	0.846
Weighted Average	688	-----	0.864

average of all the tests yields a coefficient of variation of 0.846. A weighted average (using the sample size as the weighting criteria) yields an average of 0.864. Both of these averages compare favorably with a coefficient of variance of 0.877 as presented in "Results of Eleven Maintainability Demonstrations" which was published in the IEEE Transactions on Reliability (Vol. R-16, #1, May 1967). MIL-HDBK-472 Procedure 3 proposes a coefficient of variance of 1.07 but this is considered of little value, based on the out-dated base from which this was derived. In general it appears that the coefficient of variance decreases as the degree of fault isolation automaticity and degree of modularity increase.

2.5.2.2 Detailed M_{max} (ϕ) Analysis

This section presents the basic methodology for predicting M_{max} (ϕ) when an accurate representation of the overall repair time distribution is desired. The methodology requires that a distribution of time for each maintenance element (i.e., preparation, fault isolation, etc.) be known or assumed.

The methodology is general and can be applied to any definable distribution or combinations there of, however, the complexity of computing the overall distribution increases proportionately with the complexity of the maintenance element distributions. A simplifying assumption can be made that all maintenance elements have normally distributed times. This simplifying assumption is reasonable since each maintenance element is the sum of many independent task times, e.g. the maintenance task "preparation" may include time for equipment warm-up, acquisition of necessary tools, etc. By the central limit theorem in statistics, the distribution of the maintenance element approaches a normal distribution as the number of contributing task times increases. Based on this assumption the detailed procedure has been developed and a computer program written for computing the desired $M_{max}(\Phi)$. Programs based on other distributions of maintenance elements can be similarly developed and programmed.

2.5.2.2.1 General Approach

In the general approach, we have a system with total failure rate λ_T, and with N x J possible repair types with random repair times R_{nj}, n=1, ..., N, j=1, ..., J where J is the total number of unique fault isolation outputs and N is the total number of repairable items. Let λ_{nj} be the failure rate of that portion of the n^{th} repairable item which is covered by fault isolation output j. Further, let $f_{R_{nj}}$ (t) be the probability density function for R_{nj}, n=1, ..., N, j=1, ..., J. It is assumed that $f_{R_{nj}}$ is continuous and concentrated on $[0, \infty)$. If T is the system repair time, then its density function g_T (t) (since the events $\left\{T = R_{nj}\right\}$ are mutually exclusive) is:

$$g_T(t) = \sum^{*} P_{nj} f_{R_{nj}}(t) \quad (1)$$

where

$$\sum^{*} = \sum_{n=1}^{N} \sum_{j=1}^{J} \ ; \text{ and } P_{nj} = \lambda_{nj}/\lambda_T.$$

The mean system repair time is

$$\mu_T \quad E(T) = \int_0^{\infty} t g_T(t)dt = \sum^{*} P_{nj} \int_0^{\infty} t f_{R_{nj}}(t)dt = \sum^{*} P_{nj}\mu_{R_{nj}} \quad (2)$$

where

$\mu_{R_{nj}} = E(R_{nj})$ = mean repair time R_{nj}, and the variance of the system repair time is

$$\sigma_T^2 = E(T^2) - \mu_T^2 = \sum^{*} P_{nj} \int_0^{\infty} t^2 f_{R_{nj}}(t)dt - \mu_T^2 \quad (3)$$

$$= \sum^{*} P_{nj} (\sigma_{R_{nj}}^{2} + \mu_{R_{nj}}^{2}) - \mu_T^2$$

where

$\sigma_{R_{nj}}^2$ = variance of the repair time R_{nj}.

Values of $M_{max}(\Phi)$ are given as solutions to the equation

$$\int_0^{M_{max}(\Phi)} g_T(t)\, dt = \sum^* P_{nj} \int_0^{M_{max}(\Phi)} f_{R_{nj}}(t)\, dt = \Phi \qquad (4)$$

which are not, in general, unique. Sufficient conditions for the existence of a unique solution are that $f_{nj}(t) > 0$ for all $t > 0$, $n=1, \ldots, N$, $j=1, \ldots, J$ and that each $f_{nj}(t)$ be continuous, conditions easily met in practice. Equation (4) can easily be solved, under these sufficient conditions, by using iterative means on a computer.

2.5.2.2.2 Assuming Normal Densities for the R_{nj}'s

In practice, R_{nj}, $n=1, \ldots, N$, $j=1, \ldots, J$ are sums of several independent repair element times which are themselves sums of a large number of independent repair task times. An application of the central limit theorem suggests that the densities $f_{R_{nj}}$ are approximately normal. Specifically, the density $f_{R_{nj}}$ will be (approximately)

$$f_{R_{nj}}(t) = \frac{1}{\sqrt{2\pi}\,\sigma_{R_{nj}}} \exp\left\{-\frac{1}{2}\left(\frac{t-\mu_{R_{nj}}}{\sigma_{R_{nj}}}\right)^2\right\}$$

where

$\mu_{R_{nj}}$ and $\sigma_{R_{nj}}^2$ are the sums of the elemental repair time means and variances,

respectively. Presumably, $\mu_{R_{nj}}$ and $\sigma_{R_{nj}}^2$ will be such that the normal density is, approximately, concentrated on the positive real axis, i.e.,

$$\frac{1}{\sqrt{2\pi}\,\sigma_{R_{nj}}} \int_{-\infty}^{0} \exp\left\{-\frac{1}{2}\left(\frac{t-\mu_{R_{nj}}}{\sigma_{R_{nj}}}\right)^2\right\} dt \approx 0 \qquad (5)$$

If we let $n(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} e^{-x^2/2}\, dx$, then equation 4 becomes

$$\sum^{*} P_{nj}\ n\left(\frac{M_{max}(\Phi) - \mu_{R_{nj}}}{\sigma_{R_{nj}}}\right) = \Phi \tag{6}$$

which will have a unique solution for all Φ where $0 < \Phi < 1$. The advantage here is that only one density function need be programmed in order to calculate $M_{max}(\Phi)$ using a computer.

2.5.2.2.3 Computer Program

A computer program listing is provided in figure 10 for performing the normal case described above. A sample input/output for the program is shown in Table 20. The resulting distribution for the example is shown in figure 11.

The means and variances for each repair element which makes up the individual repair times R_{nj} are inputed. $\mu_{R_{nj}}$ and $\sigma^2_{R_{nj}}$ are then computed and equation (6) is solved for $M_{max}(\Phi)$ for the given Φ using the secant method. The secant method solves equations of the form

$$f(x) = 0$$

by forming the sequence (for n=1, 2, ...)

$$x_{n+1} = x_n - (x_n - x_{n-1})\ f(x_n)/(f(x_n) - f(x_{n-1}))$$

after choosing x_0 and x_1 as starting points. The sequence is terminated after the desired accuracy is reached. Several points concerning the computer program deserve discussion.

First, no integration is performed per se in the calculations of

$$n\left(\frac{M_{max}(\Phi) - \mu_{R_{nj}}}{\sigma_{R_{nj}}}\right)$$

Instead, the following approximation is used.*

$$n(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} e^{-x^2/2}\, dx$$

$$= 1 - (\sqrt{2\pi})^{-1} e^{-t^2/2}\left[b_1 A + b_2 A^2 + b_3 A^3 + b_4 A^4 + b_5 A^5\right] + \epsilon(t)$$

*Abramowitz, M., and Stegun, I. A ed , Handbook of Mathematical Functions, (Washington, D.C.; The Government Printing Office, 1972), p. 932.

where

$|\epsilon(t)| < 7.5 \times 10^{-8}$ for all t and

$A = 1/(1 + 0.2316419t)$ with the b_i's given by:

$b_1 = 0.319381530$

$b_2 = -0.356563782$

$b_3 = 1.781477937$

$b_4 = 1.821255978$

$b_5 = 1.330274429$

Secondly, the user must provide two initial guesses to $M_{max}(\Phi)$ denoted by X0 and X1 in the computer program. It is essential that X0 not equal X1 since this would cause "zero divides" in the program. The best way to pick X0 and X1 is to guess at an interval in which $M_{max}(\Phi)$ will lie. Then, select X0 and X1 as the endpoints of that interval.

Finally, although the present discussion deals with double subscripts n and j, the distinctions indicated by these subscripts are independent of the calculations performed. Hence, the program uses the data in single dimensioned arrays of length N x J.

The input data is read in the following order:

X0 (Initial guess), X1 (Initial guess), PHI (Φ), LT (Total system failure rate)

N1 (Number of elements contributing to first R), LAMBDA (1) (Failure rate)

MU, SIG2 (mean, variance for first element)

MU, SIG2 (mean, variance for 2nd element)

. . . .

. . . .

. . . .

N2 (Number of elements contributing to second R), LAMBDA (2) (Failure rate)

MU, SIG2

. .

. .

. .

The following condition must be met:

$$\sum_{\text{All } I} \text{LAMBDA (I)} = \text{LT}$$

Sample input/output, and program listing follow.

Table 20. Sample Input/Output Data for M_{max} (Φ) Computer Program

Input Data

```
7.0D0    9.0D0    .90D0    250.0D0
4     50.0D0
2.0D0     .24D0
2.2D0     .21D0
1.8D0     .20D0
2.1D0     .18D0
2     100.0D0
2.7D0     .15D0
3.0D0     .14D0
4     50.0D0
1.5D0     .10D0
1.4D0     .08D0
1.7D0     .11D0
1.9D0     .09D0
2     50.0D0
1.0D0     .05D0
1.3D0     .80D0
```

Output from Program

```
             8.17
             8.09
             8.10
             8.10
MMAX(.900)=     8.10
```

The resulting distribution of the sample data is shown in Figure 11.

Figure 10. Listing for Computer Program to Compute $M_{max}(\Phi)$ When Elemental Maintenance Activities are Normally Distributed

```
      IMPLICIT REAL*8(A-H),REAL*8(O-Z)
      REAL*8 MUR,SIG2R,MU,SIG2,N,LAMBDA,LT
      COMMON PHI, LAMBDA(100),MUR(100),SIG2R(100),ITOTAL
C       X0,X1 ARE INITIAL GUESSES TO MMAX(PHI).  LT IS TOTAL
C       FAILURE RATE OF SYSTEM.
      READ(5,*) X0,X1,PHI,LT
C      ERR=MAX ERROR IN MMAX(PHI)
       ERR=0.005D0
      J=0
 30   J=J+1
      READ(5,*,END=10) NN,LAMBDA(J)
      LAMBDA(J)=LAMBDA(J)/LT
      MUR(J)=0.D0
      SIG2R(J)=0.D0
      DO 20 I=1,NN
C       NN IS THE NUMBER OF ELEMENTS TO FOLLOW.
C       LAMBDA(J) IS THE FAILURE RATE OF THE REPLACEABLE ITEM
C       WHOSE REPAIR TIME IS MADE UP OF THE ELEMENTS WHICH FOLLOW.
      READ(5,*) MU,SIG2
C       MU IS THE MEAN, SIG2 IS THE VARIANCE OF EACH ELEMENT.
      MUR(J)=MUR(J)+MU
 20   SIG2R(J)=SIG2R(J)+SIG2
      GO TO 30
 10   ITOTAL=J-1
      XN=X1
      XNM1=X0
 40   XN1=XN-(XN-XNM1)*F(XN)/(F(XN)-F(XNM1))
      WRITE(6,2) XN1
C       MMAX(PHI) IS PRINTED AT EACH ITERATION.
      IF(DABS(XN1-XN).LE.ERR) GO TO 50
      XNM1=XN
      XN=XN1
      GO TO 40
 50   CONTINUE
      WRITE(6,1) PHI,XN1
 1    FORMAT(1X,'MMAX(',F4.3,')=',F7.2)
 2    FORMAT(5X,F10.2)
      STOP
      END
      FUNCTION N(T)
      IMPLICIT REAL*8(A-H,N),REAL*8(O-Z)
C  STANDARD NORMAL DISTRIBUTION  FUNCTION
C  FOR THE METHOD, SEE THE NATIONAL BUREAU OF STANDARDS
C  HANDBOOK OF MATHEMATICAL FUNCTIONS
      A=1.D0/(1.D0+.2316419D0*T)
      Z=.3989422BD0*DEXP(-.5D0*(T**2))
      N=.31938153D0*A-.356563782D0*(A**2)
      N=N+1.781477937D0*(A**3)-1.821255978*(A**4)
      N=N+1.330274429D0*(A**5)
      N=1.D0-Z*N
      RETURN
      END
      FUNCTION F(X)
      IMPLICIT REAL*8(A-H,L,M,N),REAL*8(O-Z)
       COMMON PHI, LAMBDA(100),MUR(100),SIG2R(100),ITOTAL
       F=0.D0
       DO 10 I=1,ITOTAL
 10    F=F+LAMBDA(I)*N((X-MUR(I))/SIG2R(I))
       F=F PHI
       RETURN
       END
```

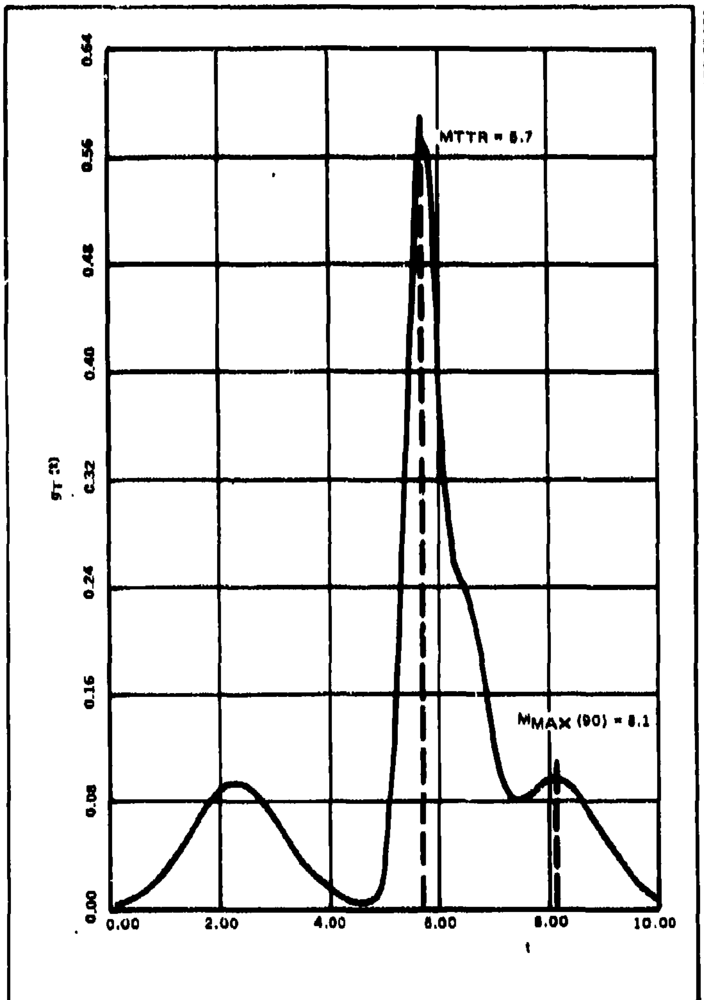


Figure 11. Resulting Repair Time Distribution for a Sample System Containing Four (4) Repair Types with Different Normally Distributed Repair Times

2.6 OTHER PREDICTION PARAMETERS

As was mentioned previously in Section 2.3.1 MTTR is the prediction parameter most often specified in DOD contract requirements. This section presents some other prediction parameters that may require prediction and the prediction model for each. The prediction procedure is basically the same as for the MTTR predictions. The prediction parameters covered here are MTTR with periodic adjustments, mean maintenance man hours per repair ($\overline{MMH}$/REPAIR), mean maintenance man hours per maintenance action ($\overline{MMH}$/MA) including false alarm rate, and mean maintenance man hours per operating hour ($\overline{MMH}$/OH).

2.6.1 MTTR with Periodic Adjustments

Some systems are required to be operational twenty-four hours a day. Due to this continuous operation any downtime affects the availability of the system (availability is defined as UPTIME/(UPTIME + DOWNTIME)). One possible downtime other than downtime for corrective maintenance (MTTR) associated with predicted failure rate is the downtime required to perform necessary periodic adjustments. If downtime for periodic adjustments must be accounted for, the following model can be used

$$\text{MTTR} = \frac{\sum_{n=1}^{N} \lambda_n R_n + \sum_{b=1}^{B} f_b T_b}{\sum_{n=1}^{N} \lambda_n + \sum_{b=1}^{B} f_b}$$

where:

λ_n = the failure rate of the n^{th} RI

R_n = the average repair time for the n^{th} RI

f_b = the frequency of occurrence of the b^{th} periodic adjustment (per 1 million hours)

T_b = the time required to perform the b^{th} periodic adjustment

N = the quantity of RIs

B = the quantity of Periodic Adjustments Required

2.6.2 Mean Maintenance Man Hours Per Repair (MMH/Repair)

Some contracts require the determination of the manning level required to perform corrective maintenance. To satisfy this requirement the general form of the MTTR equation must be modified to predict the maintenance man hours per repair instead of elapsed time per repair (MTTR). This can easily be done by replacing the repair times, in the appropriate MTTR models with the maintenance man hours required for each repair action. The resultant form is:

$$\overline{MMH}/\text{Repair} = \frac{\sum_{n=1}^{N} \lambda_n \cdot \overline{MMH}_n}{\sum_{n=1}^{N} \lambda_n}.$$

where:

N = the quantity of RIs

λ_n = the failure rate of the n^{th} RI

$\overline{MMH}_n$ = the average maintenance man hours required to repair the n^{th} RI

The equation for $\overline{MMH}_n$ (analagous to R_n) can be expressed as:

$$\overline{MMH}_n = \frac{\sum_{j=1}^{J} \lambda_{nj}\, MMH_{nj}}{\sum_{j=1}^{J} \lambda_{nj}}$$

where:

J = the quantity of FD&I results

λ_{nj} = the failure rate associated with the j^{th} result for the n^{th} RI

MMH_{nj} = the maintenance man hours required to repair the n^{th} RI given the j^{th} result

2.6.3 Mean Maintenance Man-Hours Per Maintenance Action ($\overline{MMH}$/MA)

$\overline{MMH}$/MA is the same as $\overline{MMH}$/Repair except that it includes maintenance performed as the result of system failure false alarms. For purposes of this procedure, maintenance due to failure false alarms will be limited to the following:

1) a fault is detected during normal operations but cannot be repeated during the fault isolation process.
2) a fault is detected and isolated to an RI when the RI does not have an actual fault (This is usually caused by testing conditions such as BIT tolerances).

The model for $\overline{MMH}$/MA including the false alarm conditions noted in 1) & 2) above is

$$\overline{MMH}/MA = \frac{\sum_{n=1}^{N} (1 + F_{2n}) \lambda_n \overline{MMH}_n + \sum_{n=1}^{N} F_{1n} \lambda_n \overline{MMH}_D}{\sum_{n=1}^{N} (1 + F_{2n}) \lambda_n + \sum_{n=1}^{N} F_{1n} \lambda_n}$$

where:

F_{1n} = frequency of occurrence of type 1 false alarms (expressed as a fraction of the n^{th} RI failure rate)

F_{2n} = frequency of occurrence of type 2 false alarms associated with n^{th} RI type

$\overline{MMH}_D$ = mean maintenance man hours associated with type 1 false alarms. This time is normally limited to preparation time and fault isolation time which can be computed similar to sections 2.4.2.3.1 and 2.4.2.3.2 respectively.

2.6.3.1 False Alarm Rates (FAR)

The false alarm rates (F_1 & F_2) described in section 2.6.3 are dependent on the system type, operating environment, maintenance environment, system design, and fault detection and isolation implementation. Therefore a set of standards to be used on prediction maintainability characteristics including FAR is not possible. A sample of FARs experienced on 2 current systems is shown in Table 21. It should not be construed that these are representative values to be used as standards.

Table 21. Examples of Experienced False Alarm Rates

System/Equipment	FAR Type 1 (F_{1n})*	FAR Type 2 (F_{2n})**
Weapon Control System		
• Radar Subsystem	.41	.25
• Computer Subsystem	.63	.65
• Control Subsystem	1.32	.31
• Power Subsystem	.37	.66
• Auxiliary Subsystem	1.31	.54
Airborne Radar System		
• RF Unit	N/A	.44

*The ratio of Type 1 false alarms to actual failures
**The ratio of Type 2 false alarms to actual failures

Table 21. Examples of Experienced False Alarm Rates (Continued)

System/Equipment	FAR Type 1 (F_{1n})*	FAR Type 2 (F_{2n})**
Airborne Radar System (cont)		
• Transmitter	N/A	.31
• Receiver	N/A	.12
• Antenna	N/A	.08
• Analog Processor	N/A	.07
• Digital Processor #1	N/A	.65
• Digital Processor #2	N/A	.50
• Control Unit	N/A	.00
• Power and Ant. Servo	N/A	.33

N/A - Not Available

2.6.4 Mean Maintenance Man-Hours Per Operating Hour ($\overline{MMH}$/OH)

This maintainability parameter includes the manpower that is required to maintain a system completely. This includes all aspects of maintenance; corrective maintenance, preventive maintenance, and maintenance caused by false alarms. The average number of maintenance man-hours expended per operating hour can be expressed as:

$$\overline{MMH}/OH = \sum_{n=1}^{N} (1 + F_{2n})\ \lambda'_n\ \overline{MMH}_n + \sum_{n=1}^{N} F_1\ \lambda'_n\ \overline{MMH}_D + \sum_{r=1}^{PM} F_r\ \overline{MMH}_r$$

where:

λ'_n = λ_n expressed in failures per operating hour

F_r = frequency of r^{th} preventive maintenance action expressed in occurrences per hour

$\overline{MMH}_r$ = maintenance man hours to perform r^{th} preventive maintenance type

PM = quantity of unique preventive maintenance types

SECTION 3.0 DATA COLLECTION

In order to provide an appropriate data base for the development of the prediction models (primarily the regression equations defined in section 2.4.1) 73 systems/equipments developed by Hughes in the past ten years were surveyed.

From the surveyed systems, 26 were identified as possible candidates for extraction of data pertinent to the study. Table 22 identifies the candidate systems and the characteristics, features, and data available from each system. From the 26 systems, 9 systems were finally selected to provide the study data base. The criteria for selection of the 9 systems was;

- the systems selected must represent all possible environments (i.e. ground, airborne, shipboard)
- the systems must have designed-in maintainability features for fault detection and isolation
- the systems must be of recent vintage, constructed with modern packaging techniques
- a maintainability analysis and prediction must have been previously completed on the system
- maintainability analysts familiar with the system must be available
- some form of maintainability evaluation data must be available (e.g. M verification test, M demonstration, or field evaluation)

The final nine systems selected for data collection and establishment of the study data base are denoted by an asterisk in table 22. They are:

- Ground Radar #1
- Ground Radar #2
- Radar Data Processor
- Shipboard Radar #2
- Shipboard Display System #1
- Weapon Data Converter
- Airborne Radar #1
- Weapon Control System
- Communications Terminal

Seven out of nine systems selected represent large scale systems comprising a variety of equipment types and a broad scope of packaging concepts.

The systems selected represent all possible operating environments: 3 airborne, 3 shipboard, and 3 ground. The data base is made up of approximately fifty equipments grouped into 10 functional equipment types. This is considered to be a representative sample for the data analysis.

TABLE 22. CANDIDATE SYSTEMS TO BE USED FOR THE STUDY DATA BASE

Candidate Systems	System Composition										Features			Prior Activity						
	Antenna/ Pedestal	Transmitter	Receiver/ Exciter	Signal Processor	Display Console	Computer	Peripherals	Power Supply Unit	Control Unit	Ancillary	On-Line Software Diagnostics	Off-Line Software Diagnostics	Hardware Self-Test Features	M Analysis	M Predictions	ORLA/LORA	Maintenance Engineering Analysis	M Testing	M Demonstration	Field Evaluation
GROUND-BASED SYSTEMS																				
Command and Reporting System					X	X	X			X	X	X	X	X	X		X		X	X
Post for Sensor Reporting					X	X	X			X	X	X	X	X	X		X	X		X
*Ground Radar #1	X	X	X	X		X	X		X	X	X	X	X	X	X			X	X	
*Ground Radar #2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X
Antiaircraft Weapon System	X	X	X		X				X				X	X		X				
Antitank Missile System			X						X	X			X	X	X		X	X		X
Manpack Radio Set		X	X										X	X	X					
TADIL-B Modem				X									X	X	X				X	X
*Radar Data Processor				X								X	X	X	X				X	X
Ground Fixed Computer						X					X		X							
SHIPBOARD SYSTEMS																				
Shipboard Radar #1	X	X	X	X		X	X	X	X	X		X	X	X	X		X	X		X
*Shipboard Radar #2	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X		X
Electronic Warfare System #1	X	X	X	X	X				X	X		X	X	X	X					X
Electronic Warfare System #2	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X			
Shipboard Display System #1				X	X					X	X	X	X	X	X					
*Weapon Data Converter				X							X	X	X	X	X				X	
*Shipboard Display System #2					X						X	X	X	X	X			X	X	
Sonar System			X	X									X	X	X					
Shipboard Display System #3			X	X					X		X	X	X	X	X		X		X	
AIRBORNE SYSTEMS																				
*Airborne Radar #2	X	X	X	X				X	X			X	X	X	X	X	X	X	X	
Detecting and Ranging Set	X			X	X			X					X	X	X					
*Weapon Control System	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X
*Communication Terminal		X	X	X		X		X	X		X	X	X	X	X					
Vision Image Intensifier System														X	X				X	
Forward Looking IR Set	X			X					X				X	X			X			
Infrared Night Vision Sight													X	X	X				X	
Target Designator		X												X	X		X		X	
Missile Data Link		X	X	X									X	X	X		X			

*System selected for Data Base

3.1 DEFINITION OF DATA COLLECTED

Data was collected on the selected systems in three general categories

1. physical data
2. maintainability data
3. fault isolation data

Data was collected at the lowest level of replacement, the RI level for the organizational level of repair. This was the most appropriate level to perform the data collection, since the data could then be summarized for the upper levels (equipment and system) by simple summations. The following pages list and define each type of data collected.

3.1.1 Physical Data

Physical data is that information which defines the physical attributes of the hardware such as number of components, circuitry type, failure rate, and quantity of replaceable items. Fifteen classes of physical data, as defined below, were collected on each of the selected systems. Included in the following definitions (within the parentheses) is the variable name associated with each type of data that was assigned in the computer data bank.

- Quantity of RIs (RIQ) the total number of replaceable items in the system at the organizational level
- Modular RI Qty (MRIQ) the total number of easily replaceable modules in the system at the organizational level. Easily replaceable modules are defined as items not hard wired in (e.g. plug-in cards).
- Qty of Active Components (ACT) the total number of active components in each RI. Active components were defined as transistors, diodes, SCRs, ICs and Hybrids
- Qty of Passive Components (PAS) the total number of passive components in each RI. Passive components were defined as resistors, capacitors, inductors, etc.
- Predicted Failure Rate (FR) the predicted failure rate of each RI. Failure rate is expressed in failures per 10^6 hours.
- Qty of Digital ICs (IC) the total number of digital ICs in each RI. This includes SSI, MSI, LSI, and memory
- Qty of Hybrids (HYB) the total number of hybrids in each RI.

- Qty of Linear ICs (LIN) the total number of linear ICs in each RI
- Percent Analog (ANA) the fraction of analog type RIs in the equipment (percent weighted by failure rate, ANA ≤ 1.0)
- Percent Digital (DIG) the fraction of digital type RIs in the equipment (percent weighted by failure rate, DIG ≤ 1.0)
- Percent RF (RF) the fraction of RF type RIs in the equipment (percent weighted by failure rate, RF ≤ 1.0)
- Percent P/S (PS) the fraction of power supply type RIs in the equipment (percent weighted by failure rate, PS ≤ 1.0)
- Percent Piece Parts (PP) the fraction of piecepart type RIs in the equipment (percent weighted by failure rate, PP ≤ 1.0)
- Percent Alignment (ALI) the fraction of RIs that require alignment when replaced, (percent weighted by failure rate, ALI ≤1.0)
- Percent Plug-in (PLG) the fraction of RIs that are quickly replaced via plug-in connectors (percent weighted by failure rate, PLG ≤ 1.0)

3.1.2 Fault Isolation Data

Fault isolation data is that information which defines the characteristics of the fault detection and isolation implementation and capability. Ten classes of fault isolation data, as defined below, were collected on each of the selected systems.

- Diagnostic Size (DIAG) the size of the fault isolation diagnostic program in terms of K computer words (e.g. 1K = 1024 words)
- Quantity of Fault Isolation Results (QFIR) the unique number of results that a technician may observe after he runs a diagnostic program (automatic or semi-automatic)
- Fault Isolation Type – (automatic or semi-automatic (TYPA, TYPS) the fault isolation method used to isolate a fault
- Percent Automatic (KA) the fraction of faults isolated automatically (percent weighted by failure rate, KA ≤ 1.0)
- Percent Semi-automatic (KS) the fraction of faults isolated semi-automatically (percent weighted by failure rate, KS ≤ 1.0)
- Percent Manual (KM) the fraction of faults isolated manually (percent weighted by failure rate, KM ≤ 1.0)
- Percent Resolution to 1 RI (RES1) the fraction of faults isolated down to one RI (for automatic and semi-automatic FI, RES1 ≤ 1.0)

- Percent Resolution to 3 RIs or Less (RES3) the fraction of faults isolated down to three RIs or less (for automatic or semi-automatic FI, RES 3 $\leq$ 1.0)
- Average RI Group Size (AVG) average RI group size that faults were isolated down to (automatic and semi-automatic only)
- Maximum RI Group (MAX) defined as the maximum RI group size in a fault isolation result.

3.1.3 Maintainability Data

Maintainability data refers to the assessed MTTR of the RIs. The MTTR is broken down into isolation, fault correction, and checkout. Data was collected for both predicted MTTR and demonstrated MTTR as available.

- MTTR (ISO) - the mean time required to isolate a fault down to a single RI or a replaceable group of RIs.
- MTTR (RR) - the mean time required to effect a repair on a fault that has been isolated.
- MTTR (CO) - the mean time required to verify that a fault has been repaired.
- MTTR (TOT) - the mean time required to return a system back to operational status once a fault has been detected. This is just the sum of $MTTR_{ISO}$, $MTTR_{RR}$, and $MTTR_{CO}$.

3.1.4 Data Collection Summary

Tables 23 thru 40 present the data that was collected and used for the correlation analyses described in section 2.4.1. The data is presented at the system and equipment levels and is contained in two separate tables for each system. The first set of tables (23 through 31) provide data on the physical attributes of each system. The second set of tables (32 through 40) summarize the maintainability and fault isolation characteristics of each system.

The following paragraphs define the data contained within each table type. Further definition of some entries is provided by the definitions in section 3.1.1, 3.1.2 and 3.1.3.

PHYSICAL DATA SUMMARY (REFER TO TABLES 23 THRU 31)

- EQUIP TYPE – defines the equipment within each system by its generic type. The ten generic codes used were; transmitter (XMTR), receiver (RCVR), signal processor (SP), computer (COMP), antenna/pedestal (ANT), display console (DISP), power supply (P/S), peripheral devices (PERI), control unit (CNTL), and ancillary equipment (ANC).
- FAIL RATE – the predicted failure rate of each equipment expressed in failures per million hours.
- RI QTY – the number of RIs within each equipment that are replaced by organizational maintenance men. A value of one usually indicates that the entire unit is replaced at the organizational level.
- MODRI QTY – the number of modular RIs that are replaced at the organizational level for each equipment.
- Parts Quantities – the following columns define the total number of each part type contained within each equipment:

  QTY ACTIV – quantity of active components

  QTY PASS – quantity of passive components

  QTY ICS – quantity of digital ICs

  QTY LIN – quantity of linear ICs

  QTY HYB – quantity of hybrid circuits

  Zero entries for both QTY ACTIV and QTY PASS indicates that no data was available for that particular unit (usually a vendor item). The part quantities for the digital ICs, linear ICs, and hybrid circuits are summarized at the system level and not entered for each equipment.
- Fraction of Failure Rate Due to RI type – these columns define the fractional portion of the equipment failure rate associated with the following RI types:

  ANAL – RIs that perform analog functions

  DIG – RIs that perform digital functions

  RF – RIs that perform RF (radio frequency) functions

  P/S – RIs that perform power supply functions

  PP – RIs that were considered piece parts (e.g. switches)

  ALIGN – RIs that required some type of alignment when replaced

  PLUG – RIs that were modular or plug-in types.

  The above entries were based on the failure rates of RIs of each type divided by the total failure rate of the equipment.

- System Totals – the entries in this row provide a summation of the equipment level entries for failure rate, RI quantities, part quantities, and circuit types. Also included in this row is the environment (ENV) in which the system is operated. The environments are defined as airborne (AIR), shipboard/submarine (SEA), and ground (GRND).

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY
(REFER TO TABLES 32 THRU 40)

- Predicted Repair Times – the predicted repair times of each equipment

  ISO – fault isolation time

  R/R – disassembly, interchange, and reassembly time

  C/O – alignment and checkout time

  TOTAL – the predicted MTTR equal to ISO + R/R + C/O
- Demonstration Repair Times – the demonstrated repair times of each equipment. Entries in the columns were extracted from available maintainability demonstrations results.

  ISO – fault isolation time

  R/R – disassembly, interchange, & reassembly time

  C/O – alignment and checkout time

  TOTAL – the demonstrated MTTR equal to ISO + R/R + C/O
- Fault Isolation Data – entries in the following columns define the automaticity and fault isolation implementation for each of the listed equipments. The data presented was extracted from BIT analyses, diagnostic program documentation, and maintenance manuals for each of the systems examined.

  KA – fractional portion of faults isolated automatically
  KS – fractional portion of faults isolated semi-automatically
  KM – fractional portion of faults isolated manually

  The type of fault isolation is defined for each equipment by entries under the TYPA (type of automatic FI) and TYPS (type of semi-automatic FI). The following codes were used:

  1 – computer controlled test
  2 – status monitors
  3 – operator observations/deductions FI
  4 – indicator lights
  5 – lamp test
  6 – display unit callout & maintenance manual

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (Continued)

- RI Resolution – these columns define the equipment fault isolation capabilities relative to the level of fault isolation and the amount of fault isolation data available to the maintenance technician.

  RES1 – is the fraction of faults isolated to 1 RI

  RES3 – is the fraction of faults isolated to 3 RIs or less.

  AVG – is the average number of RIs contained in a fault isolation output. This is equivalent to S_G defined in section 2.4.2.3.3.2.1

  QFIR – is the quantity of fault isolation results that isolate a fault to an RI within the equipment.

  DIAG – the size of the diagnostic program associated with each equipment (in K words).

TABLE 23. PHYSICAL DATA SUMMARY (WEAPON CONTROL SYSTEM)

PHYSICAL DATA SUMMARY

***SYSTEM: WEAPON CONTROL

EQUIP TYPE	FAIL RATE	PE QTY	MOUNT QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY MTS	ANAL	DIG	RF	MS	PP	ALIGN	PLUG
									FRACTION OF FAILURE RATE DUE TO MT TYPE						
FCVR	2400.	1.	1.	1467.	514.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
RTIR	3035.	1.	1.	204.	495.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
P/S	303.	1.	1.	26.	54.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
P/S	564.	1.	1.	31.	80.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
P/S	333.	1.	1.	38.	79.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
FCVR	1000.	1.	1.	295.	521.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
AIF	1105.	1.	1.	139.	552.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
SP	1250.	1.	1.	545.	1735.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
SP	1000.	2.	2.	2085.	1800.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
SP	1250.	1.	1.	575.	940.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
SP	1000.	1.	1.	943.	1179.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
FCVR	1000.	1.	1.	130.	823.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
CMRP	417.	1.	1.	6624.	2625.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
CMPP	555.	1.	1.	14447.	2583.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
CMAP	1250.	1.	1.	1015.	866.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
P/S	500.	1.	1.	283.	656.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
CATL	100.	1.	1.	42.	126.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
CATL	250.	1.	1.	65.	617.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
LISP	1000.	1.	1.	425.	1675.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
CATL	1250.	1.	1.	36.	66.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
LISP	1000.	1.	1.	325.	796.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
P/S	155.	1.	1.	118.	197.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
P/S	317.	1.	1.	407.	252.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
SP	1458.	1.	1.	1210.	610.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
SP	1530.	1.	1.	985.	1120.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
P/S	768.	1.	1.	346.	796.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
SYSTEM TOTALS															
ENVRAIN	27150.	27.	27.	31604.	21749.	N/A	N/A	N/A	0.38	0.20	0.32	0.16	0.0	0.0	1.00

TABLE 24. PHYSICAL DATA SUMMARY (SHIPBOARD RADAR #2)

PHYSICAL DATA SUMMARY

***SYSTEM: SHIPBOARD RADAR NO. 2

EQUIP TYPE	FAIL RATE	RI QTY	HOURI QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	ANAL	DIG	RF	PS	PP	ALIGN	PLUG
									FRACTION OF FAILURE RATE DUE TO RI TYPE						
XMTR	721.	972.	36.	757.	2590.				0.23	0.15	0.16	0.08	0.37	0.27	0.37
SP	530.	283.	86.	2849.	2831.				0.16	0.57	0.0	0.13	0.14	0.24	0.73
SF	964.	714.	124.	5314.	5328.				0.21	0.69	0.0	0.05	0.05	0.34	0.84
COMP	530.	174.	63.	4964.	2598.				0.6	0.86	0.0	0.10	0.04	0.10	0.86
PERI	751.	0.	4.	0.	0.				0.0	0.5	0.0	0.0	1.00	0.0	1.00
RCVR	360.	1022.	59.	522.	2780.				0.53	0.03	0.10	0.11	0.23	0.37	0.46
ANCL	16.	35.	0.	0.	35.				0.0	0.0	0.0	0.0	1.00	0.0	0.0
ANCL	13.	39.	0.	0.	39.				0.0	0.0	0.0	0.0	1.00	0.0	0.0
ANT	148.	39.	0.	0.	39.				0.0	0.0	0.0	0.0	1.00	0.0	0.0
CNTL	28.	142.	1.	0.	282.				0.0	0.0	0.0	0.07	0.95	0.07	0.0
CNTL	123.	234.	1.	96.	259.				0.0	0.0	0.0	0.14	0.86	0.14	0.0
CNTL	573.	424.	36.	819.	2601.				0.38	0.12	0.0	0.21	0.30	0.39	0.50
DISP	1260.	187.	80.	2614.	3409.				0.36	0.14	0.0	0.10	0.38	0.20	0.32
SYSTEM TOTALS															
MK=24 ENV=SEA	6121.	3969.	492.	15060.	22559.	7484	363	250	0.22	0.31	0.03	0.09	0.36	0.22	0.60

TABLE 25. PHYSICAL DATA SUMMARY (SHIPBOARD DISPLAY #2)

PHYSICAL DATA SUMMARY

***SYSTEM: SHIPBOARD RADAR NO. 2

EQUIP TYPE	FAIL RATE	RI QTY	MODRI QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	FRACTION OF FAILURE RATE DUE TO RI TYPE ANAL	DIG	RF	PS	PP	ALIGN	PLUG
DISP	2060.	408.	188.	8830.	8857.	5701	141	215	0.24	0.66	0.0	0.14	0.02	0.73	0.16
SYSTEM TOTALS															
ENVRSEA	2060.	408.	188.	8830.	8857.	5701	141	215	0.24	0.60	0.0	0.14	0.02	0.73	0.16

TABLE 26. PHYSICAL DATA SUMMARY (GROUND RADAR #2)

PHYSICAL DATA SUMMARY

***SYSTEM: GROUND RADAR NO. 2

EQUIP TYPE	FAIL RATE	RI QTY	MODRI QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	ANAL	DIG	RF	PS	PP	ALIGN	PLUG
									FRACTION OF FAILURE RATE DUE TO RI TYPE						
P/S	42.	13.	6.	0.	13.				0.0	0.0	0.0	0.89	0.11	0.0	0.98
PERI	144.	5.	0.	0.	5.				0.0	0.0	0.0	0.0	0.01	0.0	0.0
SP	1803.	267.	107.	3663.	3656.				0.05	0.93	0.0	0.0	0.02	0.02	0.98
DISP	35.	113.	2.	32.	80.				0.0	0.17	0.0	0.0	0.83	0.0	0.17
COMP	157.	195.	49.	735.	1371.				0.0	0.77	0.0	0.0	0.23	0.0	0.71
COMP	174.	14.	14.	0.	0.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
XMTR	265.	278.	12.	645.	1016.				0.28	0.0	0.0	0.31	0.40	0.0	0.60
RCVR	112.	70.	18.	3.	66.				0.51	0.0	0.09	0.23	0.17	0.0	0.83
ANCL	99.	58.	19.	378.	464.				0.03	0.60	0.0	0.28	0.09	0.0	0.91
ANT	12.	5.	0.	0.	5.				0.0	0.0	0.0	0.0	1.00	0.0	0.0
DISP	178.	1.	0.	0.	0.				1.00	0.0	0.0	0.0	0.0	0.0	0.0
ANT	84.	11.	3.	0.	11.				0.30	0.0	0.0	0.0	0.70	0.0	0.0
ANCL	17.	40.	0.	1.	39.				0.0	0.0	0.0	0.0	1.00	0.0	0.0
SYSTEM TOTALS															
ENV=GRND	2322.	1062.	222.	5257.	6726.	9810	612	346	0.17	0.56	0.00	0.08	0.13	0.01	0.71

TABLE 27. PHYSICAL DATA SUMMARY (WEAPON DATA CONVERTER)

PHYSICAL DATA SUMMARY

***SYSTEM: WEAPON DATA CONVERTER

EQUIP TYPE	FAIL RATE	RI QTY	MODRI QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	FRACTION OF FAILURE RATE DUE TO RI TYPE: ANAL	DIG	RF	PS	PP	ALIGN	PLUG
SP	793.	381.	165.	9209.	23330.	2714	514	43	0.49	0.39	0.0	0.06	0.06	0.14	0.83
SYSTEM TOTALS															
ENV=SEA	793.	381.	165.	9209.	23330.	2714	514	43	0.49	0.39	0.0	0.06	0.06	0.14	0.83

TABLE 28. PHYSICAL DATA SUMMARY (RADAR DATA PROCESSOR)

PHYSICAL DATA SUMMARY

***SYSTEM: RADAR DATA PROCESSOR

MODULE TYPE	FAIL RATE	WT LBS	MODULE QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	FRACTION OF FAILURE RATE DUE TO HI TYPE: ANAL	DIG	RF	PS	PP	ALIGN	PLUG
SP	792.	275.	129.	3165.	5545.	2513	192	5	0.24	0.66	0.01	0.05	0.03	0.0	0.97
SYSTEM TOTALS															
[illegible]	792.	275.	129.	3165.	5545.	2514	192	5	0.24	0.66	0.01	0.05	0.03	0.0	0.97

TABLE 29. PHYSICAL DATA SUMMARY (AIRBORNE RADAR #1)

PHYSICAL DATA SUMMARY

***SYSTEM: AIRBORNE RADAR NO. 1

EQUIP TYPE	FAIL RATE	MI QTY	COMPT QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	FRACTION OF FAILURE RATE DUE TO RI TYPE: ANAL	DIG	RF	PS	PP	ALIGN	PLUG
RCVR	794.	1.	1.	65.	524.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
XMTR	2671.	1.	1.	434.	460.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
MLXR	135.	1.	1.	115.	578.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
ANT	2304.	1.	1.	44.	70.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
SP	1279.	1.	1.	555.	1295.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
SP	6625.	1.	1.	3649.	2676.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
COMP	1776.	1.	1.	2394.	3165.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
P/S	275.	1.	1.	205.	634.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
CNTL	100.	1.	1.	4.	23.				1.00	0.0	0.0	0.0	0.0	0.0	1.00
SYSTEM TOTALS															
ENV=AIR	15822.	9.	9.	7517.	9695.	N/A	N/A	N/A	0.09	0.53	0.37	0.02	0.0	0.0	1.09

TABLE 30. PHYSICAL DATA SUMMARY (COMMUNICATIONS TERMINAL)

PHYSICAL DATA SUMMARY

***SYSTEM: COMMUNICATIONS TERMINAL

EQUIP TYPE	FAIL RATE	RI QTY	HYBRI QTY	QTY ACTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	ANAL	DIG	RF	FS	FP	ALIGN	PLUG
									FRACTION OF FAILURE RATE DUE TO RI TYPE						
XMTR	1567.	98.	11.	552.	2157.				0.0	0.0	0.59	0.0	0.50	0.0	0.85
RCVR	475.	137.	9.	541.	694.				0.0	0.0	0.62	0.0	0.38	0.0	0.0
SP	1405.	54.	58.	5209.	6099.				0.65	0.67	0.0	0.0	0.28	0.0	0.92
CMP	651.	1.	1.	1645.	2525.				0.0	1.00	0.0	0.0	0.0	0.0	1.00
P/S	70.	39.	3.	204.	324.				0.0	0.0	0.0	0.67	0.33	0.0	0.0
P/S	71.	1.	1.	112.	277.				0.0	0.0	0.0	1.00	0.0	0.0	1.00
ANT	51.	1.	1.	8.	60.				0.0	0.0	1.00	0.0	0.0	0.0	1.00
CNTL	157.	195.	9.	473.	525.				0.0	0.25	0.0	0.06	0.67	0.0	0.09
SYSTEM TOTALS															
ENVRAIR	4447.	550.	93.	8744.	12661.	2590	268	57	0.01	0.39	0.25	0.03	0.32	0.0	0.76

TABLE 31. PHYSICAL DATA SUMMARY (GROUND RADAR #1)

PHYSICAL DATA SUMMARY

***SYSTEM: GROUND RADAR NO. 1

EQUIP TYPE	FAIL RATE	RI QTY	NON-RI QTY	QTY ALTIV	QTY PASS	QTY ICS	QTY LIN	QTY HYB	ANAL	DIG	RF	PS	PP	ALIGN	PLUG
									FRACTION OF FAILURE RATE DUE TO RI TYPE						
CISP	50.	47.	11.	341.	660.				0.0	0.87	0.0	0.0	0.13	0.02	0.46
SP	1255.	135.	240.	4424.	8259.				0.23	0.72	0.0	0.33	0.02	0.14	0.98
DISP	170.	113.	35.	1127.	1711.				0.09	0.56	0.6	0.12	0.23	0.19	0.60
MCYT	747.	142.	95.	1409.	5304.				0.58	0.07	0.46	0.08	0.01	0.09	0.39
ANT	643.	165.	23.	2777.	4911.				0.88	0.10	0.0	0.01	0.01	0.05	0.09
X-TR	467.	172.	20.	712.	1626.				0.04	0.19	0.0	0.0	0.77	0.0	0.25
COMP	476.	102.	44.	2.	8780.				0.00	0.99	0.0	0.0	0.90	0.0	0.99
PERI	350.	2.	2.	1.	0.				0.0	0.0	0.0	0.0	1.00	0.0	0.0
SYSTEM TOTALS															
ENVIGRND	4194.	1171.	500.	13926.	29181.	3429	88	41	0.29	0.42	0.09	0.03	0.18	0.08	0.56

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TABLE 32. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (WEAPON CONTROL SYSTEM)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: WEAPON CONTROL SYSTEM

EQUIP TYPE	PREDICTED REPAIR TIMES ISO	R/R	C/O	TOTAL	DEMO. REPAIR TIMES ISO	R/R	C/O	TOTAL	FAULT ISOLATION DATA RA	TYPA	RS	TYFS	RM	RI RESOLUTION RES1	RES3	AVG	OFIR	DIAG
HCVR	16.0	19.0	8.0	43.0	13.0	19.0	8.0	40.0	0.0	0.	1.00	63.	0.0	0.90	0.94	1.0	76.	1.1
XMTR	17.0	51.0	8.0	76.0	17.0	51.0	8.0	76.0	0.0	0.	1.00	63.	0.0	0.91	0.91	1.0	62.	1.6
F/S	19.0	15.0	8.0	42.0	18.0	13.0	9.0	41.0	0.0	0.	1.00	63.	0.0	0.78	0.96	1.2	15.	0.2
P/S	18.0	9.0	6.0	33.0	25.0	8.0	5.0	41.0	0.0	0.	1.00	63.	0.0	0.80	0.80	1.0	10.	0.1
P/S	21.0	4.0	8.0	33.0	27.0	4.0	8.0	39.0	0.0	0.	1.00	63.	0.0	0.90	1.00	1.1	3.	0.0
RCVR	14.0	17.0	6.0	37.0	1.0	17.0	8.0	26.0	0.0	0.	1.00	63.	0.0	0.94	0.97	1.0	60.	0.5
ANT	19.0	50.0	8.0	77.0	31.0	50.0	8.0	89.0	0.0	0.	1.00	63.	0.0	0.82	0.89	1.1	134.	2.3
SP	15.0	5.0	8.0	28.0	11.0	5.0	8.0	24.0	0.0	0.	1.00	63.	0.0	0.96	0.98	1.0	101.	2.1
SP	13.0	5.0	8.0	26.0	20.0	5.0	8.0	33.0	0.0	0.	1.00	63.	0.0	0.96	1.00	1.0	66.	1.0
SP	19.0	9.0	8.0	36.0	25.0	9.0	8.0	42.0	0.0	0.	1.00	63.	0.0	0.93	0.97	1.0	517.	4.4
SP	15.0	5.0	8.0	28.0	16.0	5.0	8.0	29.0	0.0	0.	1.00	63.	0.0	0.90	0.96	1.1	65.	2.1
RCVR	17.0	5.0	8.0	30.0	21.0	5.0	8.0	34.0	0.0	0.	1.00	63.	0.0	0.93	0.97	1.0	63.	0.6
CMP	17.0	5.0	9.0	31.0	33.0	5.0	8.0	46.0	0.0	0.	1.00	63.	0.0	0.78	0.98	1.2	99.	0.7
CMP	17.0	5.0	8.0	30.0	25.0	5.0	8.0	38.0	0.0	0.	1.00	63.	0.0	0.95	0.97	1.0	11.	0.6
CMP	16.0	5.0	8.0	29.0	28.0	5.0	8.0	41.0	0.0	0.	1.00	63.	0.0	0.88	0.93	1.1	214.	0.1
P/S	22.0	5.0	8.0	35.0	23.0	5.0	8.0	36.0	0.0	0.	1.00	63.	0.0	0.89	0.92	1.0	0.	0.0
CNTL	13.0	4.0	8.0	25.0	28.0	4.0	8.0	43.0	0.0	0.	1.00	63.	0.0	0.96	0.96	1.0	3.	0.7
CNT	5.0	4.0	8.0	17.0	16.0	4.0	8.0	28.0	0.0	0.	1.00	63.	0.0	0.78	0.89	1.1	1.	0.1
DISP	15.0	15.0	5.0	37.0	19.0	15.0	9.0	43.0	0.0	0.	1.00	63.	0.0	0.95	0.95	1.0	4.	0.2
CNTL	7.0	5.0	8.0	20.0	15.0	5.0	9.0	29.0	0.0	0.	1.00	63.	0.0	0.88	1.00	1.2	1.	0.1
DISP	14.0	24.0	4.0	42.0	27.0	24.0	8.0	59.0	0.0	0.	1.00	63.	0.0	0.94	0.94	1.0	0.	0.1
P/S	7.0	5.0	9.0	21.0	22.0	5.0	8.0	35.0	0.0	0.	1.00	63.	0.0	0.62	0.69	1.1	0.	0.0
P/S	15.0	5.0	4.0	24.0	25.0	5.0	6.0	36.0	0.0	0.	1.00	63.	0.0	0.86	0.89	1.0	3.	0.0
SP	15.0	125.0	4.0	144.0	46.0	125.0	8.0	179.0	0.0	0.	1.00	63.	0.0	0.96	0.94	1.0	79.	0.1
SP	16.0	125.0	[illegible]	144.0	67.0	125.0	[illegible]	206.0	0.0	0.	1.00	63.	0.0	0.97	0.97	1.0	21.	3.6
P/S	15.0	55.0	9.0	79.0	55.0	55.0	8.0	118.0	0.0	0.	1.00	63.	0.0	0.93	0.93	1.0	23.	1.0
SYSTEM TOTALS																		
ENVRAIP	15.2	32.2	9.0	54.7	24.4	32.4	8.0	64.8	0.0		1.00		0.0	0.91	0.94	1.1	1453.	24.1

TABLE 33. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (SHIPBOARD RADAR #2)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: SHIPBOARD RADAR NO. 2

EQUIP TYPE	PREDICTED REPAIR TIMES ISO	R/R	C/O	TOTAL	DEMO. REPAIR TIMES ISO	R/R	C/O	TOTAL	FAULT ISOLATION DATA NA	TYPA	RS	TYPS	RP	RI RESOLUTION RES1	RES3	AVG	UFIR	DIAG
XMTR	4.9	31.4	8.3	44.6	0.0	0.0	0.0	0.0	0.0	0.	0.17	3.	0.83	1.00	1.00	1.0	58.	1.0
SP	22.5	36.4	9.2	67.5	0.0	0.0	0.0	0.0	0.0	0.	0.46	3.	0.54	1.00	1.00	1.0	236.	0.8
SP	5.2	17.3	21.8	47.2	0.0	0.0	0.9	0.0	0.0	0.	0.69	3.	0.31	0.62	0.98	1.7	211.	1.2
COMP	29.6	16.1	5.9	35.6	0.0	0.0	0.0	0.0	0.0	0.	0.82	3.	0.18	0.88	0.97	1.2	339.	0.8
PERI	1.6	25.6	11.8	37.0	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
RCVR	22.4	12.6	7.0	41.4	0.0	0.0	0.0	0.0	0.0	0.	0.25	3.	0.75	1.00	1.00	1.0	228.	0.5
ANCL	1.0	10.0	6.0	19.0	0.9	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
ANCL	1.0	20.0	9.0	30.0	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
ANT	45.9	102.0	16.9	165.0	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
CNTL	9.3	19.4	9.1	36.9	0.0	0.0	0.0	0.0	0.0	0.	0.18	3.	0.86	1.00	1.00	1.0	1.	0.0
CNTL	17.1	21.7	7.2	45.0	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
CNTL	23.2	20.7	9.9	53.8	0.0	0.0	0.0	0.0	0.0	0.	0.85	3.	0.92	1.00	1.00	1.0	7.	0.0
DISP	21.6	33.4	4.0	59.0	0.0	0.0	0.0	0.0	0.0	0.	0.67	3.	0.33	0.94	0.96	1.0	181.	1.7
SYSTEM TOTALS																		
ENV=SEA	16.9	27.2	9.8	55.9	0.0	0.0	0.0	0.0	0.0		0.41		0.59	0.78	0.81	1.0	1241.	6.0

TABLE 34. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (SHIPBOARD DISPLAY #2)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: SHIPBOARD DISPLAY NO. 2

EQUIP TYPE	PREDICTED REPAIR TIMES				DEMO. REPAIR TIMES				FAULT ISOLATION DATA					RI RESOLUTION				DIAG
	ISO	R/R	C/O	TOTAL	ISO	R/R	C/O	TOTAL	KA	TYPA	KS	TYPS	KR	RES1	RES3	AVG	QFIR	
DISP	3.0	3.5	0.6	8.0	2.0	5.2	6.0	13.2	0.93	1.	0.83	3.	0.04	0.10	0.90	3.0	575.	16.0
SYSTEM TOTALS																		
ENV=SEA	3.0	3.5	0.6	8.0	2.0	5.2	6.0	13.2	0.93		0.03		0.04	0.10	0.90	3.0	575.	16.0

TABLE 35. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (GROUND RADAR #2)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: GROUND RADAR NO. 2

EQUIP TYPE	PREDICTED REPAIR TIMES ISO	R/R	C/O	TOTAL	DEMO. REPAIR TIMES ISO	R/R	C/O	TOTAL	FAULT ISOLATION DATA RA	TYPA	RS	TYPS	RR	MI RESOLUTION RES1	RES3	AVG	GFIR	DIAG
P/S	21.5	7.7	8.0	37.2	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
PEHI	11.3	5.6	8.0	24.9	7.4	2.1	0.5	10.0	0.9	0.	0.82	3.	0.58	0.0	0.0	0.0	0.	0.[illegible]
SP	6.7	6.1	7.1	19.9	3.7	0.4	0.4	4.5	0.83	1.	0.0	0.	0.17	0.45	0.81	2.3	448.	6.[illegible]
DISP	49.0	13.2	8.0	70.2	4.7	0.5	0.2	5.4	0.0	0.	0.17	3.	0.83	1.06	1.00	1.0	2.	0.[illegible]
COMP	21.1	7.3	8.0	36.4	12.2	0.8	2.6	15.6	0.0	0.	0.79	3.	0.21	0.60	0.93	1.6	1405.	2.[illegible]
COMM	19.0	3.0	8.0	39.0	0.0	0.0	0.0	0.0	0.0	0.	1.00	3.	0.0	0.0	0.0	0.0	0.	0.0
XMTR	29.3	9.7	6.0	45.4	18.2	14.8	8.9	41.9	0.0	0.	0.0	3.	1.00	0.0	0.0	0.0	0.	0.0
RCVR	24.1	7.2	8.0	39.3	9.3	5.4	5.3	20.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
ANCL	20.8	7.0	8.0	35.9	3.7	1.4	0.2	5.3	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
ANT	18.0	7.0	8.0	33.0	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
DISP	19.0	6.0	8.0	33.0	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
ANT	39.8	6.4	8.0	54.2	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
ANCL	34.0	12.0	8.0	54.0	0.0	0.0	0.0	0.0	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
SYSTEM TOTALS																		
ENVGRND	15.2	6.6	7.4	30.2	5.6	2.4	1.7	9.7	0.36		0.16		0.48	0.25	0.43	1.1	1855.	0.0

TABLE 36. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (WEAPON DATA CONVERTER)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: WEAPON DATA CONVERTER

EQUIP TYPE	PREDICTED REPAIR TIMES				DEMO. REPAIR TIMES				FAULT ISOLATION DATA					RI RESOLUTION				DIAG
	ISO	R/R	C/O	TOTAL	ISO	R/R	C/O	TOTAL	KA	TYPA	KS	TYPS	KM	RES1	RES3	AVG	QFIR	
SP	4.1	9.6	1.1	14.8	0.1	1.7	2.0	3.7	0.05	1.	0.06	3.	0.08	0.27	0.75	2.4	295.	4.0
SYSTEM TOTALS																		
ENV=SEA	4.1	9.6	1.1	14.8	0.1	1.7	2.0	3.7	0.05		0.06		0.08	0.27	0.75	2.4	295.	4.0

TABLE 37. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (RADAR DATA PROCESSOR)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: RADAR DATA PROCESSOR

EQUIP TYPE	PREDICTED REPAIR TIMES ISO	R/R	C/O	TOTAL	DEMO. REPAIR TIMES ISO	R/R	C/O	TOTAL	FAULT ISOLATION DATA FA	TYFA	KS	TYPS	RM	RI RESOLUTION RES1	RES3	AVG	QFIH	DIAG
SP	6.0	[illegible]	0.0	25.2	5.0	2.5	4.4	12.5	0.0	0.	0.95	3.	0.05	0.17	0.87	4.5	180.	0.0
SYSTEM TOTALS																		
ENV=GRND	0.0	0.0	0.0	25.2	5.0	2.5	4.3	12.5	0.0		0.95		0.05	0.17	0.87	4.5	180.	0.0

TABLE 38. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (AIRBORNE RADAR #1)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: AIRBORNE RADAR NO. 1

EQUIP TYPE	PREDICTED REPAIR TIMES				DEMO. REPAIR TIMES				FAULT ISOLATION DATA					RI RESOLUTION				DIAG
	ISO	R/R	C/O	TOTAL	ISO	R/R	C/O	TOTAL	KA	TYFA	KS	TYPS	KM	RES1	RES5	AVG	QFIR	
MCVR	5.0	4.0	1.0	10.0	4.0	4.0	5.0	13.0	0.26	1.	0.71	6.	0.01	0.95	0.95	1.0	7.	0.8
XMTR	5.0	55.0	1.0	61.0	0.0	55.0	5.0	60.0	0.05	1.	0.93	6.	0.62	0.99	1.00	1.0	6.	0.2
RCVR	5.0	4.0	1.0	10.0	4.0	4.0	5.0	13.0	0.19	1.	0.70	6.	0.11	0.75	1.00	1.4	6.	0.2
ANT	5.0	35.0	1.0	39.0	7.0	35.0	5.0	47.0	0.62	1.	0.11	6.	0.67	0.88	1.00	1.1	6.	0.2
SP	5.0	4.0	1.0	9.0	3.0	4.0	5.0	12.0	0.53	1.	0.13	6.	0.04	0.96	0.97	1.0	13.	0.4
SP	5.0	6.0	1.0	12.0	3.0	6.0	5.0	14.0	0.91	1.	0.00	6.	0.01	1.00	1.00	1.0	4.	0.8
COMP	5.0	6.0	1.0	12.0	3.0	6.0	5.0	14.0	0.93	1.	0.0	0.	0.07	0.99	1.00	1.0	17.	0.7
P/S	5.0	4.0	1.0	10.0	3.0	4.0	5.0	12.0	0.94	1.	0.0	0.	0.06	1.00	1.00	1.0	8.	0.4
CNTL	5.0	4.0	1.0	10.0	0.0	0.0	0.0	0.0	0.0	0.	0.17	0.	0.63	0.85	1.00	1.1	9.	0.5
SYSTEM TOTALS																		
CHASAIR	5.0	14.3	1.0	19.0	4.1	14.5	5.0	25.0	0.71		0.25		0.04	0.97	1.00	1.0	76.	4.2

TABLE 39. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (COMMUNICATIONS TERMINAL)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: COMMUNICATIONS TERMINAL

MAJOR TYPE	PREDICTED REPAIR TIMES ISO	R/R	C/O	TOTAL	DEMO. REPAIR TIMES ISO	R/R	C/O	TOTAL	FAULT ISOLATION DATA R2	TYP2	R3	TYP3	R4	FI RESOLUTION RES1	RES3	AVG	QFIR	DIAG
XMTR	11.0	8.2	2.0	21.2	0.0	0.0	0.0	0.0	0.50	1.	0.50	5.	0.0	0.85	0.99	1.3	10.	0.0
XCVR	7.3	14.5	2.0	25.5	0.0	0.0	0.0	0.0	0.62	4.	0.38	2.	0.0	0.96	0.96	1.0	6.	0.0
SP	1.7	6.1	1.4	9.2	0.0	0.0	0.0	0.0	0.97	1.	0.02	3.	0.01	0.85	0.98	1.3	35.	0.7
COMP	2.0	8.3	2.0	12.0	0.0	0.0	0.0	0.0	0.75	1.	0.25	5.	0.0	0.96	0.99	1.1	0.	0.4
P/S	8.3	11.7	2.0	22.0	0.0	0.0	0.0	0.0	0.0	0.	1.00	5.	0.0	0.69	0.94	1.5	0.	0.0
F/S	5.0	2.0	2.0	9.0	0.0	0.0	0.0	0.0	1.00	2.	0.0	0.	0.0	0.99	1.00	1.0	2.	0.0
ANT	5.0	11.0	2.0	18.0	0.0	0.0	0.0	0.0	0.0	0.	1.00	3.	0.0	0.93	0.99	1.1	0.	0.0
CNTL	8.7	13.2	2.5	24.4	0.0	0.0	0.0	0.0	0.56	14.	0.80	3.	0.0	0.98	0.99	1.0	14.	0.0
SYSTEM TOTALS																		
ENVSIM	6.0	8.5	1.9	16.4	0.0	0.0	0.0	0.0	0.65		0.31		0.00	0.89	0.99	1.2	67.	1.3

TABLE 40. MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY (GROUND RADAR #1)

MAINTAINABILITY AND FAULT ISOLATION DATA SUMMARY

***SYSTEM: GROUND RADAR NO. 1

EQUIP TYPE	PREDICTED REPAIR TIMES				DEMO. REPAIR TIMES				FAULT ISOLATION DATA					RI RESOLUTION				DIAG
	ISO	R/R	C/O	TOTAL	ISO	R/R	C/O	TOTAL	KA	TYPA	KS	TYPS	KM	RES1	RESS	AVG	UFIR	
DISP	12.3	17.8	6.5	36.6	12.8	1.4	1.8	16.0	0.0	0.	0.65	0.	0.35	0.74	1.00	1.3	39.	2.0
SP	12.1	15.6	5.5	32.3	7.7	1.9	1.5	11.1	0.38	0.	0.30	0.	0.32	0.28	0.83	2.4	105.	4.0
DISP	13.2	15.4	6.5	35.1	5.2	2.4	1.0	8.6	0.0	0.	0.18	0.	0.80	0.94	1.00	1.1	17.	0.0
RCVR	11.1	13.4	6.4	30.9	5.5	1.0	3.1	7.7	0.0	0.	0.0	0.	1.00	0.0	0.0	0.0	0.	0.0
ANT	11.3	[illegible]	6.2	25.5	4.2	2.5	0.5	7.2	0.04	0.	0.0	0.	0.96	0.29	0.65	2.2	17.	0.0
XMTR	[illegible]	36.[illegible]	[illegible]	47.[illegible]	9.7	2.6	0.8	12.5	0.0	0.	0.25	0.	0.75	1.00	1.00	1.0	34.	0.0
COMP	5.0	9.1	6.0	23.1	4.9	1.7	1.1	7.7	0.0	0.	0.79	0.	0.21	0.60	0.93	1.6	1405.	2.0
PERI	4.0	10.0	6.3	24.5	7.7	3.7	0.5	11.7	0.0	0.	1.00	0.	0.0	1.00	1.00	1.0	7.	0.0
SYSTEM TOTALS																		
ENVSGRND	13.8	14.6	6.7	35.2	6.2	2.[illegible]	1.4	9.0	0.12		0.30		0.57	0.42	0.70	1.5	1624.	8.0

3.2 MAINTENANCE CONCEPT DATA

Included as part of the data collected for this study was a definition of the maintenance concepts currently followed for military electronic systems. This data was collected to determine if (and how) the maintainability prediction model(s) and/or prediction procedure is affected by different maintenance concepts.

The maintenance concepts of twelve systems were reviewed. The results of the review indicate that maintenance concepts can generally be defined by the type of system (avionics, ground electronics, shipboard electronics) and the maintenance environment involved. Figure 12 shows the 7 unique maintenance environments into which the 12 systems reviewed were categorized. The maintenance concept associated with each of the 7 environments are defined in Tables 41 through 43.

The tables are segregated by type of system and provide the following information:

1. Installation – The environment in which the system is installed and operates and generally (excepting small aircraft) where the organizational level maintenance is performed.
2. Maintenance Level – The levels at which maintenance is performed.
3. F.D. Type – The primary method of fault detection. In all cases Built in Test capability was the primary method.
4. F.I. Type – The primary method of fault isolation at the indicated maintenance level. Defined as automatic (A), Semi-automatic (S), Manual (M), or combination thereof.
5. Repair Level – The hardware level at which repair is performed for the subject maintenance level.
6. R/R Level – The type(s) of replaceable items typically removed at the subject maintenance level.
7. Repair Location – The location at which the repair is accomplished for the subject maintenance level.
8. Sources – The system(s) from which the defined maintenance concept was extracted. The service organization associated with each system is identified in parenthesis.

In general the maintenance concepts reviewed do not impair the developed maintainability prediction models or procedures. An impact could be realized if logistic delays were defined as part of the MTTR. In this case the model would have to account for the operating location, the repair location, the type of transportation, the availability of spares, etc. These factors are not considered pertinent to inherent maintainability and are not addressed in this report.

One maintenance factor that does affect a system's maintenance time is the repair policy. If the fault isolation capability isolates a fault to a group of RIs (vice a single RI), there are two paths a maintenance technician can follow. One, he could replace all the RIs in the group, or he could replace the RIs one by one until the fault has been corrected. The detailed prediction model accounts for the repair policy in the maintenance flow diagram and the assignment of Knj (refer to section 5.1.5). For the early prediction procedure, the prediction models used for spare retrieval time, disassembly/reassembly time, interchange time, and checkout time vary depending on the repair policy (refer to section 5.2.4).

Table 44 summarizes the repair policies for each system reviewed.

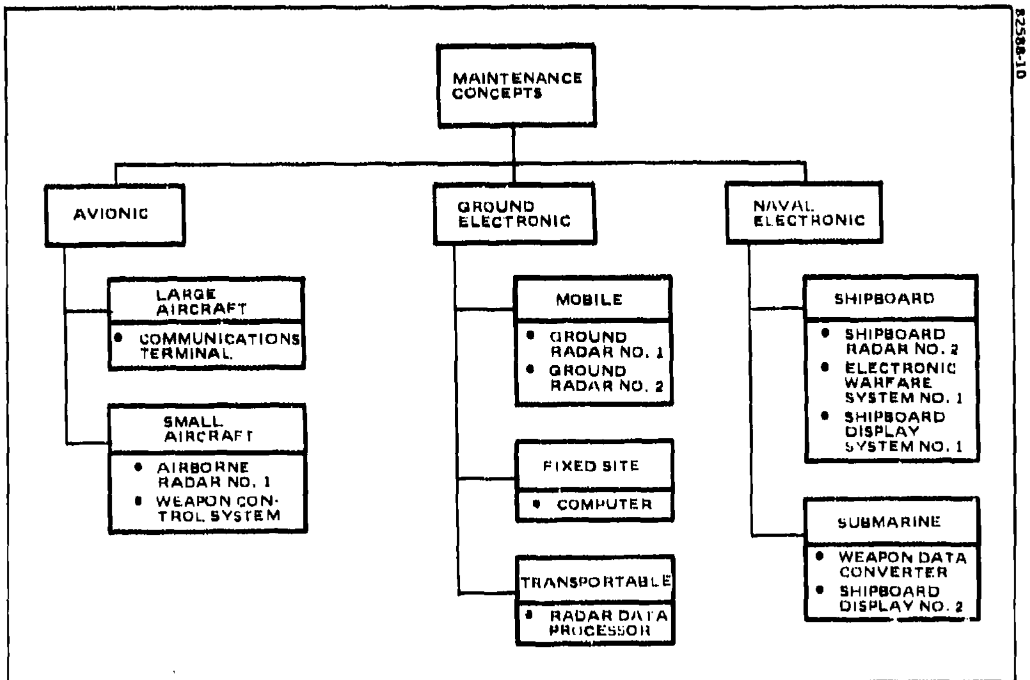

Figure 12. Categorization of Maintenance Concepts for Surveyed Systems

TABLE 41. MAINTENANCE CONCEPTS OF AVIONIC EQUIPMENT

Installation	Maint. Level	F.D. Type	F.I. Type	Repair Level	R/R Level	Repair Location	Sources
Large Aircraft	In Flight	BIT	A	System	Units & Cards	In Flight	Communications terminal (USAF)
	Flight Line	BIT	A, S&M	System	Units, Cards & Parts	Flight Line	
	Intermediate		A&M	Unit	Cards	Field Shop	
	Depot		S&M	Units & Cards	Parts	Remote Facility	
Small Aircraft	In Flight	BIT	A	–	–	–	Airborne Radar #1 (USAF)
	Flight Line	BIT	A&M	Sys.	Units & Parts	Flight Line	Weapon Control System
	Intermediate		A&M	Units	Cards & Parts	Field Shop	(NAVAIR)
	Depot		S&M	Cards & Assemblies	Parts	Remote Facility	

A = automatic
S = semi-automatic
M = manual

TABLE 42. MAINTENANCE CONCEPTS OF GROUND ELECTRONIC EQUIPMENT

Installation	Maint. Level	F.D. Type	F.I. Type	Repair Level	R/R Level	Repair Location	Sources
Mobile	Organizational	BIT	A, S&M	System	Cards & Parts	On Site	Ground Radar #1 (ARMY)
	Direct Support		S&M	System	Cards & Parts	On Site (Mobile Unit)	Ground Radar #2 (ARMY)
	General Support		S&M	System	Cards & Parts	Field Shop	
	Depot		A	Card	Parts	Remote Facility	
Trans-portable	Organizational	BIT	A&M	System	Cards	On Site	Radar Data Processor
	Depot		A	Card	Parts	Remote Facility	(USAF)
Fixed	Operator	BIT	A	–	–	–	Computer
	Organizational		A&S	System	Card	On Site	(USAF)
	Depot		S	Card	Parts	Remote Facility	

A – automatic
S = semi-automatic
M = manual

TABLE 43. MAINTENANCE CONCEPTS OF NAVAL EQUIPMENT

Installation	Maint. Level	F.D. Type	F.I. Type	Repair Level	R/R Level	Repair Location	Sources
Shipboard	Organizational	BIT	A, S, &M	System	Cards, Assembly & Parts	On Site	(NAVY) (NAVY) (NAVY)
	Intermediate		M	Cards & Assembly	Parts	Shore Facility or Tender	Shipboard Radar #2 (NAVY) Electronic Warfare #1 (NAVY) Electronic Warfare #2 (NAVY)
	Depot		M	Cards	Parts	Remote Facility	
Submarine	Organizational	BIT	A&S	System	Card, Assembly & Parts	On Site	(NAVY) Weapon Data Converter (NAVY) Shipboard Display System #2 (NAVY)
	Intermediate		A&M	System	Parts	On Site (In Port)	
	Depot		M	Card	Parts	Remote Facility	

A = automatic
S = semi-automatic
M = manual

TABLE 44. REPLACEMENT POLICIES OF THE SYSTEMS REVIEWED

System	Group RI Replacement	Iterative RI Replacement
Ground Radar #1		*
Ground Radar #2		*
Radar Data Processor	*	
Shipboard Radar #2		*
Electronic Warfare #2		*
Shipboard Display #2	*	
Airborne Radar #1		*
Communications Terminal		*
Shipboard Display #1	*	
Weapon Data Converter		*
Weapon Control		*
Computer	*	

SECTION 4.0 TIMES STANDARDS

This part of the final report addresses the time standards survey and modification task. The time standards task was part of the basic study contract but is treated as a separate entity because of its relative independence from the remainder of the study. The task is an integral part of the study however, as the resulting time standards are used as inputs in computing disassembly, interchange, and reassembly times for the corrective maintenance time predictions. The objective was to perform an investigation and survey of all available time standards (appropriate to measures of physical actions required to correct an electronic equipment malfunction), and to determine those most appropriate to modern era designs and packaging concepts. A further objective was to establish a composite set of time standards using existing standards and modified standards as appropriate or, where existing standards do not exist, establish new standards. An additional objective was to identify time standards differences for avionics, ground electronics and shipboard electronics and to develop appropriate maintenance environment factors.

The approach used to accomplish the stated objectives was:

1) Survey existing maintenance time standards
2) Examine all tasks associated with corrective maintenance and determine which are appropriate candidates for time standardization.
3) Where applicable, correlate time standardization candidates with existing time standards
4) For remaining time standardization candidates, collect sufficient data to assess and assign an appropriate standard time
5) Analyze data collected to validate results
6) Develop factors to be used in conjunction with the time standards which will provide appropriate consideration for different maintenance environments.

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4.1 TIME STANDARDS SURVEY

An extensive literature search was performed to find existing data on maintenance time standards. The primary sources used for this literature search were:

1. Defense Documentation Center (DDC)
2. NASA Scientific and Technical Information Division
3. Hughes Aircraft Technical Library

The results showed that there have been many times standards developed to date but few are applicable to maintainability prediction. The majority of standards have been prepared for industrial time standards or by the human factors community for response/reaction type analyses, but these could not be applied to corrective maintenance actions. Table 45 summarizes the results of the literature search.

After reviewing the maintenance time standards available, it was concluded that the most complete and current standards available were included in RADC-TR-70-89 (Maintainability Prediction and Demonstration Techniques). This data was therefore used as the basis for the set of time standards presented herein.

TABLE 45. SURVEY OF CURRENT TIME STANDARD DATA AVAILABLE

Report Name and Author	Date Published	Comments
1. Maintainability Prediction and Demonstration Techniques, RADC-TR-70-89, ARINC Research Corporation	1970	Good but does not have time for some modern packaging techniques
2. Index of Electronic Equipment Operability, American Institute for Research	1962	Provides times to read instrument scales of different complexity; not generally applicable
3. Electronics Industry Cost Estimating Data, Hartmeyer, F.C.	1964	Provides times for industry work, not applicable to corrective maintenance
4. Maintainability Handbook, MIL-HDBK-472	1966	Basically out of date
5. Methods-Time-Measurement, Methods Engineering Council	1948	Breaks maintenance actions down too far (e.g. time to move arm)
6. Motion-Times-Standards, General Electric Company	1950	Breaks maintenance down too far
7. Analysis of Maintenance Task Time Data, RADC-TDR-64-373; Chrysler Corporation, Missile Division	1964	Field data for repair of mechanical components, not generally applicable to maintenance of current electronic equipment
8. Dimension Motion Time, General Electric Company	1950	Breaks maintenance down too far
9. Producibility Manual, Hughes Aircraft Company	1974	Provides time standards for assembly line work, not applicable to corrective maintenance

4.2 PHYSICAL TASK ANALYSIS

The objective of this task was to determine what maintenance actions could be standardized. Also, of these maintenance actions, which ones were not already tabulated in Maintainability Prediction and Demonstration Techniques, RADC-TR-70-89.

This task was accomplished by reviewing the maintenance procedures and available technical manuals of the systems selected for use in the study. The maintenance actions were screened in the following manner. First, all the unique physical type tasks were identified and tabulated. Second, an assessment was made of the feasibility of establishing a time standard in the identified tasks. The final step was to determine whether a time standard existed and was applicable.

Table 46 is a listing of the unique tasks that were identified. The table also shows which tasks are considered viable candidates for standardization and which tasks have an existing applicable time standard.

TABLE 46. PHYSICAL TASK ANALYSIS

Task Description	Time Standard Applicable	Time Standard Exists	Task Description	Time Standard Applicable	Time Standard Exists
Lubrication	No		R/R circuit card assembly (CCA)	Yes	Yes
Run computer diagnostic	No		R/R blower fan	No	
Check power supply voltage with meter	No		R/R power supply	No	
Adjust power supply voltage	No		R/R screws/bolts	Yes	Yes
Visual inspection	No		R/R panels	Yes	Yes
Observe indicators	No		Identify components	No	
Type in test sequences	No		R/R connectors	Yes	Yes
Load fault isolation program	No		R/R snap fasteners	Yes	No
Actuate a switch	Yes	No	R/R nuts	Yes	Yes
Interpret display results	No		Solder	Yes	Yes
R/R fuse	Yes	No	Desolder	Yes	Yes
			Engage/disengage latches	Yes	Yes
			Open/close doors	Yes	Yes

Note: R/R = Remove and Replace

TABLE 46. PHYSICAL TASK ANALYSIS (Continued)

Task Description	Time Standard Applicable	Time Standard Exists
R/R control knobs	Yes	Yes
R/R 1/4 turn latches	Yes	Yes
R/R heat sink compound	Yes	No
Loosen/tighten set Screws	Yes	No
R/R flex coupling	Yes	No
R/R lamps	Yes	No
Observe LED indicators	No	
R/R cable clamps	Yes	No
R/R TWT	No	
R/R cable ties	Yes	No
R/R semi-rigid coax	Yes	No
Torque bolts down	Yes	No
Align boresight telescope	No	
R/R retaining rings	Yes	No
Level trailer with level jacks	No	
R/R quick release pins	Yes	No
Observe waveforms	No	
Compare waveforms with manual	No	
Adjust trimmers	No	
Repair scratched or gouged etch (PCB)	No	
R/R conformal coating	Yes	No
Clean surface of CCA	Yes	No

Task Description	Time Standard Applicable	Time Standard Exists
Apply soldering paste	Yes	No
R/R epoxy	Yes	No
R/R of axial component from CCA	Yes	No
R/R of transistors from CCA	Yes	Yes
R/R IC flatpacks from CCA	Yes	No
R/R of IC DIPs from CCA	Yes	No
R/R of IC DIPs from sockets	Yes	No
R/R of relays	No	
Replace coolant	No	
Clean air filter	No	
Adjust pots	No	
Lubricate bearings	No	
Observe fault indications	No	
Initiate built in test	No	
Interpret BIT results	No	
Connect RI to test equipment	No	
R/R ATR latches	Yes	No
R/R butterfly latches	Yes	No
R/R Tridair fasteners	Yes	No
R/R snap on connectors	Yes	No
R/R wirewrap connections	Yes	No
R/R termipoint connections	Yes	No
R/R crimp-on terminal lug	Yes	No

Note: R/R = Remove and Replace

TABLE 46. PHYSICAL TASK ANALYSIS (Continued)

Task Description	Time Standard Applicable	Time Standard Exists	Task Description	Time Standard Applicable	Time Standard Exists
R/R CCA w/tool	Yes	No			
R/R CCA w/jack screw	Yes	No			
R/R connectors w/jack screw	Yes	No			

Note: R/R = Remove and replace

4.3 DATA COLLECTION

For those items identified in the previous section as candidates for assignment of standard times, without available existing standards, a data collection effort was undertaken. Data was collected on an as-available basis from sources approximating a true maintenance environment. Data was not collected by using formal testing procedures, or from manufacturing/assembly areas, on the basis that any data collected would not be representative of a maintenance environment. Data was collected from the following sources:

1) Hughes IRAN (inspect and repair as necessary) shops
2) Hughes depot facilities
3) Repairs accomplished in Hughes rework areas
4) Repairs accomplished on installed equipment as reported in failure/ maintenance reports.

It was found that the data collected on failure reports was not provided to the level required and this data was discarded.

For the data collected, a goal of twenty samples for each unique task was established. The actual data collected was a function of sample availability. For each sample, the following information was recorded:

1) The appropriate task(s) to which the data applied
2) The quantity of actions (if more than a single action of the same type was accomplished)
3) The elapsed time for removal, replacement and/or total task accomplishment
4) Remarks (e.g. special tools required, fixtures required).

The total set of data collected is provided in Appendix D.

4.4 DATA ANALYSIS

The data collected for establishment of time standards was analyzed in two ways. First, the raw data was examined to define the sample mean, variance and distribution characteristics for each task type. Secondly an analysis was performed to establish confidence bounds on the data collected based on the sample size of each task.

4.4.1 Histogram Analysis

The raw data was evaluated to determine the sample mean (θ), standard deviation (σ), and apparent distribution of each task type. The mean and standard deviation were compiled from:

$$\theta = \frac{\sum_{i=1}^{N} t_i}{N}$$

$$\sigma = \sqrt{\frac{N\Sigma(t_i^2) - (\Sigma t_i)^2}{N^2}}$$

where

t_i = observed time for the ith sample

The apparent distribution of the raw data, by task type, was determined using a computer program to plot a histogram of the data. The plots were made to determine the relative shape of the distributions and the modal characteristics. The plots were expected to be unimodal with a normal or log normal shape. Multimodal distributions, if they had occurred, would have been indicative of bad raw data or the need for further analysis. Figure 13 shows the histogram for one set of data. As shown, the distribution is unimodal, and looks like a log normal distribution. Most of the collected data sets exhibited an apparent normal or lognormal distribution.

4.4.2 Confidence Estimates

In order to assure that the means computed from the data collected were good estimates of the true means an analysis of the confidence bounds was performed. From the previous section, the distribution of each set of data collected was assumed lognormal. A random sample of twenty data sets was selected and the mean (μ) and standard deviation (σ) of the logarithms of each data set were computed. The quotient σ/μ for each data set was determined, and the average σ/μ was computed for the entire random sample. The computed average was, $\sigma/\mu = 0.13\mu$.

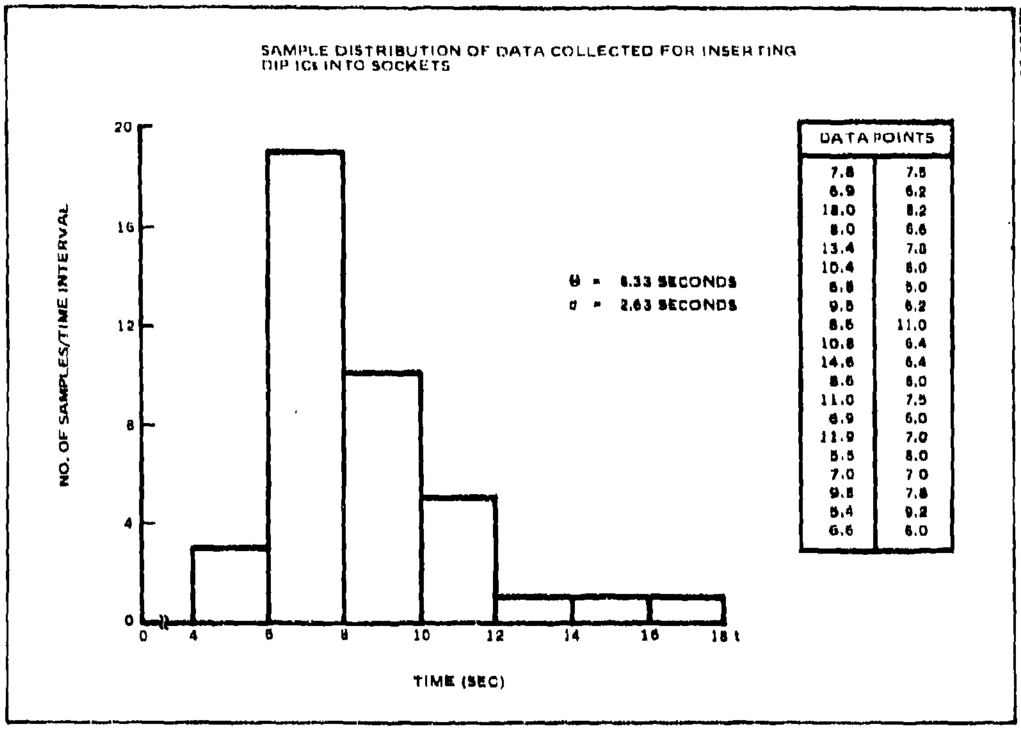

Figure 13. Sample Histogram of Data Collected

The computed average was then used in the following equation to determine the approximate confidence bound for various sample sizes:

$$\text{confidence limit} = \text{antilog}\ (\mu + \sigma T/\sqrt{N})^{*}$$

where:

N = sample size

μ = the sample mean

σ = the sample standard deviation

T = the 0.975 quantile of the t-distribution with N-1 degrees of freedom

The analysis was performed using logorithms (e.g. the antilog of each computed confidence limit was not taken) since the analysis was performed with qualitative data (e.g. σ/μ as a ratio with respect to μ, instead of actual numbers).

The results shown in Table 47 show that the goal of twenty samples for each data set gives a good approximation of the true mean and that a sample size of ten also gives a good approximation.

TABLE 47. VARIATIONS IN THE 95TH PERCENTILE CONFIDENCE BOUNDS DUE TO THE SAMPLE SIZE

Sample Size	Size of Confidence* Interval
5	0.30μ
10	0.18μ
15	0.14μ
20	0.12μ
25	0.11μ
30	0.10μ
35	0.09μ
40	0.08μ

* These computed values are based on a σ/μ = 0.13μ determined from a random sample of twenty data sets. Also the confidence interval size is presented in terms of $\log_{10}$ since the interval size varies at different portions of a lognormal axis.

4.5 TIME STANDARDS

The results of the time standards survey and modification have been tabulated in Table 48. The times tabulated in Table 48 have corresponding figures referenced which illustrate what each time represents. In addition to the basic time standards, table 49 contains composite times of common maintenance actions that may occur. The times tabulated in this table were synthesized from table 48. Columns two and four of table 49 denote which times of table 48 were used to synthesize each activity (letters denote removal (A) and replacement (B) times).

Other maintenance tasks can easily be synthesized by the following method.

1. list the actions involved for the maintenance task
2. obtain the times for each action by using table 48 (times that are not listed should be established either by actual data, time studies, or engineering judgement)
3. compute the time by summing up each individual time

The following is an example of how the procedure is implemented:

REMOVAL/REPLACEMENT OF A 16 PIN DIP IC

	Quantitity	Unit Time	Total Time
• desolder leads	16	0.16 min.	2.56 min.
• remove 16 pin IC	1	0.90	0.90
• clean PCB	1	0.29	0.29
• insert new IC	1	0.86	0.86
• solder 16 pins	16	0.06	0.96
• clip leads	16	0.03	0.48
• clean PCB	1	0.29	0.29
			6.34 min.

*See Reliability Engineering, Arinc Research Corporation 1964, pages 155-156

TABLE 48. ELEMENTAL MAINTENANCE ACTIONS

Time Standard Number	Description	Standard Times Remove (min.)	Standard Times Replace (min.)	Standard Times Interchange (min.)	Reference Figure
	FASTENERS				
1	Standard Screws	0.16	0.26	0.42	14
2	Hex or Allen Type Screws	0.17[2]	0.43[1]	0.60[1]	15
3	Captive Screws	0.15[1]	0.20[1]	0.35[1]	16
4	Dzus (1/4 Turnlock)	0.08	0.05	0.13	17
5	Tridair Fasteners	0.06	0.06	0.12	18
6	Thumbscrews	0.06[1]	0.08[1]	0.14[1]	19
7	Machine Screws	0.21	0.46	0.67	20
8	Nuts or Bolts	0.34	0.44	0.78	21
9	Retaining Rings	NA	0.27	NA	22
	LATCHES				
10	Drawhook	0.03	0.03	0.06	23
11	Spring Clip	0.04	0.03	0.07	24
12	Butterfly	0.05	0.05	0.10	25
13	ATR (spring loaded, pair)	0.45	0.69	1.14	26
14	Lift & Turn	0.03	0.04	0.07	27
15	Slide Lock	NA	NA	NA	28
	TERMINAL CONNECTIONS				
16	Terminal Posts (per lead)	0.22	0.64	*	29
17	Screw Terminals	0.23	0.45	0.68	30
18	Termipoint	0.22	0.30	*	31
19	Wirewrap	0.09	0.24	*	32
20	Taperpin	0.07[2]	0.07[2]	0.14[2]	33

TABLE 48. ELEMENTAL MAINTENANCE ACTIONS (Continued)

Time Standard Number	Description	Standard Times: Remove (min.)	Standard Times: Replace (min.)	Standard Times: Interchange (min.)	Reference Figure
	TERMINAL CONNECTIONS (cont.)				
21	PCB a) Discretes	0.14[3]	0.17[3]	*	34
22	b) Flatpacks	0.14[3] per lead	0.1[illegible][3] per flatpack	*	34
	c) DIP ICs				
23	• 8 pin	0.46[3]	0.52[3]	*	34
	• 14 & 16 pin	0.90[3]	0.86[3]	*	34
	CONNECTORS				
25	BNC (single pin)	0.07	0.10	0.17	35
26	BNC (multi pin)	0.07	0.12	0.19	35
27	Quick Release Coax	0.04	0.04	0.08	36
28	Friction Locking	NA	NA	NA	37
29	Friction Locking with one Jack Screw	0.18	0.20	0.38	38
30	Thread Locking	0.09	0.17	0.26	39
31	Slide Locking	0.09	0.12	0.21	40
	PLUG IN MODULES				
32	DIP ICs (into DIP sockets)	0.07	0.14	0.21	41
	CCAs (without tool) (guided)				
	• 40 pin	NA	NA	NA	42
33	• 80 pin	0.04	0.07	0.11	42
	CCAs (with tool) (guided)				
34	• 40 pin	0.06	0.07	0.13	43
35	• 80 pin	0.09	0.08	0.17	43

TABLE 48. ELEMENTAL MAINTENANCE ACTIONS (Continued)

Time Standard Number	Description	Standard Time Remove (min)	Replace (min.)	Interchange (min.)	Reference Figure
	PLUG IN MODULES (cont.)				
	CCAs (without tool) (not guided)				
	• 40 pin	NA	NA	NA	44
36	• 80 pin	0.04	0.16	0.20	44
37	Modules	0.09	0.11	0.20	45
	MISCELLANEOUS				
38	Strip Wire	–	–	0.10	–
39	Cut Wire of Sleeving	–	–	0.04	–
40	Dress Wire with Sleeving	–	–	0.21	–
41	Crimp Lugs	–	–	0.27	46
42	Form Leads (per lead)	–	–	0.03	47
43	Trim Leads (per lead)	–	–	0.03	–
44	Adhesives	0.55[4]	0.13[4]	0.68[4]	–
45	Conformal Coating	2.20[4]	0.23[4]	2.43[4]	–
46	Soldering A) Terminal Posts	–	–	0.22	48
47	B) PCB	–	–	0.06	49
48	Reflow Soldering	–	–	0.25	–
49	Tinning Flatpacks (dipping)	–	–	0.30	–
50	Desoldering A) Braided Wick	–	–	0.16	50
51	B) Solder Sucker	–	–	0.09	51
52	Form Flatpack Leads (Mechanically)	–	–	0.11	52
53	Clean Surface	–	–	0.29[4]	–
54	Panels, Doors, & Covers	0.04	0.03	0.07	53

TABLE 48. ELEMENTAL MAINTENANCE ACTIONS (Continued)

Time Standard Number	Description	Standard Time Remove (min.)	Replace (min.)	Interchange (min.)	Reference Figure
	MISCELLANEOUS (cont.)				
55	Drawers (Large)	0.09	0.10	0.19	54
56	Display Lamps	0.10	0.11	0.21	55
57	Threaded Connector Covers	0.11	0.14	0.25	–

1. data obtained from RADC-TR-70-89, Maintainability Prediction and Demonstration Techniques
2. data obtained from Hartmeyer, F.C., Electronic Industry Cost Estimating Data
3. does not include soldering/desoldering
4. these times apply to small areas

NA - no data available

* indicates that other times are involved in the interchange activity

TABLE 49. COMMON MAINTENANCE TASKS

Description	Elements of Removal*	Remove (min.)	Elements of Replacement*	Replace (min.)	Interchange (min.)
1. R/R of transistor from a PCB	50(3), 21A(3), 53	1.19	42(3), 21B(3), 47(3), 43(3), 53	1.16	2.35
2. R/R of a transistor from terminal posts	50(3), 16A(3), 53	1.43	42(3), 16B(3), 43(3), 46(3), 53	3.05	4.48
3. R/R of an axial component from a PCB	50(2), 21A(2), 53	0.89	42(2), 21B(2), 47(2), 43(2), 53	0.87	1.76
4. R/R of an axial component from terminal posts	50(2), 16A(2), 53	1.05	42(2), 16B(2), 43(2), 46(2), 53	1.69	2.74
5. R/R of a radial component from a PCB	50(2), 21A(2), 53	0.89	21B(2), 43(2), 47(2), 53	0.81	1.70
6. R/R of a radial component from terminal posts	50(2), 16A(2), 53	1.05	42(2), 16B(2), 43(2), 46(2), 53	1.69	2.74
7. R/R of a termi-point connection	18A	0.22	39, 20B	0.34	0.56
8. R/R of a wirewrap connection	19A	0.09	39, 38, 19B	0.38	0.47
9. R/R of a 16 pin IC from a PCB	50(16), 24A, 53	3.75	24B, 47(16), 43(16), 53	2.59	6.34
10. R/R of a 16 pin flatpack	50(16), 22A(16), 53	5.09	49, 52, 22B, 48, 53	1.08	6 17
11. R/R an 8 pin IC from a PCB	50(8), 23A, 53	2.03	23B, 47(8), 43(8), 53	1.53	3.56

*Numbers in these columns pertain to the time standard numbers in Table 48. A and B refer to removal and replacement times respectively. The number in parentheses refers to the quantity of each action.
R/R = removal and replacement

STANDARD SCREWS

- THIS TIME IS FOR ALL STANDARD THREADED FASTENERS SUCH AS; SLOTTED HEAD, PHILLIPS HEAD, AND FILLISTER HEAD
- THE TIME GIVEN IS THE TIME REQUIRED TO REMOVE/ REPLACE THE FASTENER FROM THE HOLE AND DISENGAGE/ OR ENGAGE IT BY SEVERAL TWISTING MOTIONS OF THE HAND (APPROXIMATELY 8 TWISTS)
- TOOL REQUIRED IS STANDARD SCREWDRIVER (FLAT HEAD, PHILLIPS, OR HEX)

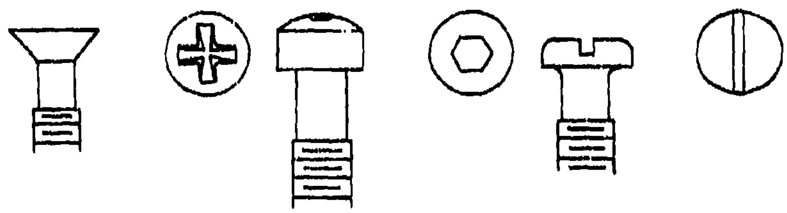

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Figure 14. Standard Screws

HEX OR ALLEN SET SCREWS

- THIS TIME IS FOR HEX OR ALLEN TYPE SET SCREWS
- THE TIME GIVEN IS FOR THE TIME TO TIGHTEN/ OR LOOSEN A HEXAGONAL TYPE SET SCREW USING AN ALLEN TYPE WRENCH
- TOOLS REQUIRED ARE HEX WRENCHES OR ALLEN TYPE WRENCHES

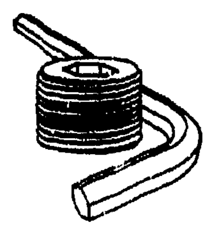

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Figure 15. Hex or Allen Set Screws

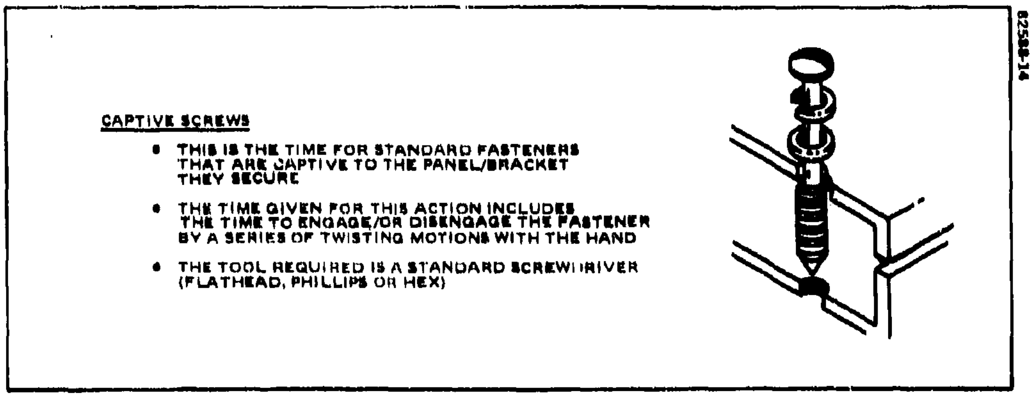


Figure 16. Captive Screws

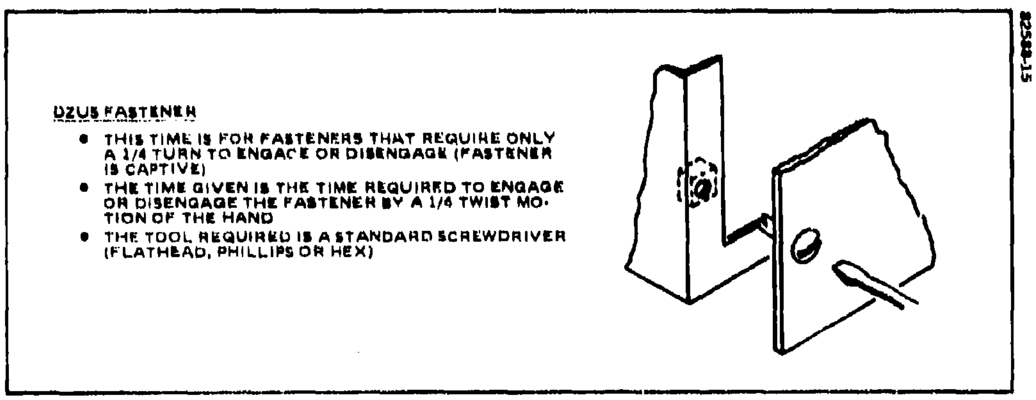
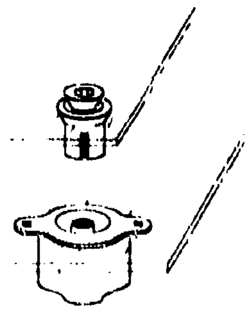


Figure 17. DZUS Fasteners

TRIDAIR FASTENER

- THIS FASTENER IS A QUICK ENGAGING FASTENER THAT REQUIRES LESS THAN ONE TURN
- THIS TIME INCLUDES THE TIME NECESSARY TO ENGAGE/OR DISENGAGE THE FASTENER USING A TURN OF THE HAND
- THE TOOL REQUIRED IS AN ALLEN WRENCH

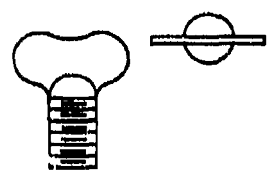


82588-16

Figure 18. Tridair Fastener

THUMBSCREWS

- THIS FASTENER IS A THREADED SCREW WITH A HEAD THAT CAN BE GRASPED EASILY BY THE HAND
- THIS TIME INCLUDES THE TIME NECESSARY TO DISENGAGE/OR ENGAGE THE FASTENER BY TURNING IT WITH THE HAND
- NO TOOLS REQUIRED



82588-17

Figure 19. Thumbscrews

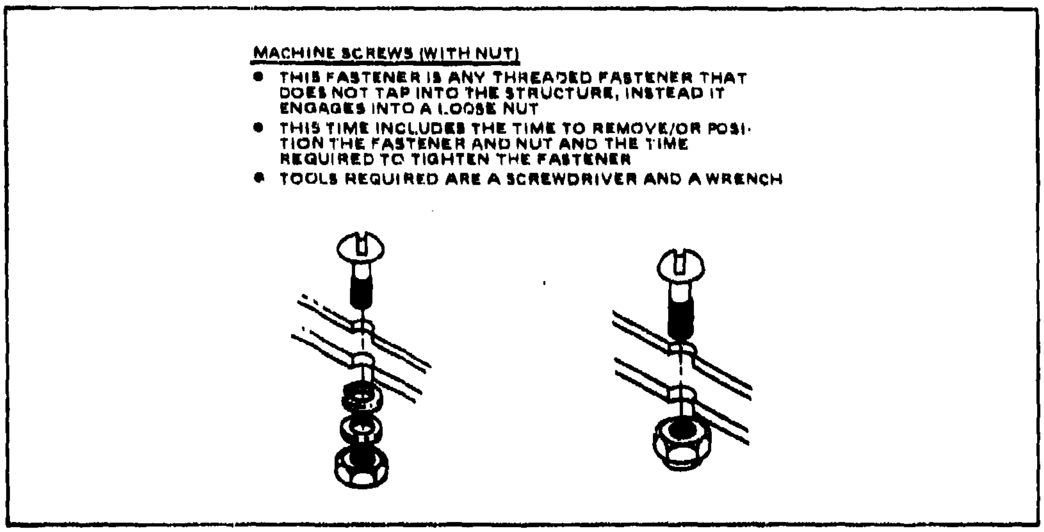


Figure 20. Machine Screws

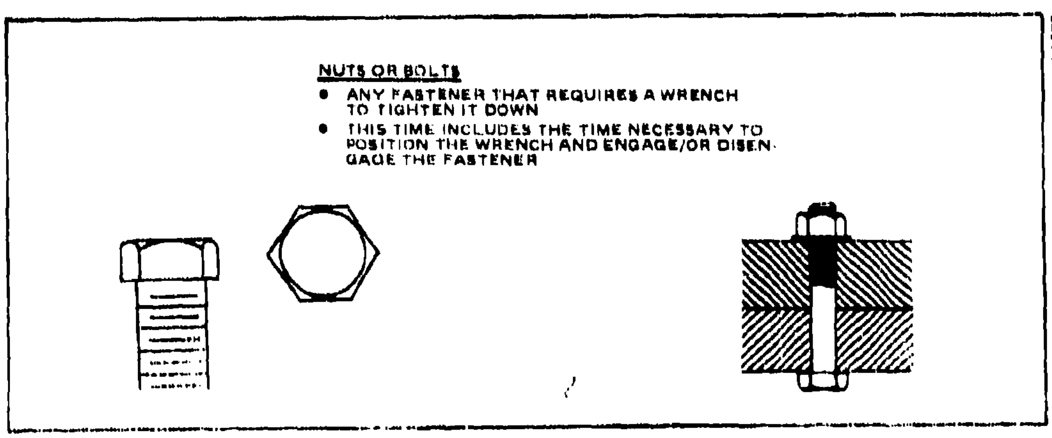
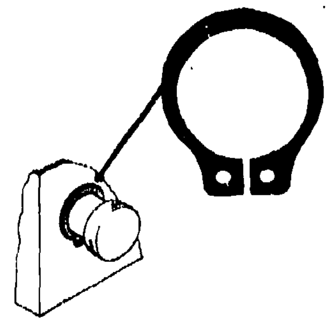


Figure 21. Nuts or Bolts

RETAINING RINGS

- THIS DEVICE IS A "U" SHAPED PIECE OF METAL THAT RETAINS A UNIT/COMPONENT IN POSITION
- THE TIME GIVEN INCLUDES THE TIME NECESSARY TO ENGAGE/OR DISENGAGE THIS FASTENER
- SPECIAL PLIERS ARE REQUIRED TO REMOVE/REPLACE THIS FASTENER

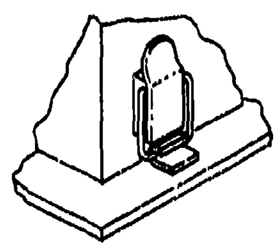


82588-20

Figure 22. Retaining Rings

DRAWHOOK LATCH

- ANY LATCH THAT IS SIMILAR TO THE ONE SHOWN
- THE TIME INCLUDES THE TIME TO ENGAGE/DISENGAGE THE LATCH COMPLETELY
- NO TOOLS REQUIRED



82588-21

Figure 23. Drawhook Latch

SPRING CLIP CATCH

- ANY LATCH SIMILAR TO THE ONE SHOWN
- TIME INCLUDES THE TIME NECESSARY TO ENGAGE/OR DISENGAGE THE LATCH COMPLETELY
- NO TOOLS REQUIRED

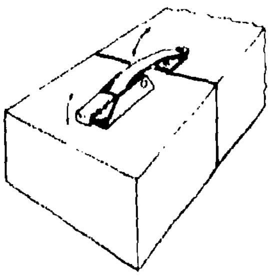


Figure 24. Spring Clip Catch

BUTTERFLY LATCH

- ANY LATCH SIMILAR TO THE ONE SHOWN
- TIME INCLUDES THE NECESSARY TIME TO ENGAGE/OR DISENGAGE THE LATCH COMPLETELY. NORMALLY CONSISTS OF LIFTING THE TAB AND TURNING IT 90°.
- NO TOOLS REQUIRED

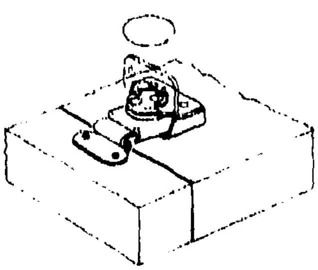


Figure 25. Butterfly Latch

ATR LATCH

- ANY LATCH SIMILAR TO THE ONE SHOWN
- TIME INCLUDES THE TIME NECESSARY TO UNSCREW/OR SCREW THE CAP OVER THE NIB TO ENGAGE/OR DISENGAGE THE SECURED UNIT. THE TIME GIVEN IS FOR A PAIR OF ATR LATCHES.
- NO TOOLS REQUIRED.

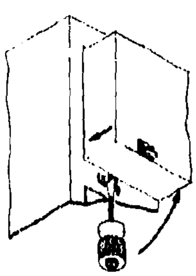
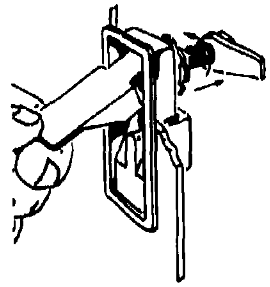


Figure 26. ATR Latch

LIFT AND TURN LATCH

- ANY LATCH SIMILAR TO THE ONE SHOWN
- TIME INCLUDES THE TIME NECESSARY TO LIFT THE HANDLE AND TURN IT TO UNSECURE OR SECURE A DOOR OR PANEL
- NO TOOLS REQUIRED

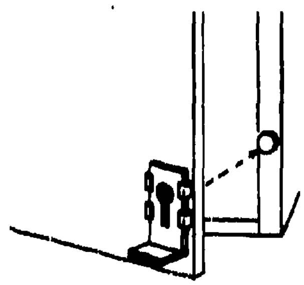


82588-25

Figure 27. Lift and Turn Latch

SLIDE LOCK LATCH

- ANY LATCH SIMILAR TO THE ONE SHOWN
- THE TIME GIVEN IS THE TIME NECESSARY TO SLIDE THE LOCKING DEVICE TO ENGAGE/OR DISENGAGE THE PANEL
- NO TOOLS REQUIRED

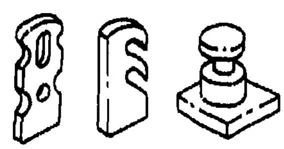


82588-26

Figure 28. Slide Lock Latch

TERMINAL POSTS

- ANY TERMINAL CONNECTION SIMILAR TO THE ONES SHOWN
- THIS TIME IS THE TIME REQUIRED TO REMOVE OR REPLACE A LEAD FROM A TERMINAL (DOES NOT INCLUDE SOLDERING OR DESOLDERING)
- NEEDLE NOSE PLIERS ARE REQUIRED FOR THIS TASK



82588-27

Figure 29. Terminal Posts Connections

SCREW TERMINALS

- ANY TERMINAL CONNECTION SIMILAR TO THE ONE SHOWN
- THE TIME GIVEN IS THE TIME REQUIRED TO REMOVE/OR POSITION THE TERMINAL LUG AND LOOSEN/OR TIGHTEN THE SCREW
- A SCREWDRIVER IS REQUIRED

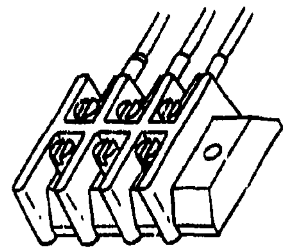


Figure 30. Screw Terminal Connections

TERMIPOINT CONNECTIONS

- ANY TERMIANL CONNECTION SIMILAR TO THE ONE SHOWN
- THIS TIME IS THE TIME TO REMOVE THE CLIP WITH A PICK OR TWEEZERS AND THE TIME TO REPLACE THE CLIP WITH A TERMIPOINT GUN
- TOOLS REQUIRED ARE TWEEZERS, OR A PICK, AND A TERMIPOINT GUN

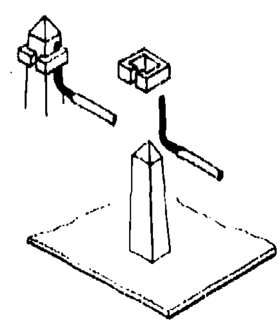
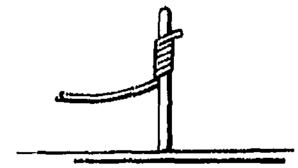


Figure 31. Termipoint Connection

WIREWRAP

- ANY TERMINAL CONNECTION SIMILAR TO THE ONE SHOWN
- THE TIMES GIVEN ARE TO REPLACE THE WIREWRAP WITH A WIREWRAP GUN AND TO REMOVE THE CONNECTION WITH AN UNWRAPPING TOOL
- TOOLS REQUIRED ARE A WIREWRAP GUN AND AN UNWRAPPING TOOL

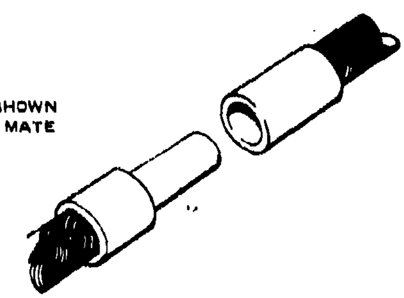


82588-30

Figure 32. Wirewrap Connection

TAPERPIN

- ANY TERMINAL CONNECTION SIMILAR TO THE ONE SHOWN
- THE TIME GIVEN IS THE TIME REQUIRED TO UNPLUG MATE OR DEMATE THE CONNECTOR
- NO TOOL REQUIRED

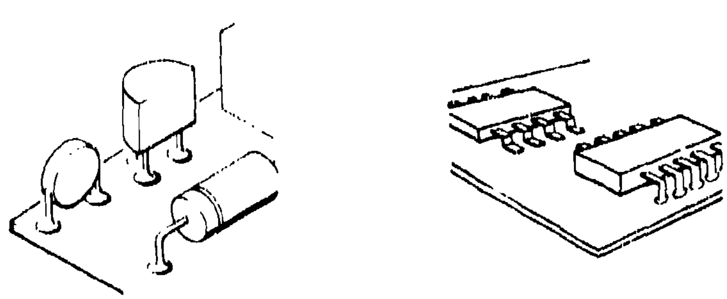


82588-31

Figure 33. Taperpin Connection

PCB

- ANY TERMINAL CONNECTED DIRECTLY TO THE PRINTED CIRCUITRY OF A CIRCUIT CARD
- THE TIME GIVEN IS THE TIME REQUIRED TO REMOVE OR REPLACE A LEAD FROM THE PCB (NO SOLDERING OR DESOLDERING TIME)
- THE TOOLS REQUIRED ARE A PICK OR NEEDLENOSE PLIERS

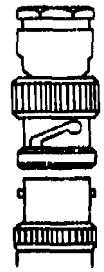


82588-32

Figure 34. PCB Connections

BNC CONNECTORS

- ANY CONNECTOR THAT HAS A BAYONET LOOKING DEVICE
- TIMES GIVEN ARE FOR MATING/DEMATING THE CONNECTORS BY A TWISTING MOTION
- NO TOOLS REQUIRED

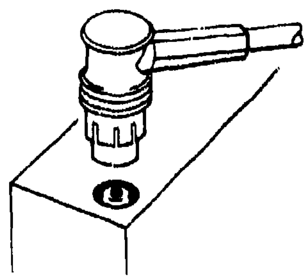


82644-2R

Figure 35. BNC Connectors

QUICK RELEASE COAX CONNECTORS

- ANY COAX CONNECTOR THAT ENGAGES OR DISENGAGES BY A PUSH OR PULL MOTION
- TIMES GIVEN ARE FOR DEMATING/MATING THE CONNECTORS BY A PULLING OR PUSHING MOTION
- NO TOOLS REQUIRED

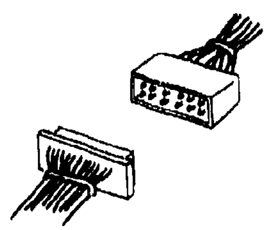


82588-34

Figure 36. Quick Release Coax Connectors

FRICTION LOCKING CONNECTORS

- ANY CONNECTOR THAT IS MATED AND SECURED BY THE FRICTION OF THE PINS AND/OR CONNECTOR CASE
- THE TIME GIVEN IS THE TIME NECESSARY TO MATE OR DEMATE THESE CONNECTOR TYPES
- NO TOOLS REQUIRED



82588-35

Figure 37. Friction Locking Connector

FRICTION LOCKING CONNECTOR WITH JACKSCREW

- ANY FRICTION LOCKING CONNECTOR THAT IS SECURED BY A JACKSCREW
- THE TIME GIVEN IS THE TIME NECESSARY TO DEMATE/MATE THE CONNECTOR BY DISENGAGING/ENGAGING THE JACKSCREW
- A SCREWDRIVER IS REQUIRED

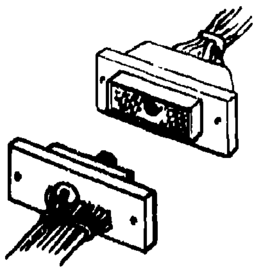


Figure 38. Friction Locking Connector with Jackscrew

THREADLOCKING CONNECTOR

- ANY CONNECTOR THAT IS SECURED BY A THREADED CONNECTOR SHELL
- THE TIME GIVEN IS FOR THE DEMATING/MATING OF THE CONNECTOR AND THE SECURING/UNSECURING OF IT BY A TURNING MOTION
- NO TOOLS REQUIRED

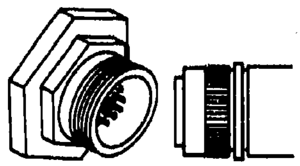


Figure 39. Threadlocking Connector

SLIDE LOCKING CONNECTOR

- ANY CONNECTOR THAT IS SECURED BY A SLIDE LOCK
- THE TIME GIVEN IS THE TIME REQUIRED TO MATE/DEMATE THE CONNECTOR AND ENGAGE/DISENGAGE THE SLIDE LOCK
- NO TOOLS REQUIRED

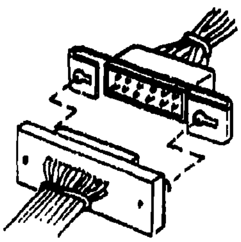


Figure 40. Slide Locking Connector

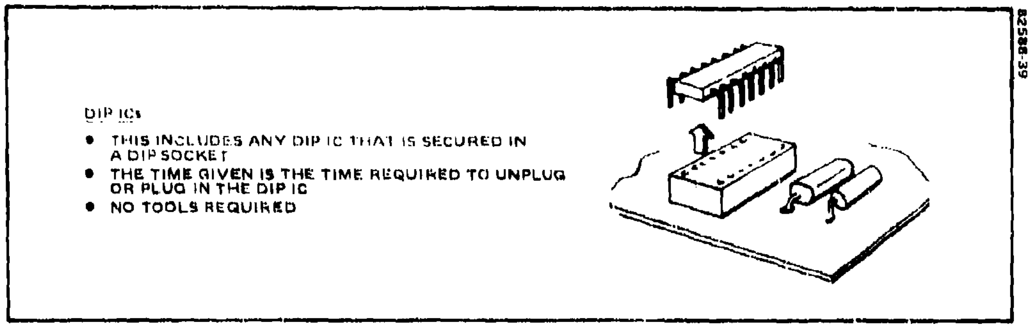


Figure 41. Dip ICs

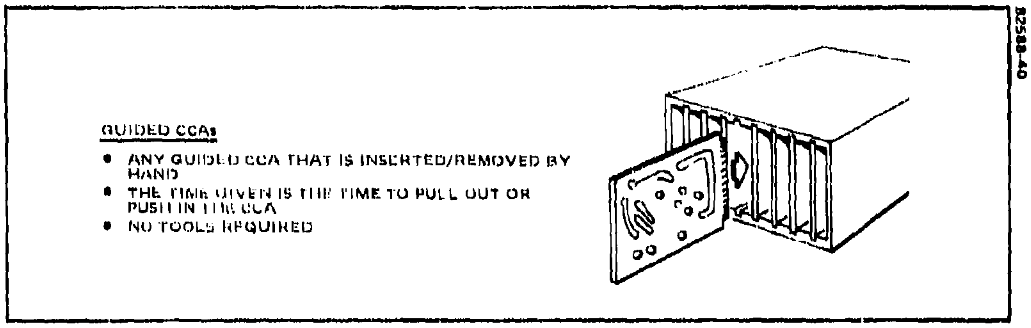


Figure 42. Guided CCAs

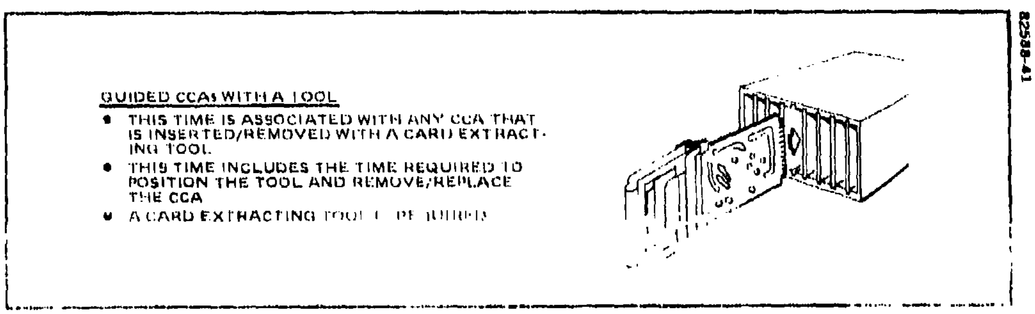


Figure 43. Guided CCAs with a Tool

NON-GUIDED CCAs
- THIS TIME IS ASSOCIATED WITH PLUG-IN CARDS THAT ARE NOT GUIDED
- THIS TIME INCLUDES THE TIME NECESSARY TO REMOVE/REPLACE THE CCA FROM THE EDGE CONNECTOR (DOES NOT INCLUDE TIME FOR FASTENERS)
- NO TOOLS REQUIRED

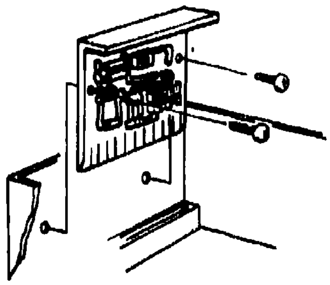


Figure 44. Non-Guided CCAs

MODULES
- THIS IS THE TIME ASSOCIATED WITH REMOVING OR POSITIONING A MODULAR ASSEMBLY
- THIS TIME IS THE TIME NECESSARY TO REMOVE THE MODULE OR POSITION IT IN PLACE
- NO TOOLS REQUIRED

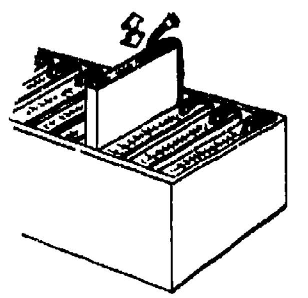


Figure 45. Modules

CRIMP LUGS
- THIS IS THE TIME ASSOCIATED WITH SECURING A TERMINAL LUG TO A WIRE
- THE TIME GIVEN INCLUDES THE TIME TO POSITION THE WIRE IN THE LUG AND CRIMP IT
- A CRIMPING TOOL OR PLIERS IS REQUIRED

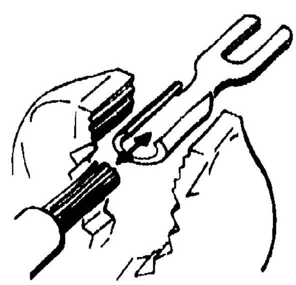
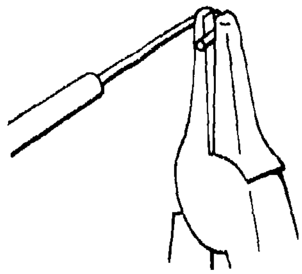


Figure 46. Crimp Lugs

FORM LEADS

- THIS IS THE TIME ASSOCIATED WITH FORMING A LEAD ON A COMPONENT PRIOR TO CONNECTING IT TO A TERMINAL
- THE TIME GIVEN IS THE TIME NECESSARY TO GRASP THE LEAD WITH THE PLIERS AND FORM IT
- NEEDLE NOSE PLIERS ARE REQUIRED

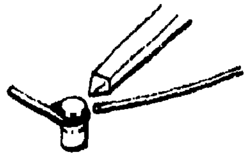


82588-45

Figure 47. Form Leads

SOLDERING TERMINAL POSTS

- THE TIME ASSOCIATED WITH SOLDERING A LEAD TO A TERMINAL POST
- THE TIME GIVEN IS THE TIME TO HEAT THE TERMINAL POST AND APPLY THE SOLDER
- A SOLDERING IRON IS REQUIRED

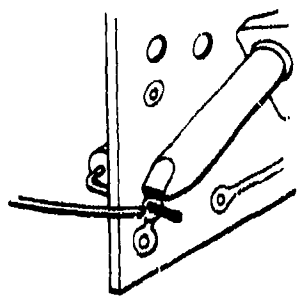


82588-46

Figure 48. Soldering Terminal Posts

SOLDERING PCB CONNECTIONS

- THE TIME ASSOCIATED WITH SOLDERING A LEAD TO A PCB ETCHING
- THE TIME GIVEN IS THE TIME TO HEAT THE ETCHING PAD AND APPLY THE SOLDER
- A SOLDERING IRON IS REQUIRED



82588-47

Figure 49. Soldering PCB Connections

DESOLDERING USING A BRAIDED WICK

- THE TIME ASSOCIATED WITH DESOLDERING A CONNECTION USING A BRAIDED COPPER WICK
- THE TIME GIVEN IS THE TIME TO REHEAT THE SOLDER AND EXTRACT IT FROM THE PCB OR TERMINAL USING A BRAIDED COPPER WICK
- A SOLDERING IRON AND BRAIDED COPPER WICK ARE REQUIRED

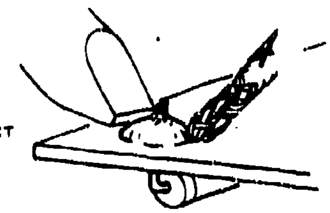


Figure 50. Desoldering with a Braided Wick

DESOLDERING USING A VACUUM

- THE TIME ASSOCIATED WITH DESOLDERING A CONNECTION USING A VACUUM ASSISTED DESOLDERING IRON
- THE TIME GIVEN IS THE TIME REQUIRED TO REHEAT AND AND "SUCK-UP" THE SOLDER
- A DESOLDERING IRON IS REQUIRED

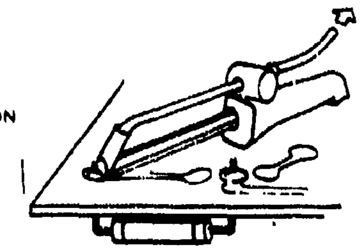


Figure 51. Desoldering Using a Vacuum

FORM FLAT PACK LEADS

- THE TIME ASSOCIATED WITH FORMING FLATPACK LEADS USING A MECHANICALLY OPERATED DIE
- THE TIME GIVEN IS THE TIME REQUIRED TO POSITION THE FLATPACK AND ACTUATE THE MECHANISM
- A MECHANICALLY OPERATED DEVICE IS USED TO DO THIS

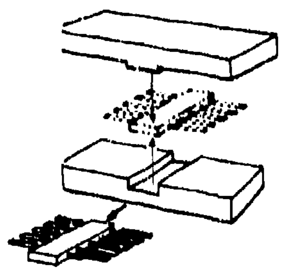


Figure 52.

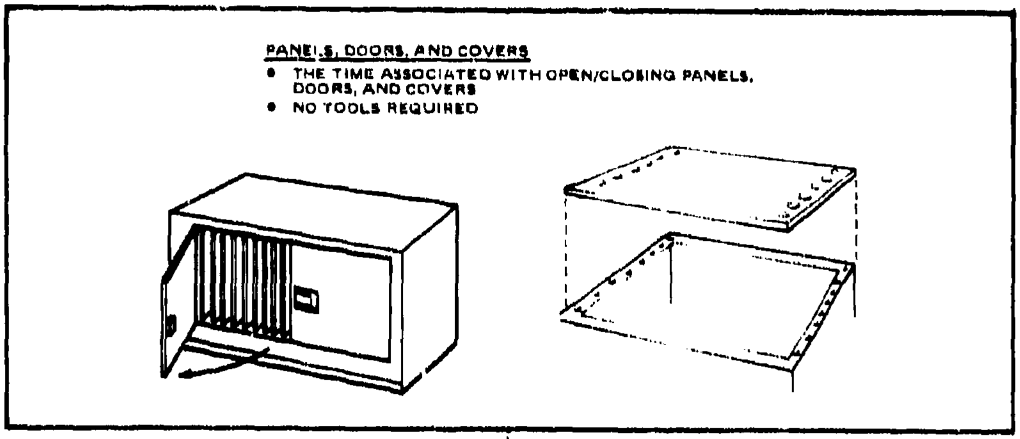


Figure 53. Panels, Doors and Covers

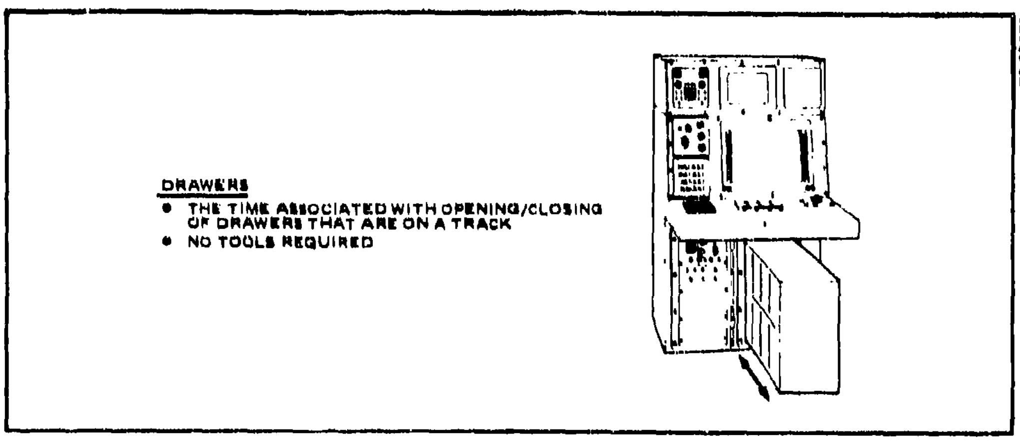


Figure 54. Drawers

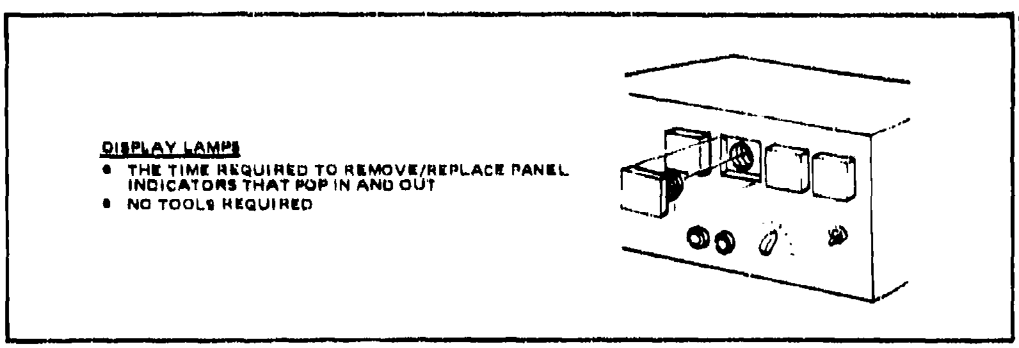


Figure 55. Display Lamps

4.6 WORK FACTORS

The maintenance time standards developed in the previous sections assume that the working environment is conducive to maintenance (i.e., moderate temperature, ample working space, and a fixed platform environment). Real world factors may result in less than ideal conditions for corrective maintenance actions. This section covers the work factors that may increase or decrease the maintenance times established in the previous section.

The main factors that have a noticeable effect on repair times are work environment and maintenance personnel. These factors can further be categorized by:

1. work environment
   a) space impediments
   b) climatic conditions (temperature)
   c) platform (airborne, ground, shipboard)
2. maintenance personnel
   a) aptitude
   b) manpower
   c) attitude

Data was collected, through a literature search, on the maintenance work factors identified above. A summary of the information found on these work factors is presented in the following sections.

It should be noted that a minimum amount of work factor data was available. That data which is presented in this section was taken at face value with no attempt made to substantiate or validate its accuracy. Utilization of the data in this section should only be used with a thorough understanding of the conditions for which it is applicable.

4.6.1 Work Environment

4.6.1.1 Space Impediment

The first factor considered was space impediments. If a technician's work is impeded by an obstruction (e.g. another RI) or if he must perform his work in an awkward position then corrective maintenance time will increase. Therefore, predicted repair times, must be corrected by some factors to account for these impediments or cramped working spaces. Table 50 is a reproduction of a table which appears in RADC-TR-70-89, Maintainability Prediction and Demonstration Techniques, written by ARINC Research Corporation. The table contains correction factors that the times standards (supplied in that report) must be multiplied by when working conditions are not ideal. Use of these factors must be restricted to the conditions defined in RADC-TR-70-89 for which they were developed. A separate analysis of work factors due to space impediments was not performed for this study.

TABLE 50. IMPEDIMENT CORRECTION FACTORS

Device Category	Tool or Device	Impediment Correction Factor
Fastening Parts	Non-captive screws, captive fasteners	1.5 1.2
Connecting Elements	Soldered devices, nonsoldered devices, connecting devices	3.4 * 1.4
Plug-in Components, Assemblies, and Subassemblies	Discrete parts, plug-in assemblies, and subassemblies	3.4 1.6
External Access	Covers, panels, enclosures, doors, etc.	*
Adjustable Items	Knob, screwdriver, wrench, etc.	1.2

*No data available.

4.6.1.2 Climatic Conditions

The next maintenance work factor considered was climatic conditions. This work factor accounts for the effects of temperature (hot and cold) on repair times.

Information was found for both extremes of the temperature scale. Figure 56 extracted from AMCP-706-134, Maintainability Guide for Design shows how a technician's accuracy decreases (thus increasing repair times) as the temperature increases. The figure does not provide quantitative information on the increase of maintenance times.

Data for maintenance under cold temperatures was extracted from Maintenance Performance in an Arctic Environment, written by the United States Army Arctic Test Center. This report collected data on maintenance actions in sub-zero temperatures, but the data was never analyzed due to the cancellation of the study.

A regression analysis was performed on data to see if any correlation between the temperature and the repair times existed. This analysis resulted in the curve shown in figure 57. The data points and the regression equations are tabulated in appendix E.

The data extracted from the previously mentioned report pertained to repair times of mechanical items. Therefore, the curve shown can only be applied to maintenance actions that require physical movements. For example, times pertaining to physical actions such as removing and replacing a fastener, or opening and closing a latch can be adjusted by the curve shown, but non-physical actions such as running a computer

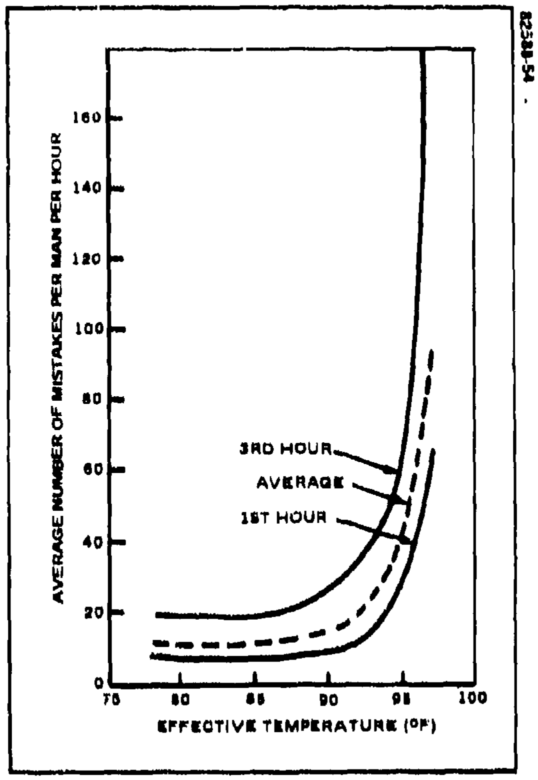


Figure 56. Error Increases Due to Temperature

controlled diagnostic program would not be affected by the temperature difference. Also since the data extracted was in the temperature range of -50°F to 0°F, the curve is considered valid only for that temperature range.

4.6.1.3 Platform Stability (Airborne, Ground, Shipboard)

The last environmental work factor considered is the platform on which maintenance is performed. It appears obvious that there is a relationship between the time to perform physical actions associated with maintenance and the stability of the platform on which maintenance is performed. However, the literature search yielded little quantitative analysis of this relationship

A maintainability analysis performed on the Surface Towed Array Sonar System does provide a relationship between maintenance under different sea state conditions (with sea state "0" considered equivalent to ground maintenance). The analysis is summarized in Table 51. The sea state data was extracted from Oceanography

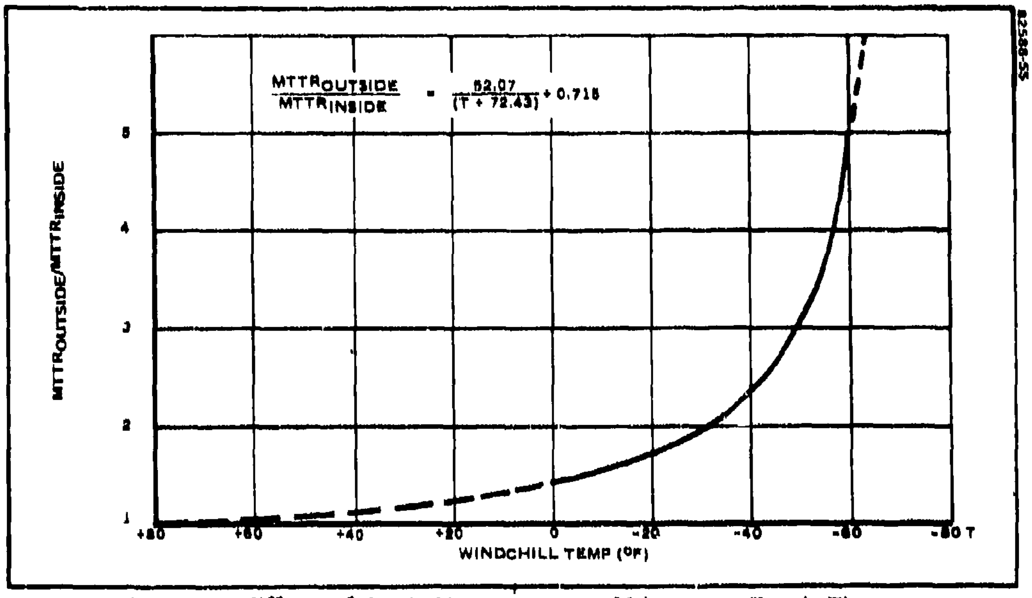


Figure 57. Effects of Arctic Temperature on Maintenance Repair Times

TABLE 51. INCREASE IN MAINTENANCE TIME AS A FUNCTION OF SEA STATE

Sea State	Wave Height (ft)	Frequency Occurance	% Increase In Physical Task Time
0-2	0-3 ft.	0.20	0
3	3-5	0.25	15
4	5-8	0.25	50
5	8-12	0.10	100
6	12	0.20	—

by M. G. Gross, Prentice Hall, 1972. The maintenance factor data was based on best engineering judgement of several experienced shipboard technicians. This data is considered applicable only to the equipment characteristics and installation characteristics (e.g. ship size, mounting location, etc.) of the referenced system. Application of this data to other shipboard installations must be limited to like conditions.

4.6.2 Maintenance Personnel Factors

Proficiency, attitude, and manpower were the personnel factors considered. The literature search came up with several documents that contained information on the effects of maintenance personnel on repair times. The documents that contained the most useful information were:

1. Siegal, A.I., Wolf, J.J., Williams, A.R., A Model For Predicting Integrated Man-Machine Reliability, March 1976
2. Foley, J.P. Jr., Airforce Research and Development Program for the Improvment of Maintenance Efficiency, November 1973
3. Elliot, T.K., Effects of Electronic Aptitude on the Performance of Proceduralized Troubleshooting Guides, November, 1967
4. Pieper, W.J., et al, Effects of Ambiguous Test Results on Troubleshooting Procedures, November 1967

4.6 2.1 Aptitude

The conclusion reached after a review of the referenced documents is that the proficiency or aptitude of a technician has a negligible effect on repair times once the fault has been isolated to a single RI or group of RIs. The time associated with fault isolation procedures that require operator interactions (either semi-automatic or manual fault isolation) can be affected by the proficiency or aptitude of the maintenance technician or operator. However, the proficiency of a technician has a negligible effect on fault isolation time with automatic fault isolation techniques or if a good proceduralized troubleshooting manual is used. The effects of proficiency are primarily due to ambiguous fault isolation results. However, if a step by step procedure is used to aid the technician, then the differences caused by different aptitude levels diminish. The methodology presented in this report requires the fabrication of a maintenance flow diagram that reduces the effects of aptitude and proficiency due to ambiguity on repair times predictions.

4.6.2.2 Manpower Availability

The manpower available to perform corrective maintenance can have a considerable effect on maintenance repair times. As is shown in section 5.1.7 (timeline analysis), the manpower available can reduce the total repair time by allowing for multiple actions to occur at the same time. Since a time synthesis model was developed for this methodology, the effects of the manning level can be accounted for directly when the repair times are synthesized (refer to section 2.6.2).

4.6.2.3 Attitude

Technician attitude or motivation is probably the most dominant factor in the variation of time to perform maintenance between technicians. It is also the one factor that is unpredictable or unquantifiable. As indicated in Section 2.2, the purpose of the procedure developed here is to predict inherent maintainability. Within this framework, technician attitude was excluded from further consideration.

SECTION 5.0 PREDICTION PROCEDURE

5.1 DETAILED PREDICTION PROCEDURE

This section provides a step by step procedure for performing a detailed prediction of MTTR as described in Section 2.3. The tasks involved in performing the prediction are:

1. Define the prediction requirements
2. Define the maintenance concept
3. Identify the fault detection and isolation outputs (FD&I outputs)
4. Correlate the FD&I outputs and hardware features
5. Correlate RIs and FD&I outputs
6. Prepare a maintenance flow diagram
7. Prepare time line analyses
8. Compute the maintainability parameters

Descriptions of each of the tasks are provided in the following subsections. A sample prediction is provided in Appendix F.

5.1.1 Prediction Requirements Definition

This step of the prediction is in some respects the most important aspect since it establishes a common baseline of understanding the prediction purpose, approach and scope. During this step, the maintainability parameter(s) to be evaluated is defined, the prediction ground rules are established, and the maintenance level for which the prediction is being made is defined.

Parameter definition includes the selection (if required) of the parameter(s) to be evaluated and the establishment of a qualitative and quantitative definition of each parameter. In most cases, the parameter in question can be defined by the mathematical models presented in Sections 2.3.2, 2.5, and 2.6. If the prediction is being performed in compliance with a customer statement of work defining the parameter to be analyzed, it must be determined if the stated parameter is consistent with the equivalent parameter defined in Section 2. If not, the prediction models must be changed accordingly. As part of the parameter evaluation, it must be determined which elemental maintenance tasks (e.g., preparation, isolation, etc.) are to be included in the analysis and which are to be excluded.

For a system which includes redundancy, non mission critical elements, or degraded operating modes, the failure state(s) for which the maintainability parameter is to be evaluated must be defined. For simple cases such as non essential

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equipments, the evaluation is simply performed with the exclusion of the non essential equipment. For more complex situations such as redundancy, the redundant equipments are first evaluated independent of any redundancy considerations, and then the redundancy is evaluated using standard techniques such as Reliability Handbook by B. A. Kozlov and I. A. Ushakov.

The last aspect of this step is to explicity define the maintenance level for which the prediction is being made. If the level is defined in terms of a specific maintenance organization (e.g., direct support unit, depot, etc.) then the tasks to be performed are readily defined by the maintenance concept as described in the following section. If the level is defined by operating level or location (e.g., on-site, flight-line etc.), then this level must be redefined in terms of the maintenance organization(s) performing maintenance at that level/location. For example, the maintenance concept for a given Air Force system may be repair on-site by a combination of organizational and intermediate level maintenance personnel, depending on the nature of the support required. In this case it must be determined whether the maintainability parameter is to be computed for the two maintenance organizations as a single entity or whether it is to be computed separately for each organization.

5.1.2 Maintenance Concept Definition

The maintenance concept must be established, so that in conjunction with a definition of the prediction requirements (refer to previous section), a baseline is established which defines the prediction to be performed. This step amplifies the preceding step by explicitly defining the who, where, what and when of maintenance. Depending on the state of the maintenance engineering effort associated with a particular program, the maintenance concept can be derived from, or used to generate a maintenance allocation chart (MAC).

With respect to the maintainability prediction, the primary output of the maintenance concept is the definition of how a repair is effected and what the replaceable items are. Specific questions which will be answered are:

1. Does the same maintenance organization perform all maintenance actions (e.g., isolation vs replacement)?
2. What is the replacement level (i.e., equipment, unit, module, piece part, etc.)?
3. Is repair effected by single RI replacement or group RI replacement?

4. For group replacement, is the entire group replaced or is iterative replacement used?

5. How many maintenance men are available and what are their skill levels?

As part of the above process, a complete set of replaceable items is identified. If the maintenance concept allows for fault isolation to a group of RIs and repair by group replacement, then the RI groups can be reclassified as RIs if each of the groups is independent of other groups.

5.1.3 Fault Detection and Isolation Output Identification

This step involves the identification of all the "outputs" which are used in the fault detection and isolation process. Normally the fault detection and isolation processes are segregated. However, for purposes of maintainability prediction, the fault detection methodology is considered as the first step of fault isolation and is properly included as a part of the isolation capability. Any time associated with fault detection (e.g., mean fault detection time) is normally excluded from the prediction model.

The term fault detection and isolation outputs is defined as those indications, symptoms, printouts, readouts, or the results of manual procedures which separately or in combination identify to the maintenance technician the procedure to follow in performing maintenance.

These outputs will vary in form, format, complexity and data content from system to system and some will be more obvious than others. The maintenance actions taken in response to these outputs may depend upon the system maintenance environment and the system operating criticality. For example, a system might have a set of idiot lights which isolate to the most probable unit and also have a comprehensive semi-automatic BIT routine which isolates to a single RI within the unit. If the system is in a low criticality environment, the maintenance concept might be to always use the BIT to isolate to a single RI. However, if the system is in a high criticality environment where downtime is crucial, the idiot lights may be the primary fault isolation output with repair by replacement of the most probable unit. It is important therefore, not only to identify the outputs but also to ensure that the outputs identified are the ones that will be used in the intended environment.

Some of the more common generic fault detection and isolation outputs are:

1. Indicator light or annunciator
2. Diagnostic or BIT readout/printout
3. Meter readings

4. Circuit breaker and fuse indicators
5. Display presentation
6. Alarms
7. Improper system operation
8. Improper system response
9. System operating alerts

To apply the prediction methodology presented herein, identify all unique fault detection and isolation outputs (single outputs or combinations) which will be used by the maintenance technician. This may be an iterative process for a system with ambiguous fault isolation (refer to the detailed prediction example in Appendix F). The predictor should first identify all primary unique outputs upon which the maintenance technician relies to make decisions on the repair methodology (e.g., perform adjustment, replace RI, proceed to a different method of fault isolation, etc.). Secondary outputs should then be identified for those cases where the primary output yielded a result which did not correct the problem and further isolation is required.

5.1.4 FD&I Outputs and Hardware Correlation

The key to this prediction methodology, and by far the most demanding of the prediction tasks, is the establishment of a correlation between the FD&I Outputs as defined in the preceeding paragraph, and the hardware for which the prediction is being made. This step demands a thorough understanding of the system hardware and software, and of the FD&I features inherent to the system (i.e., hardware and software monitoring and diagnostic capabilities).

This task can be accomplished either from the top down or bottom up. The top down approach involves a fault tree technique where the top of the tree is each unique FD&I output; the next tier identifies the FD&I feature(s) which can yield the subject output; and, the bottom tier identifies the RIs or partial RIs which upon failure would be detected and/or isolated by the subject FD&I feature. The bottom up approach involves identification of circuitry (in terms of RIs) associated with each FD&I feature, and the analysis of how a failure (i.e. no go) of each FD&I feature presents itself to the operator/maintainer in terms of a FD&I output.

Either approach requires the same five steps to be performed:

1. Identify all FD&I features
2. Identify the circuitry associated with each feature
3. Identify the FD&I sequencing

4. Establish the RI failure rate associated with each FD&I feature

5. Correlate the FD&I features with the FD&I outputs

FD&I features are those hardware/software elements, or combinations thereof, which generate or cause to be generated each FD&I output. Typical features include diagnostic program routines, BIT routines, BITE, performance monitoring programs, status monitors, and test points. These items normally correlate on a one-to-one basis with the FD&I outputs. FD&I by operator observation of improper system response or improper system operation cannot normally be associated with any specific FD&I feature.

After the FD&I features are identified, the circuit schematics are mapped to identify the components tested or verified by each feature. A sample mapping is shown in figure 58. The mapping is then translated into a matrix as shown in figure 59. The matrix identifies, for each FD&I feature, the RIs and components which are tested/verified by that feature. Also included in the matrix is an identifier which defines the order in which the FD&I features are utilized during the isolation process.

The matrix is used to identify the failure rate of each RI associated with each feature. The first FD&I feature is examined and the failure rate of each component associated with that feature is entered in the matrix under that feature. The second feature is then examined, etc. If a component is tested/verified by more than one feature, the failure rate is assigned to the first feature which would result in a "no-go" result. If different tests of the same component check different failure modes, then the failure rate is apportioned to each feature based on the relative occurrence of each failure mode. In completing the matrix, the failure rates for the components under each FD&I feature are summed together and entered as the failure rate for the RI checked by that particular feature. Those components which are not included under any FD&I features represent undetected failures or failures not isolated with the FD&I features (i.e., they require manual hunt and peck type fault isolation). The failure rate of the undetected failures is noted in the appropriate column of the matrix as is that portion isolatable by means other than the dedicated FD&I features (e.g., operator observations of improper system response).

In those cases where the exact failure rate of the nth RI, which can result in the jth FD&I output, is not know, the failure rate (or unknown portion thereof) can be evenly distributed among the corresponding FD&I outputs as an approximation of the actual distribution.

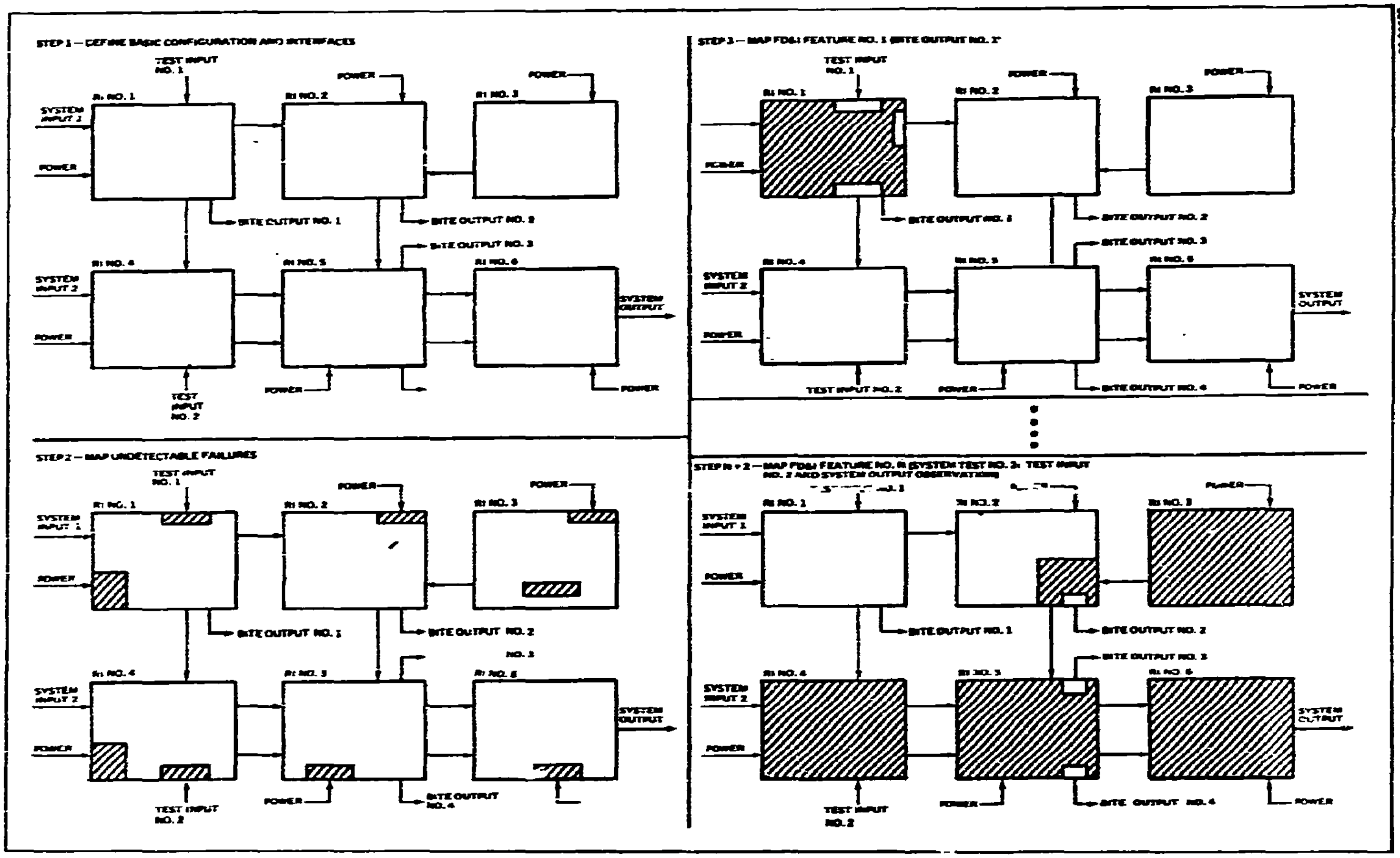

Figure 58. Approach to RI Mapping for RD&I Features

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		FAULT DETECTION AND ISOLATION FEATURES							
RI/COMPONENT	FAILURE RATE	FEATURE 1 SEQ NO. ___	FEATURE 2 SEQ NO. ___	FEATURE 3 SEQ NO. ___	FEATURE 4 SEQ NO. ___	FEATURE 5 SEQ NO. ___	FEATURE N SEQ NO. ___	UNDETECTED FAILURE RATE	MANUAL ISOLATION FAILURE RATE
RI NO. 1									
• COMPONENT A									
• COMPONENT B									
• COMPONENT C									
• COMPONENT D									
• COMPONENT E									
• COMPONENT F-M									
• COMPONENT N									
• COMPONENT P-V									
RI NO. 2									
• COMPONENT A									
• COMPONENT B									
•									
•									
•									
•									
•									

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Figure 59. Matrix for Correlating FD&I Features with RIs

The next step in the correlation process is to associate the FD&I features with the FD&I outputs. This is accomplished using a fault tree type diagram such as the sample shown in figure 60. The top of the tree consists of all FD&I outputs; the second tier contains the FD&I features which separately or jointly result in the given FD&I output; and, the bottom tier presents the RIs associated with each FD&I feature and the failure rate associated with that feature. The circles are used to assign numbers to all unique FD&I outputs. The triangles identify the order in which RIs are replaced when the maintenance policy calls for iterative replacement.

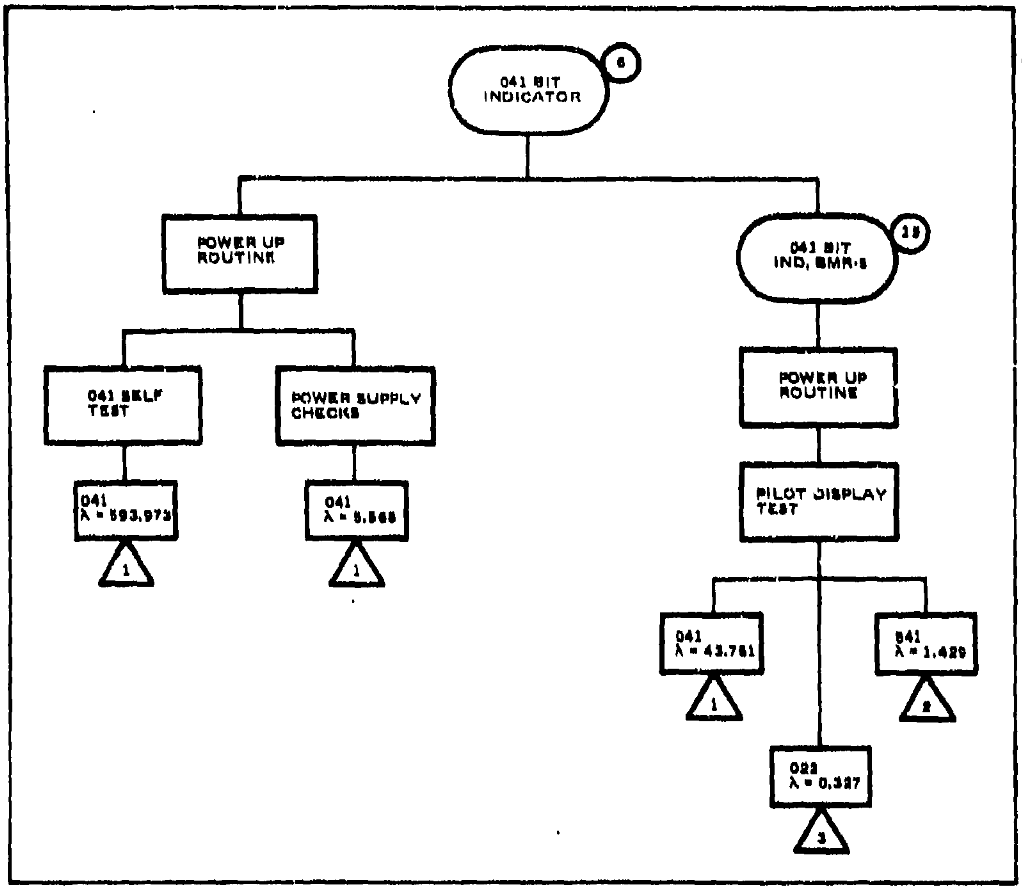


Figure 60. Sample FD&I Correlation Tree

5.1.5 RI and FD&I Output Correlation

The results of the preceeding section are summarized in a matrix which shows the relationship between the RIs for which the prediction is being performed and the total set of FD&I outputs. The matrix (refer to figure 61) identifies the RIs across the top and the unique FD&I Outputs down the left column. (The matrix can also be shown with the rows and columns reversed for convenience.) In reference to the math models (refer to Section 2.3.2) the RIs are the "n" parameters and the Outputs are the "j" parameters. Each RI column is further divided into three columns: K_{nj}, λ_{nj}, and R_{nj}.

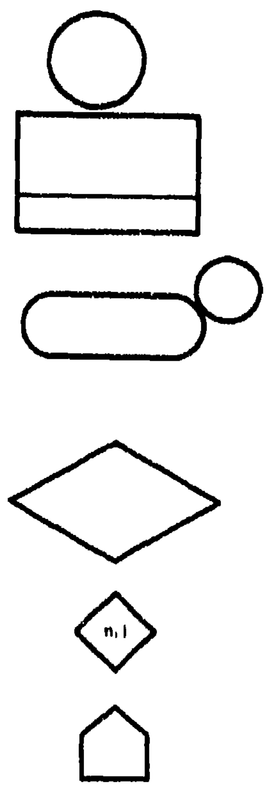
RI_n	1			2			3			4			5		
FD&I OUTPUTS (j) / λ_n	λ_1			λ_2			λ_3			λ_4			λ_5		
	K_{1j}	λ_{1j}	R_{1j}	K_{2j}	λ_{2j}	R_{2j}	K_{3j}	λ_{3j}	R_{3j}	K_{4j}	λ_{4j}	R_{4j}	K_{5j}	λ_{5j}	R_{5j}
1															
2															
3															
4															
5															
6															
•															
•															
•															

Figure 61. Maintenance Correlation Matrix Format

Under each RI column, enter the failure rate (λ_{nj}) of the RI that could result in the jth output. Now, for each unique output which has only one RI associated with it, enter a 1 in the K_{nj} column for that combination. For those outputs which are associated with 2 or more RIs, the K_{nj} value depends on the maintenance concept. If the maintenance concept is group RI replacement, enter under K_{nj} the number of RIs associated with each output. For example, if three RIs could contribute to the same FD&I output, then a 3 is entered in the K_{nj} for each of those RIs. If the maintenance concept is iterative replacement, then K_{nj} is assigned based on the order of replacement. That is, the first RI to be replaced upon recognition of the subject FD&I output is designated as $K_{nj} = 1$, the second $K_{nj} = 2$ and so forth. The typical assignment of values for each K_{nj} is based on the relative failure rates of the RIs, with the highest failure rate RI assigned as the first replacement item.

5.1.6 Prepare Maintenance Flow Diagrams

A maintenance flow diagram (MFD) is prepared to establish the R_{nj} values for insertion in the Maintenance Correlation Matrix (figure 61). The MFD is prepared to illustrate the sequencing of maintenance as performed by the designated maintenance technician. The symbols used in the MFD are:



Starting Point (i.e., Fault Occurs & Detected) or Ending Point

Activity Block. The top of the block indicates a specific maintenance activity and the bottom indicates the time associated with that activity. This is the only symbol that denotes time.

FD&I Outputs. Designates the primary or secondary unique FD&I output which defines the subsequent maintenance activity to be performed. The "j" associated with the output is entered in the circle.

Decision Point. Defines a point in the maintenance flow at which time the maintenance technician must make a decision on which subsequent path to take.

Path Identifier. Uniquely identifies each path by unique RI (n), and FD&I Output (j).

Continuation. Designates continuation from or to another place in the maintenance flow diagram.

The MFD (as illustrated in figure 62) starts on the left hand side of the figure as a "Fault Occurs and Detected" event. If isolation is inherent in fault detection, the next item shown in the MFD is the unique FD&I outputs. If isolation is not inherent in detection, the next item in the MFD is the fault detection output. This would be followed by activity blocks which define the procedure followed to achieve fault isolation. The fault isolation activity block(s) would then be followed by the unique primary FD&I outputs associated with the aforementioned fault detection output and associated fault

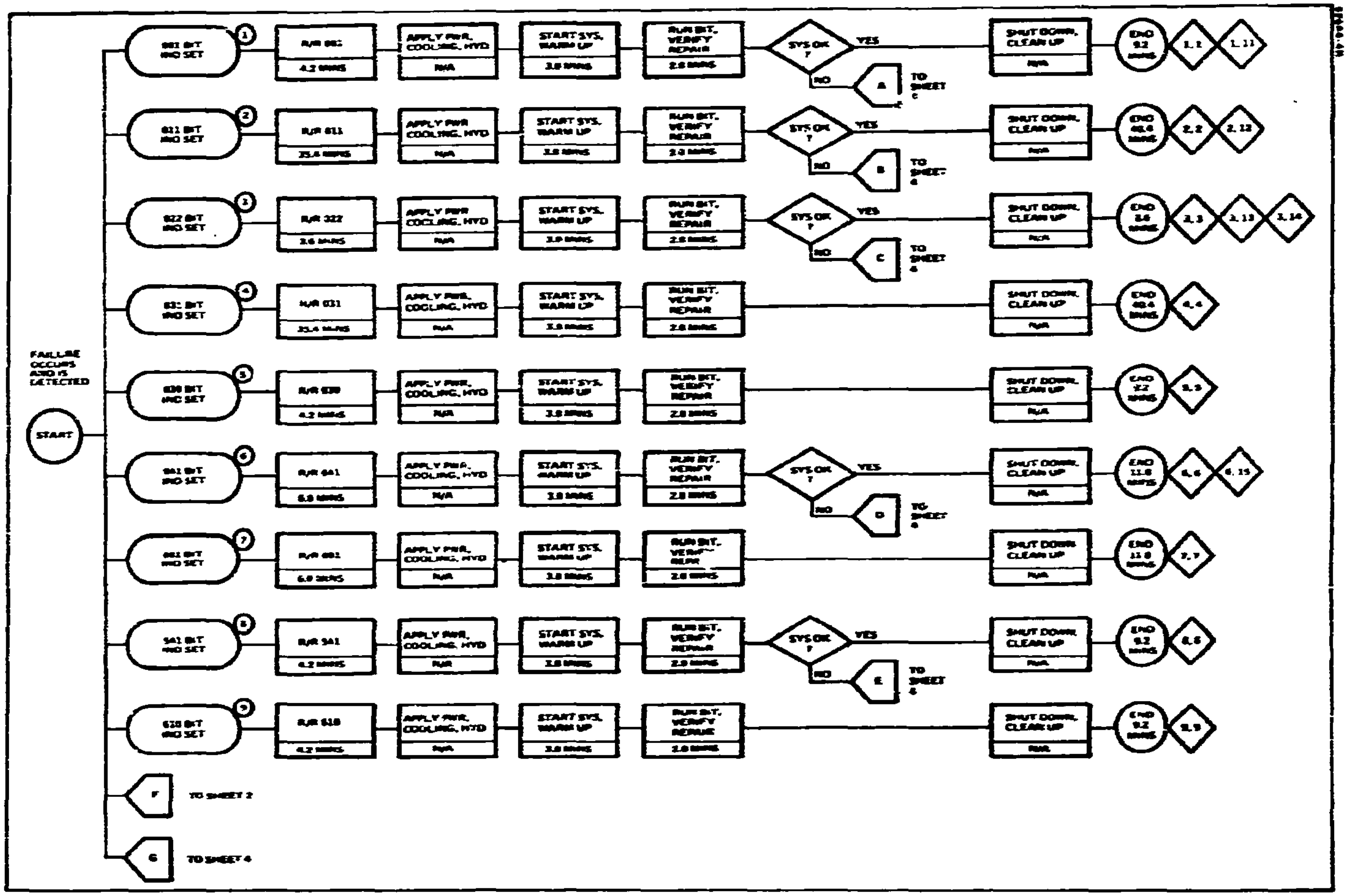


Figure 62. Sample Maintenance Flow Diagram

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isolation activity. Following the FD&I Output symbols are shown the activities required for fault correction and repair verification.

If a FD&I Output results in non-ambigious maintenance (i.e., primary isolation to a single RI, or group RI replacement), then an "End" symbol will directly follow the fault correction and verification activities. If a FD&I Output results in an ambiguous result, a verification decision block is shown after each verification activity (except the last). Any activity (e.g., clean up) performed after a positive verification decision is shown in an activity block(s) between the decision block and the End symbol. Associated with each End symbol is a path identifier which uniquely identifies each path by RI and FD&I output. For example, the path associated with the second RI and FD&I Output #12 would be designated as 2,12.

The R_{nj} values inserted in the Maintenance Correlation Matrix are computed by adding the times associated with each activity block from the "Fault Occurs and Detected" event to the "end" event for the subject (n, j) pair. Note that only the activity blocks have times associated with them. The time entered in the individual activity blocks is computed from a time line analysis prepared in accordance with section 5.1.7. Elemental times entered in the time line analysis are extracted from the following sources in the order given:

1. Actual times experienced on the subject equipment.
2. Standard times from Section 4.5.
3. Actual times experienced on similar equipment.
4. Engineering Judgment.

In the establishment of the time line analyses, the number of maintenance men must be considered. For example, if a given equipment has two technicians performing maintenance, one technician may perform disassembly to achieve access to the faulty RI while the second technician simultaneously retrieves a spare RI. In the maintenance flow diagram, this would show as a single maintenance activity with the associated time being the elapsed clock time. If the parameter of interest was MMH/OH, instead of MTTR, then the time entered in the activity block would be the combined MMH in lieu of the elapsed time.

5.1.7 Time Line Analysis

The estimated times used in the two prediction methodologies are synthesized using a time line analysis method. A time line analysis consists of computing the total elapsed time of a maintenance action by accounting for the time required to perform each step. The procedure for performing a time line analysis is as follows:

1. Identify each task that comprises the maintenance action.
2. Determine the time required to perform each task by either actual times, maintenance time standards, time studies, or engineering judgement.
3. Determine which actions can be done simultaneously if more than one maintenance personnel is available.
4. Determine the overall time to perform the maintenance action by summing up each time to perform each action.

Figure 63 is an example of how a time is synthesized for a simple physical task. The time associated with each task is extracted from the table of maintenance time standards shown in table 48.

RI NAME: MODULE (T/R) ELEMENT MAINTENANCE ACTION: INTERCHANGE

DESCRIPTION OF THE ELEMENTAL TASKS	TIME/ACTION	QTY	TOTAL TIME
REMOVE QUICK RELEASE COAX	0.04	4	0.16
REMOVE SLIDE LOCK CONNECTOR	0.09	1	0.09
REMOVE MODULE	0.09	1	0.09
REPLACE MODULE	0.11	1	0.11
REPLACE SLIDE LOCK CONNECTOR	0.12	1	0.12
REPLACE QUICK RELEASE COAX	0.04	4	0.16
		TOTAL TIME	0.73

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Figure 63. Example Time Synthesis Analysis

The time line analysis is also very helpful when analyzing the difference in repair time due to the number of maintenance personnel available. Figure 64 and 65 are the time line analyses of the same maintenance action with two different manpower levels.

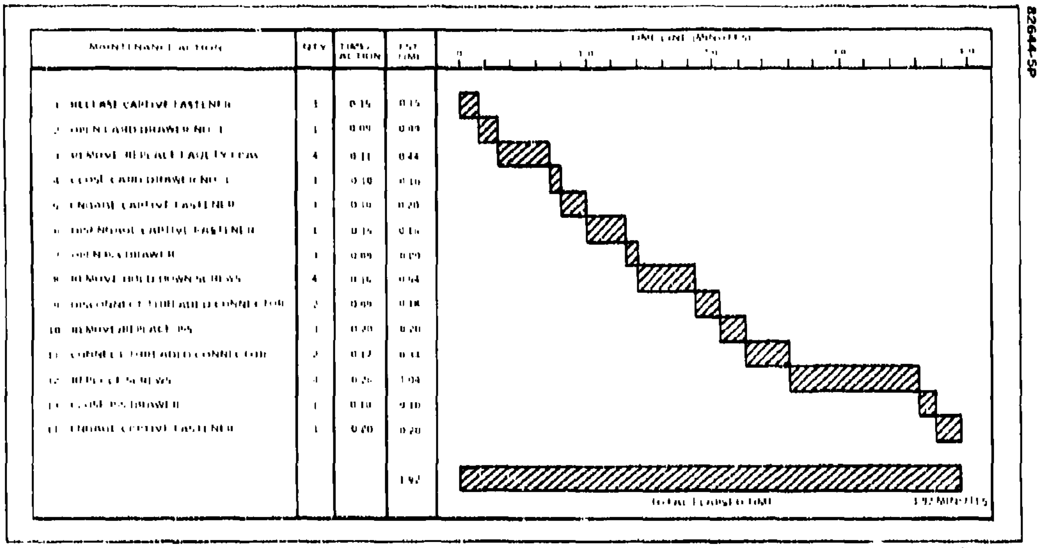

Figure 64. Time Line Analysis of the Time Required to Interchange a Group of 5 RIs from 2 Different Accesses Using One Maintenance Man

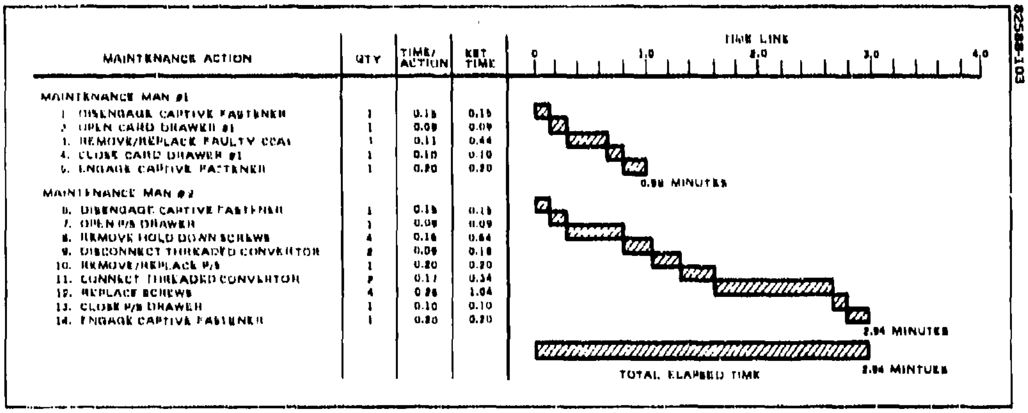

Figure 65. Time Line Analysis of the Time Required to Interchange a Group of 5 RIs from 2 Different Accesses Using Two Maintenance Men

6.1.8 Compute Maintainability Parameters

Once the MFD and Maintenance Correlation Matrix have been completed, it is an easy matter to compute the desired maintainability parameter(s). For example:

1. Mean Repair Time of nth RI

$$R_n = \frac{\sum_{j=1}^{J} \lambda_{nj} R_{nj}}{\sum_{j=1}^{J} \lambda_{nj}}$$

2. Equipment MTTR

$$MTTR = \frac{\sum_{n=1}^{N} \lambda_n R_n}{\sum_{n=1}^{N} \lambda_n}$$

Note that MTTR and R_n are computed on the basis of detectable failures.

3. Percent Isolation to a Single RI

$$I_1 = \frac{\sum_{k=1}^{K} \lambda_k}{\sum_{n=1}^{N} \sum_{j=1}^{J} \lambda_{nj}} \times 100$$

λ_k = failure rate associated with the kth FD&I Output which results in isolation to a single RI (i.e., $K_{nj} = 1$)

4. Percent Isolation to a Group of N or Less RIs

$$I_N = \frac{\sum_{k=1}^{K} \lambda_k}{\sum_{n=1}^{N} \sum_{j=1}^{J} \lambda_{nj}} \times 100$$

λ_k = failure rate associated with the kth FD&I Output which results in isolation to N or less RIs (i.e., $K_{nj} = 1 \ldots N$)

5.2 EARLY PREDICTION PROCEDURE

The tasks involved in performing an early prediction are:

1. definition of the prediction requirements
2. definition of the maintenance concept
3. determination of the prediction parameters
4. selection of the models
5. computation of the MTTR

The tasks mentioned above are expanded upon in more detail in the following subsections. Sample predictions are provided in Appendix G.

5.2.1 Definition of the Prediction Requirements

This step is the same as that required for a detailed prediction. Refer to section 5.1.1.

5.2.2 Definition of the Maintenance Concept

This step is the same as that required for a detailed prediction. Refer to section 5.1.2.

5.2.3 Determination of the Prediction Parameters

This task involves the tabulation and computation of the data necessary for the prediction models. The data necessary to perform this type of a prediction are:

1. configuration index defining the primary RIs
2. the failure rate (predicted or estimated) associated with each RI
3. the basic fault isolation test methodology of each RI
4. the replacement concept (if fault isolation is to a group of RIs)
5. the packaging philosophy
6. the fault isolation resolution, either estimated or required (e.g. x% to 1 RI or average RI group size)

Forms similar to the ones in figures 66 and 67 should be used for the data collection process.

Data is collected on Forms A and B at the level for which MTTR predictions are performed. For example, if a repair time is computed for every equipment within a system then a separate data collection form should be used for each equipment. The data may be tabulated on one data collection form, if the RIs are given in general terms, (e.g. computer memory, 15 CCAs, λ_T = 150 failures/10^6 hours) to avoid unnecessary paper. Data should be tabulated as follows:

1. First tabulate all the primary RIs and their associated failure rates in the respective columns of form A (figure 66). An example of a computed form A is provided in table G-5 of Appendix G.
2. Next described all the unique types (v) of performing each elemental activity (m) on form B (figure 67). Note that some maintenance actions (or predictions thereof) do not require that all the maintenance elements be included. These elements should be excluded from form B. Table G-4 of Appendix G is an example of how each unique activity should be entered.
3. Next enter the appropriate number of headings (V_m) for each elemental activity type along the top of form A.
4. For each unique activity type (m, v), synthesize times (T_{mv}) using actual times, time standards, time studies, or engineering judgment, and denote them in the respective column of form B.
5. Next denote the associated failure rate of each RI, with the corresponding activity type(s) that pertains to it on form A (refer to Table G-5).

The two completed RI data sheets (A and B) provide the basis for the early prediction technique. Once they have been completed the submodels can now be applied. How the data is used depends on which submodels are selected. The submodel selections are covered in the next section.

5.2.4 Selection of the Prediction Models

The general form of the prediction model is

$$MTTR = \bar{T}_P + \bar{T}_{FI} + \bar{T}_{SR} + \bar{T}_{FC} + \bar{T}_A + \bar{T}_{CO} + \bar{T}_{ST} = \sum_{m=1}^{M} \bar{T}_m$$

where:

$$\overline{T_{FC}} = \overline{T_D} + \overline{T_I} + \overline{T_R}$$

Variations of the model will be limited to the deletion of one or more elemental activity terms where appropriate.

FIGURE 66. RI DATA ANALYSIS SHEET - A

				Preparation				Fault Isolation				Spare Retrieval				
RI Description	λ	Qty	λ x Qty	$\lambda_{P_{1n}}$	$\lambda_{P_{2n}}$	•••	$\lambda_{P_{V_{pn}}}$	$\lambda_{FI_{1n}}$	$\lambda_{FI_{2n}}$	•••	$\lambda_{FI_{V_{FI}}n}$	$\lambda_{SR_{1n}}$	$\lambda_{SR_{2n}}$	•••	•••	
RI_1																
RI_2																
RI_3																
⋮																
RI_n																
Totals $\Sigma\lambda$																

FIGURE 67. RI DATA ANALYSIS SHEET - B

MTTR Element (m)	v	Description of the v^{th} Method	T_{m_v}	λ_{m_v}

The selection of the submodels to predict the various elemental times is dependent upon the maintenance concept imposed. Tables 52 and 53 summarize the forms of each sub-model for the various maintenance philosophies that can occur. Note that some elemental maintenance times may be constant over all the RIs. Therefore, the failure rate weighting model is not really necessary. Instead the average time can be computed by synthesizing the time required to perform the task.

The models presented in Table 52 are of a general form and generally can be applied to any equipment level (i.e., system, subsystem, equipment, unit, etc). The only limitation is that if $\bar{\bar{S}}_G$ or $\bar{\bar{S}}_I$ are computed, the prediction level must be consistent with the RI grouping ground rules presented in section 5.2.5.1. Otherwise, the elemental activity submodels are applied as the lowest level for which an MTTR prediction is desired. Higher level MTTR estimates are found by a failure rate weighted average of the lower levels. For example, the model to compute a system level MTTR, and equipment level MTTRs, for a system containing "D" equipments would be:

$$MTTR_{sys} = \frac{\sum_{d=1}^{D} \lambda_d MTTR_d}{\sum_{d=1}^{D} \lambda_d}.$$

where:

D = quantity of equipments contained in the system

λ_d = the failure rate of the d^{th} equipment

$MTTR_d$ = the mean time to repair of the d^{th} equipment

and

$$MTTR_d = \sum_{m=1}^{M} \bar{T}_{dm}$$

Table 52

Maintenance Philosophy			Preparation $\bar{T}_P$	Fault Isolation $\bar{T}_{FI}$	Spare Retrieval – $\bar{T}_{SR}$: Obtain All at Once	Spare Retrieval – $\bar{T}_{SR}$: Obtain When Needed	Disassembly/Reassembly $\bar{T}_D/\bar{T}_R$	Interchange $\bar{T}_I$	Alignment $\bar{T}_A$	Check Out $\bar{T}_C$	Startup $\bar{T}_{ST}$
Isolation to a Single RI							$\bar{T}_m = \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$ m = D, R	$\bar{T}_I = \frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_I} \lambda_{I_v}}$			
Isolation to a Group of RIs	Group Replacement	Multiple Access				$\bar{T}_{SR} = \frac{\sum_{v=1}^{V_{SR}} \lambda_{SR_v} T_{SR_v}}{\sum_{v=1}^{V_{SR}} \lambda_{SR_v}}$	$\bar{T}_m = \sum_{v=1}^{A} \left[[illegible] \left(\frac{\lambda_T - \lambda_a}{\lambda_T} \right)^{\bar{N}_G} \right] T_{m_a}$ m = D, R	$\bar{T}_I = \bar{T}_G \frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_I} \lambda_{I_v}}$		$\bar{T}_C = \frac{\sum_{v=1}^{V_C} \lambda_{C_v} T_{C_v}}{\sum_{v=1}^{V_C} \lambda_{C_v}}$	
		Single Access					$\bar{T}_m = \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$ m = D, R				
	Iterative Replacement: Multiple Access	Reassembly Not Required for Checkout	$\bar{T}_P = \frac{\sum_{v=1}^{V_P} \lambda_{P_v} T_{P_v}}{\sum_{v=1}^{V_P} \lambda_{P_v}}$	$\bar{T}_{FI} = \frac{\sum_{v=1}^{V_{FI}} \lambda_{FI_v} T_{FI_v}}{\sum_{v=1}^{V_{FI}} \lambda_{FI_v}}$	$\bar{T}_{SR} = \frac{\sum_{v=1}^{V_{SR}} \lambda_{SR_v} T_{SR_v}}{\sum_{v=1}^{V_{SR}} \lambda_{SR_v}}$		$\bar{T}_m = \left(\frac{\bar{N}+1}{2} \right) \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$ m = D, R		$\bar{T}_A = \frac{\sum_{v=1}^{V_A} \lambda_{A_v} T_{A_v}}{\sum_{v=1}^{V_A} \lambda_{A_v}}$		$\bar{T}_{ST} = \frac{\sum_{v=1}^{V_{ST}} \lambda_{ST_v} T_{ST_v}}{\sum_{v=1}^{V_{ST}} \lambda_{ST_v}}$
		Reassembly Required for Checkout				$\bar{T}_{SR} = (\bar{N}) \frac{\sum_{v=1}^{V_{SR}} \lambda_{SR_v} T_{SR_v}}{\sum_{v=1}^{V_{SR}} \lambda_{SR_v}}$	$\bar{T}_m = (\bar{N}_I) \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$ m = D, R	$\bar{T}_I = (\bar{N}) \frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_I} \lambda_{I_v}}$		$\bar{T}_C = (\bar{N}) \frac{\sum_{v=1}^{V_C} \lambda_{C_v} T_{C_v}}{\sum_{v=1}^{V_C} \lambda_{C_v}}$	
	Iterative Replacement: Single Access	Reassembly Not Required for Checkout					$\bar{T}_m = \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$ m = D, R				
		Reassembly Required for Checkout					$\bar{T}_m = (\bar{N}_I) \frac{\sum_{v=1}^{V_m} \lambda_{m_v} T_{m_v}}{\sum_{v=1}^{V_m} \lambda_{m_v}}$ m = D, R				

TABLE 53. DEFINITION OF EARLY PREDICTION MODEL TERMS

T_{P_v}	- time required to prepare a system for fault isolation using the v^{th} method
T_{FI_v}	- time required to isolate a fault using the v^{th} method
T_{SR_v}	- time required to obtain a spare using the v^{th} method
T_{D_v}	- time required to perform disassembly using the v^{th} method
T_{R_v}	- time required to perform reassembly using the v^{th} method
T_{I_v}	- time required to interchange an RI using the v^{th} method
T_{A_v}	- time required to align or calibrate an RI using the v^{th} method
T_{C_v}	- time required to check a repair using the v^{th} method
T_{ST_v}	- time required to start up a system using the v^{th} method
λ_{P_v}	- failure rate of RIs associated with the v^{th} method of performing preparation
λ_{FI_v}	- failure rate of RIs associated with the v^{th} method of performing fault isolation
λ_{SR_v}	- failure rate of RIs associated with the v^{th} method of performing spare retrieval
λ_{D_v}	- failure rate of RIs associated with the v^{th} method of performing disassembly
λ_{R_v}	- failure rate of RIs associated with the v^{th} method of performing reassembly
λ_{I_v}	- failure rate of RIs associated with the v^{th} method of performing interchange
λ_{A_v}	- failure rate of RIs associated with the v^{th} method of performing alignment
λ_{C_v}	- failure rate of RIs associated with the v^{th} method of performing checkout
λ_{ST_v}	- failure rate of RIs associated with the v^{th} method of performing start-up
V_P	- the number of unique ways to perform preparation
V_{FI}	- the number of unique ways to perform fault isolation

TABLE 53. DEFINITION OF EARLY PREDICTION MODEL TERMS (Con't)

V_{SR}	- the number of unique ways to perform spare retrieval
V_D	- the number of unique ways to perform disassembly
V_R	- the number of unique ways to perform reassembly
V_I	- the number of unique ways to perform interchange
V_A	- the number of unique ways to perform alignment
V_C	- the number of unique ways to perform check-out
V_{ST}	- the number of unique ways to perform start-up
$\overline{S}_G$	- the average number of RIs contained in a fault isolation result
$\overline{S}_I$	- the average number of interchanges required to correct a fault
A	- the number of unique accesses ($A \leq V_D$ or V_R)
$\overline{A}$	- the average number of unique accesses required per fault isolation result
λ_a	- the failure rate of the RIs that require the a^{th} type of access
λ_T	- the total system failure rate
T_{D_a}	- the time required to disassemble the a^{th} access
T_{R_a}	- the time required to reassembly the a^{th} access

where

$$\bar{T}_{dm} = \frac{\sum_{v=1}^{V_{dm}} \lambda_{dmv} T_{dmv}}{\sum_{v=1}^{V_{dm}} \lambda_{dmv}}$$

5.2.5 Computation of the MTTR

Once the submodels have been selected the data tabulated on Forms A and B of section 5.2.3 can now be used to compute the average times for each elemental maintenance task.

The MTTR is computed at the level at which $\bar{S}$(I or G) is established. For example if $\bar{S}$(I or G) can be estimated for each equipment within a system, then the lowest level that the MTTR can be predicted is the equipment level. Higher level predictions of the MTTR, such as the system MTTR, can be computed by taking a failure rate weighted average of the equipment MTTRs within the system.

Computation of repair times below the level at which $\bar{S}$(I or G) is established may result in an inaccurate account of repair times. For example, if $\bar{S}$(I or G) were computed at the system level and MTTRs were computed at the equipment level, then the computed equipment MTTRs may be in error since they will not account for repair actions that may involve other equipments. Therefore, in order to compute repair times at lower levels, a value for $\bar{S}$(I or G) must be established at that level.

The only exception to the above, is if fault isolation is down to a single RI ($\bar{S}$ = 1 for the entire system, equipment ...), then the MTTR may be computed at any level since ambiguities between RIs do not exist. Otherwise the following criteria must be followed.

> In order to compute a repair time at a given level, a value for $\bar{S}$(I or G) must be established at that level.

Once the level at which the repair times will be computed has been established, the models selected are then used to compute the times for each elemental activity at that level. The higher level repair times are computed by a failure rate weighted average as mentioned previously.

Values for $\bar{S}_G$, $\bar{S}_I$, $\bar{A}$, T_D' and/or T_R', where required for insertion into the elemental activity submodels, should be computed in accordance with the following subsections.

5.2.5.1 Method of Computing $\bar{S}_G$ and $\bar{S}_I$

The average number of RIs in a fault isolation result ($\bar{S}_G$) and the average number of iterations required to correct a fault ($\bar{S}_I$) play an important role in the prediction of MTTR when fault isolation is to a group of RIs. Two methods are presented for computing $\bar{S}$(I or G), 1) compute $\bar{S}$(I or G) using the specified or design requirements or 2) compute $\bar{S}$(I or G) by assessing the approximate fault isolation capabilities of the system/equipment.

The first method of computing $\bar{S}$(I or G) depends upon how the fault isolation requirements are specified. If the fault isolation resolution is specified as follows:

X_1% to $\leq N_1$ RIs

X_2% to $\leq N_2$ RIs, but $> N_1$ RIs

X_3% to $\leq N_3$ RIs, but $> N_2$ RIs

and $X_1 + X_2 + X_3 = 100\%$

then,

$$\bar{S} = \frac{X_1 \left(\frac{N_1 + 1}{2}\right) + X_2 \left(\frac{N_1 + N_2 + 1}{2}\right) + X_3 \left(\frac{N_2 + N_3 + 1}{2}\right)}{100}$$

If the fault isolation requirements are specified as follows:

X_1% to $\leq N_1$ RIs

X_2% to $\leq N_2$ RIs

100% to $\leq N_3$ RIs

where $X_1\% < X_2\% < 100\%$

then,

$$\bar{S} = \frac{X_1 \left(\frac{N_1 + 1}{2}\right) + (X_2 - X_1) \left(\frac{N_1 + N_2 + 1}{2}\right) + (100 - X_2)\left(\frac{N_2 + N_3 + 1}{2}\right)}{100}$$

The predicted MTTR using this method of computing $\bar{S}$ is based on the assumption that the specified fault isolation requirements have been (or will be) met. The resulting prediction is the inherent MTTR that will be realized by achieving the specified requirements.

This approach is valuable during the early stages of equipment development for purposes of allocation and assessment of the requirements facility. This approach should not be used when data is available on the actual fault isolation characteristics.

The second method of computing $\bar{S}$(I or G) involves an analysis of the fault isolation characteristics of the subject equipment/system as follows:

1. prepare a simple block diagram depicting the system and how each major function is related (i.e. show functional interfaces). As an example refer to the data processing and display subsystem block diagram of figure G-2 in Appendix G.
2. Group the functions (RIs) into "G" RI sets such that:
   - an estimate of the fault isolation can be determined for each RI set
   - each RI set is independent of any other RI set
   - each RI set established is the smallest set that can be established

   For example, figure G-3 of Appendix G shows how the RIs for the DP&D subsystem can be grouped.
3. For each RI set (g) estimate the average fault isolation resolution or the average number of RIs per fault isolation result depending on the maintenance philosophy in question ($\bar{S}_{(I)_g}$ if iterative replacement, $\bar{S}_{(G)_g}$ if group replacement)
4. Compute the average $\bar{S}$(I or G) for the system using a failure rate weighted model.

$$\bar{S}(\text{I or G}) = \frac{\sum_{g=1}^{G} \lambda_g \bar{S}_g}{\sum_{g=1}^{G} \lambda_g}$$

   If the repair times are computed at lower levels then the overall $\bar{S}$ does not have to be computed.

5.2.5.2 Computation of $\bar{A}$, $\overline{T}'_D$, and $\overline{T}'_R$

The average number of accesses (disassemblies and reassemblies) required per fault isolation result $(\overline{A})$ can be computed as follows:

$$\bar{A} = \frac{\sum_{g=1}^{G} \lambda_g \bar{A}_g}{\sum_{g=1}^{G} \lambda_g}$$

and,

$$\bar{A}_g = \sum_{a=1}^{A_g} P_{ga} = \sum_{a=1}^{A_g} \left[1 - \frac{(\lambda_g - \lambda_{ga})^{\bar{S}_g}}{\lambda_g} \right]$$

where:

$\bar{A}_g$ = the average number of accesses required per fault isolation result in the g^{th} RI set, ("G" RI sets established the same way as was done for $\bar{S}$)

P_{ga} = the probability that the a^{th} access will be required for any random fault isolation result

A_g = the number of unique accesses in the g^{th} RI set

λ_g = the failure rate of the RIs located in the g^{th} RI set

λ_{ga} = the failure rate of the RIs located in the a^{th} access location of the g^{th} RI set

$\bar{S}_g$ = average number of RIs per fault isolation result for the g^{th} RI set

The computation of $\bar{T}'_D$ and $\bar{T}'_R$ is exactly like the method used for $\bar{A}$ with one modification. Each probability is multiplied by its appropriate disassembly or reassembly time. The equation for $\bar{T}'_D$ or $\bar{T}'_R$ is:

$$\bar{T}'_D = \frac{\sum_{g=1}^{G} \lambda_g \bar{T}'_{D_g}}{\sum_{g=1}^{G} \lambda_g}$$

and,

$$\overline{T}'_R = \frac{\sum_{g=1}^{G} \lambda_g \overline{T}'_{D_g}}{\sum_{g=1}^{G} \lambda_g}$$

where:

$$\bar{T}'_{D_g} = \sum_{a=1}^{A_g} \left[1 - \left(\frac{\lambda_g - \lambda_{ga}}{\lambda_g} \right)^{\bar{S}_g} \right] T_{D_{ga}}$$

the same equations also hold true for reassembly, (T'_{R_g})

where:

$T_{D_{ga}}$ = the disassembly or reassembly time for the a^{th} access of the g^{th} RI set.

Note here also that if the RIs are grouped into just one set instead of G sets, then all the subscripts "g" will fall-out and the failure rate weighting of the g^{th} RI sets is not necessary.

5.2.5.3 Determination of MTTR

The MTTR can now be computed by summing up the average times computed from each submodel. Thus the MTTR is expressed as

$$MTTR = \sum_{m=1}^{M} \bar{T}_m$$

If the repair time computed is for a lower level then the higher level repair times are computed as follows

$$MTTR = \frac{\sum_{\ell=1}^{L} \lambda_\ell \, MTTR_\ell}{\sum_{\ell=1}^{L} \lambda_\ell}$$

$MTTR_\ell$ = mean repair time of the lower levels
λ_ℓ = failure rate of the ℓ^{th} lower level
L = quantity of lower level breakdowns

5.3 COMPATIBILITY OF THE DETAILED AND EARLY PREDICTION PROCEDURES

The early and detailed prediction methodologies presented in this report are compatible and complementary since they both incorporate a time synthesis approach to evaluate repair times. This compatibility is important since it allows a uniform approach to data collection, and provides the capability for combining the two procedures when a mixture of detailed and preliminary data is available.

Figure 68 below depicts a timeline of the phases that a system goes through from start to end. The figure shows that the preliminary model is applicable throughout all the program stages, whereas the detailed prediction model is only applicable from time t_1 to t_f. The information required to perform a detailed prediction is usually not available prior to t_1. The method presented herein is a technique to utilize the available information to get the most precise maintainability prediction that the data will allow. The general form of the model is:

$$MTTR(t) = \frac{\lambda_P \, MTTR_P + \lambda_D \, MTTR_D}{\lambda_T}$$

where:

$MTTR(t)$ = predicted MTTR for time t of a system's program

$MTTR_P$ = the predicted MTTR of that portion of the entire system, using the early prediction methodology

$MTTR_D$ = the predicted MTTR of only the RIs that have enough data available to perform a detailed analysis

λ_D = the failure rate of the RIs that have information available for detailed analysis

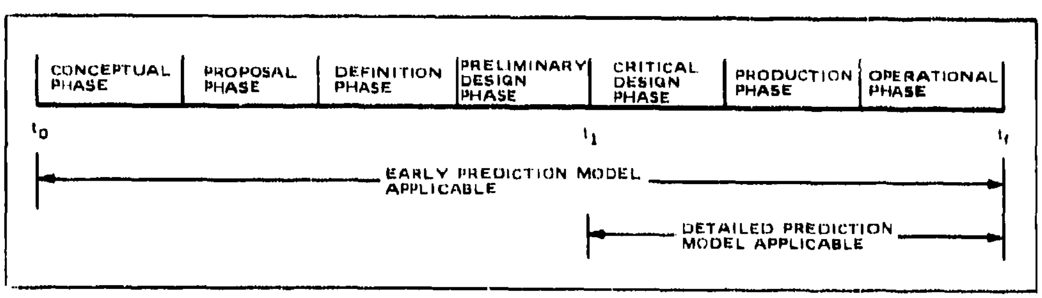

Figure 68. Various Phases of a System

λ_P = the failure rate of that portion of the system for which the early prediction methodology was used

λ_T = the failure rate of the entire system in question (equal to $\lambda_p + \lambda_D$)

Figure 69 demonstrates how the precision of MTTR(t) increases as time progresses. The shape of the curve between t_1 and t_2 is dependent upon the speed with which the detailed information is obtained and how accurate the early prediction is relative to the final value. Time t_1 typically occurs at a program's critical design review and t_2 occurs at the begging of a program's production phase.

The implementation of the model presented here allows the user to keep track of the overall system maintainability parameters throughout the design and development of a system. By using this technique the user can detect whether or not the maintainability design requirements specified will be met before the system is complete. If the maintainability requirements appear that they will not be met, then the designers can be informed to the necessary changes before it is too late. Thus time and money can be saved by carefully tracking the maintainability parameters throughout a system's development.

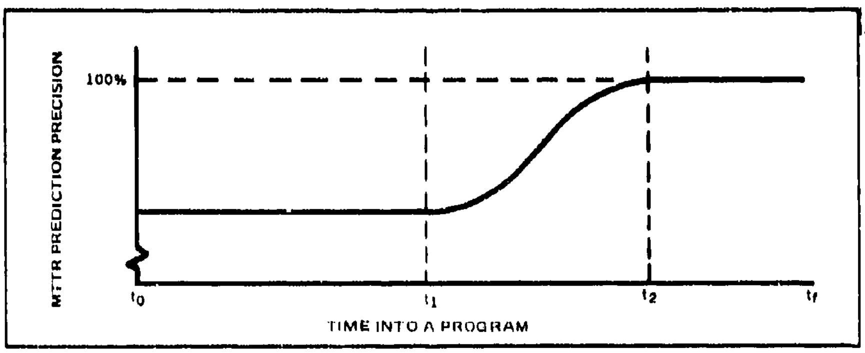

Figure 69. Precision of MTTR Prediction as Time Progresses

SECTION 6.0 CONCLUSIONS/RECOMMENDATIONS

The maintainability prediction methodology presented in this document achieves the objectives for which it was intended. It provides a technique for analyzing the maintainability of modern equipments/systems including direct accountability of diagnostic/isolation/test capabilities, packaging, replaceable item makeup and failure rates. The methodology can be applied at any maintenance level, for any maintenance concept, and for avionics, ground electronics and shipboard electronics.

The implementation of the methodology presented here allows the user to keep track of the overall system maintainability parameters throughout the design and development of a system. By using the developed techniques the user can detect whether or not the maintainability design requirements specified will be met before the system is complete. If the maintainability requirements appear that they will not be met, then the designers can be informed of the necessary changes before it is too late. Thus time and money can be saved by carefully tracking the maintainability parameters throughout a system's development.

The maintainability prediction methodology is divided into two separate procedures: 1) a detailed procedure for use when detailed design and support data is available, and 2) an early procedure for use when preliminary design data is available. Both procedures are time synthesis techniques and both use the same general model for predicting MTTR. When a combination of detailed and preliminary data is available, the two procedures can be used together to yield a composite estimate of MTTR.

In addition to the time synthesis type of early prediction procedure, a second approach using multiple regression equations was attempted. This effort produced regression equations which showed good correlation with the sample data on which they were based, however, use of the equations is not recommended. The equations are very insensitive to design factors (e.g. fault isolation automaticity) which are obviously important maintainability characteristics, and the applicability of the equations to equipments/systems other than the ones on which they were based is unknown.

The detailed prediction procedure can produce very accurate predictions (limited only by the quality of the input data) and can be applied at any hardware level for any maintenance concept. The early prediction procedure yields less accurate predictions (limited by the quality and quantity of input data) and again can be applied at any equipment level. The models used in the early prediction procedure are

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dependent on the specified maintenance philosophy and a set of seven (7) different models are used depending on the fault isolation resolution and repair policy.

The early prediction procedure can be applied at any hardware level, however, the accuracy of the result is dependent on the level selected. For most cases, the early prediction procedure requires an assessment of $\bar{S}$ (the average number of IRs in a fault isolation result or the average number of RI replacements required to correct a malfunction). The prediction is performed at the level at which $\bar{S}$ is established. Higher level predictions are computed using a failure rate weighted average of lower level predictions, and lower level predictions can be made by assuming the same $\bar{S}$ applies at lower levels. The accuracy of the prediction is directly related to a level at which $\bar{S}$ can be established; the lower the level of $\bar{S}$ the more accurate the prediction results.

The maintenance time standards provided in section 4 of this report provide a comprehensive coverage of modern packaging. Periodic updating will be required as new packaging/construction techniques are developed. The standards are applicable to any type of electronic equipment (i.e. avionics, ground electronics, shipboard electronics) however work factors may have to be applied to account for environment differences (e.g., ambient temperature, space impediments, work platform stability). Work factors for space impediments, low temperature maintenance, and maintenance in various sea states were examined. Data related to additional work factors is very limited and additional studies could be beneficial in some areas such as airborne maintenance and maintenance personnel skill levels.

The development methodologies are complete and usable as presented. Enhancement of the methodology could be provided by further study in the following areas:

1) In depth trials of both the detailed and early prediction procedures. Sample predictions were performed for both procedures (refer to appendicies F and G) however these cover only a limited set of equipment types, maintenance environments, and maintenance philosophies. Further studies are recommended to investigate and verify the use of the procedures for all maintainability predictions.
2) Development of procedures for estimating $\bar{S}$. The early prediction procedure is dependent on an accurate assessment of $\bar{S}$. Further studies are recommended for the development of techniques for assessing $\bar{S}$ based on early design data or design criteria.

3) Development of computerized techniques. A computer program was developed and presented for the calculations of M_{max} (ϕ). Other areas of the presented methodology are also amenable to computerization. The computation of $\bar{\bar{S}}$ involves the calculation of a large number of probabilities which could be simplified with the use of a simple computer program. Likewise, the determination of relationships between RIs and FD&I outputs is a long and tedious task. A considerable savings could be achieved through the use of computerized failure modes and effects analyses in conjunction with the detailed prediction procedure. Additional time savings could be realized by computerizing some of the prediction bookkeeping functions such as time line analyses, computation of repair times from the maintenance flow diagram and computation of failure rate weighted averages. Further studies are recommended for development of standard computer programs to perform the functions identified above, and to investigate and develop programs for other appropriate aspects of the prediction methodology.

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APPENDIX A — RESULTS OF COMPUTERIZED STEPWISE ANALYSIS PROGRAM

The results of the computerized stepwise regression analysis program (SRAP), which provide the four multiple linear regression equations presented in section 2.4.1, are shown in figure A-1 through A-4. The data for each of the four equations is presented in two parts. The first part, provided in the "A" portion, presents the input data and the regression equation parameters.

The input data is provided in the top portion of the "A" figures and contains the following:

Number of Cases — Defines the sample size of the data set evaluated.

Total Number of Variables — Defines the number of variables to be analyzed. It is equal to the number of independent variables plus 1.

Variables — The variables to be analyzed are listed with the dependent variable listed first. The mean and standard deviation of each variable are computed and listed.

The second half of the "A" figure provides the regression equation data that was outputted on the last step of the SRAP. Contained in this output are:

Multiple R — The multiple correlation coefficient.

Variables in Equation — Identifies the variables included in the resulting regression equation and the coefficient of each variable. The first entry is the equation constant.

The "B" part of each figure summarizes the results of the analysis obtained at each step of the stepwise regression. For each step that was performed the following information is given:

Variable Entered/Removed — This entry describes which variable was entered or removed at each step.

Multiple R and RSQ — This entry gives the multiple correlation coefficient and the square of the multiple correlation coefficient that was computed at each interval. This was the value used to determine whether the dependent and independent variable showed good correlation. (R and R squared can vary from 0 to 1).

Increase in RSQ — This value shows the increase in the square of the multiple correlation coefficient at each step that a variable was entered or removed.

F Value to Enter or Remove — This value is the value of the F statistic for the variable that is entered or removed at each step. The variable with the highest F value to enter is the variable that produces the largest increase in the multiple correlation. The variable with the lowest F value to remove is the variable that results in the lowest increase in the multiple correlation.

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Number of Independent Variables – This value denotes the number of independent variables in the regression equation computed at each step.

Predicted vs Actual – Data contained in this part of the computer results compare the observed values of the dependent values with the predicted values.

PROBLEM CODE MSTUDY
NUMBER OF CASES 31

TOTAL NUMBER OF VARIABLES 12

VARIABLE		MEAN	STANDARD DEVIATION
K=KA+KS	1	1.73245	1.47487
MRIQ	2	51.51613	62.17165
ACT	3	2032.93530	2490.69824
FR	4	410.38672	427.18628
DIAG	5	0.49806	3.05573
DIG	6	0.39284	0.37944
PP	7	0.16339	0.25589
ALI	8	0.10548	0.16897
PARTS	9	5487.51562	6663.26172
TANAL	10	0.41097	0.39729
QFIR	11	189.48386	350.06299
QFIR/MRIQ	12	5.11322	6.26759

STEP NUMBER 11
VARIABLE ENTERED 2

MULTIPLE R 0.8002

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	F TO REMOVE
(CONSTANT		0.41750)	
MRIQ	2	0.00159	0.0378 (2)
ACT	3	-0.00021	0.3277 (2)
FR	4	0.00177	7.7105 (2)
DIAG	5	0.20615	3.4588 (2)
DIG	6	0.73410	0.2645 (2)
PP	7	-0.27612	0.0483 (2)
ALI	8	-3.60056	4.0650 (2)
PARTS	9	0.00207	0.4547 (2)
TANAL	10	0.98337	0.5666 (2)
QFIR	11	-0.00104	0.5808 (2)
QFIR/MRIQ	12	0.05553	0.7716 (2)

F-LEVEL [illegible] TOLERANCE INSUFFICIENT FOR FURTHER COMPUTATION

82588-56

Figure A-1A. SRAP Computer Results for K (Run No. 1)

82588-57

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	4 – FR	0.5921	0.3506	0.3506	15.6535	1
2	7 – PP	0.6668	0.4367	0.0861	4.2812	2
3	8 – ALI	0.7131	0.5085	0.0718	3.9436	3
4	5 – DIAG	0.7626	0.5815	0.0731	4.5398	4
5	10 – TANAL	0.7805	0.6091	0.0276	1.7652	5
6	12 – QFIR/MRIQ	0.7882	0.6213	0.0121	0.7688	6
7	6 – DIG	0.7912	0.6259	0.0047	0.2876	7
8	11 – QFIR	0.7946	0.6314	0.0055	0.3265	8
9	9 – PARTS	0.7962	0.6339	0.0025	0.1480	9
10	3 – ACT	0.7998	0.6397	0.0057	0.3183	10
11	2 – MRIQ	0.8002	0.6404	0.0007	0.0378	11

LIST OF RESIDUALS

CASE NUMBER	K' COMPUTED	K ACTUAL	K COMPUTED	K' ACTUAL	RESIDUAL
1	0.1860	0.17	0.6775	0.49	-0.4915
2	0.6160	0.46	0.4988	0.39	0.1172
3	1.1710	0.69	0.7468	0.53	0.4242
4	1.7150	0.82	0.9786	0.62	0.7364
5	0.2880	0.25	0.2771	0.24	0.0109
6	0.1510	0.14	0.0615	0.06	0.0895
7	0.0830	0.08	0.2109	0.19	-0.1279
8	1.1090	0.67	1.1953	0.70	-0.0863
9	3.2190	0.96	2.9357	0.95	0.2833
10	0.5450	0.42	0.5424	0.42	0.0026
11	1.7720	0.83	2.8678	0.94	-1.0958
12	0.1860	0.17	0.3846	0.32	-0.1986
13	1.5610	0.79	1.3381	0.74	0.2229
14	2.4080	0.96	2.5121	0.92	-0.1041
15	2.9960	0.95	2.6024	0.93	0.3936
16	4.6050	0.99	2.4485	0.91	2.1565
17	3.9120	0.98	3.1269	0.96	0.7851
18	2.2070	0.89	2.0505	0.87	0.1565
19	2.6590	0.93	3.1435	0.96	-0.4845
20	3.2190	0.96	3.0173	0.95	0.2017
21	4.6050	0.99	5.0778	0.99	-0.4728
22	2.6590	0.93	3.1837	0.96	-0.5247
23	2.8130	0.94	2.1196	0.88	0.6934
24	0.1860	0.17	2.0832	0.88	-1.8972
25	4.6050	0.99	1.9332	0.86	2.6718
26	1.0500	0.65	1.1685	0.69	-0.1185
27	1.1390	0.68	1.7276	0.82	-0.5886
28	0.1510	0.14	0.4539	0.36	-0.3029
29	0.0410	0.04	1.7299	0.82	-1.6889
30	0.2880	0.25	0.8143	0.56	-0.5263
31	1.5610	0.79	1.7977	0.83	-0.2367

NOTE:

$K' = -\ln(1 - K)$

Figure A-1B. SRAP Computer Results for K (Run No. 1)

```
BMD02R - STEPWISE REGRESSION - REVISED DECEMBER 24, 1975
HEALTH SCIENCES COMPUTING FACILITY, UCLA

PROBLEM CODE                        MSTUDY
NUMBER OF CASES                         12

TOTAL NUMBER OF VARIABLES                8
```

VARIABLE		MEAN	STANDARD DEVIATION
KA	1	1,65816	1,35073
MRIQ	2	60,00000	87,51826
ACT	3	3183,75000	3368,42256
FR	4	670,12451	543,96997
DIAG	5	2,44166	4,65646
DIG	6	0,39425	0,43008
TANAL	7	0,59417	0,43408
QFIR/MRIQ	8	5,77000	4,88381

```
STEP NUMBER        6
VARIABLE ENTERED   2

MULTIPLE R              0,9348
```

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	F TO REMOVE
(CONSTANT	-0,55633)	
2 MRIQ	-0,00296	0,2266 (2)
3 ACT	0,00026	2,5925 (2)
4 FR	0,00058	1,0280 (2)
6 DIAG	0,11134	3,1569 (2)
7 TANAL	-0,26660	0,1104 (2)
8 QFIR/MRIQ	0,18208	7,9021 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR,	TOLERANCE	F TO ENTER
6 DIG	-0,51617	0,0002	1,4528 (2)

Figure A-2A. SRAP Computer Results for K_A (Run No. 2)

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SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	MULTIPLE RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	7 TANAL		0.6146	0.3778	0.3778	6.0708	1
2	5 DIAG		0.7563	0.5720	0.1942	4.0845	2
3	8 OFIR/MRIQ.		0.8723	0.7610	0.1890	6.3249	3
4	3 ACT		0.9005	0.8109	0.0499	1.8484	4
5	4 FR		0.9317	0.8681	0.0572	2.6914	5
6	2 MRIQ		0.9348	0.8736	0.0057	0.2266	6

LIST OF RESIDUALS

CASE NUMBER	K_A' ACTUAL	K_A ACTUAL	K_A' COMPUTED	$\hat{K}_A$ COMPUTED	RESIDUAL	$\hat{K}_I$
1	3.8610	0.93	4.0542	0.93	-0.1932	0.95
2	2.1450	0.83	1.8029	0.79	0.3421	0.94
3	2.5760	0.85	2.2438	0.82	0.3322	0.92
4	0.3680	0.28	0.7111	0.46	-0.3431	0.91
5	0.0530	0.05	0.8385	0.54	-0.7855	0.96
6	0.2460	0.19	0.3961	0.28	-0.1501	0.87
7	1.9250	0.82	0.7421	0.50	1.1829	0.96
8	2.0690	0.83	1.9163	0.81	0.1527	0.95
9	2.5160	0.91	2.5653	0.91	-0.0493	0.99
10	3.4660	0.93	3.5894	0.93	-0.1234	0.96
11	0.6230	0.38	0.8480	0.47	-0.2250	0.82
12	0.0500	0.04	0.1901	0.14	-0.1401	0.82

FINISH CARD ENCOUNTERED
PROGRAM TERMINATED

NOTE:
$K_A' = -\ln\left(1 - \frac{K_A}{K}\right)$

Figure A-2B. SRAP Computer Results for K_A (Run No. 2)

INPUT DATA

```
BMD02R - STEPWISE REGRESSION - REVISED DECEMBER 24, 1975
HEALTH SCIENCES COMPUTING FACILITY, UCLA

PROBLEM CODE                        MSTUDY
NUMBER OF CASES                         26

TOTAL NUMBER OF VARIABLES              11
```

VARIABLE		MEAN	STANDARD DEVIATION
DISO	1	5.98846	3.92390
MRIQ	2	45.73076	66.50197
FR	3	325.33228	447.81445
KA	4	0.30692	0.40139
KS	5	0.34346	0.36965
DIAG	6	1.14231	3.32415
RES1	7	0.57385	0.40825
AVG	8	1.30731	1.03813
PP	9	0.15527	0.28192
QFIR/MRIQ	10	5.16461	6.82695
DIG	11	0.36969	0.38260

REGRESSION EQUATION

```
STEP NUMBER    10
VARIABLE ENTERED      8

MULTIPLE R                0.6508
```

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	F TO REMOVE
(CONSTANT	7.94368)	
2 MRIQ	-0.01069	0.2456 (2)
3 FR	0.00033	0.0139 (2)
4 KA	-1.87650	0.1914 (2)
5 KS	0.76582	0.0457 (2)
6 DIAG	-0.17393	0.2729 (2)
7 RES1	-4.37948	1.6795 (2)
8 AVG	-0.23858	1.0364 (2)
9 PP	5.50142	2.2021 (2)
10 QFIR/MRIQ.	0.12732	0.6775 (2)
11 DIG	0.67562	0.0661 (2)

F-LEVEL OR TOLERANCE INSUFFICIENT FOR FURTHER COMPUTATION

Figure A-3A. SRAP Computer Results for $MTTR_{ISO}$ (Run No. 3)

SRAP SUMMARY

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	KA		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	BM		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	DFIR/MRIQ		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	MRIQ		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	DIAG		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	FR		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	DIG		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	AVG		[illegible]	[illegible]	[illegible]	[illegible]	10

PREDICTED VS ACTUAL

LIST OF RESIDUALS

CASE NUMBER	$MTTR_{ISO}$ COMPUTED	$MTTR_{ISO}$ ACTUAL
1	[illegible]	1.393[illegible]
[illegible]	[illegible]	[illegible]

Figure A-3B. SRAP Computer Results for $MTTR_{ISO}$ (Run No. 3)

8258-61

BMD02R - STEPWISE REGRESSION - REVISED DECEMBER 24, 1975
HEALTH SCIENCES COMPUTING FACILITY, UCLA

PROBLEM CODE MSTUDY
NUMBER OF CASES 26

TOTAL NUMBER OF VARIABLES 11

VARIABLE		MEAN	STANDARD DEVIATION
DCO	1	3.10000	2.38616
MRIQ	2	49.73076	69.50197
FR	3	345.33226	447.81445
KA	4	0.30256	0.40134
KS	5	0.31577	0.39094
DIAG	6	1.14231	3.15435
DIG	7	0.16654	0.35280
PP	8	0.15327	0.28193
ALI	9	0.05308	0.14763
TANAL	10	0.43654	0.42395
QFIR/MRIQ	11	5.16461	6.82695

STEP NUMBER 10
VARIABLE ENTERED 5

MULTIPLE R 0.6873

VARIABLES IN EQUATION

VARIABLE	COEFFICIENT	F TO REMOVE
(CONSTANT	0.34380)	
2 MRIQ	-0.00605	0.3343 (9)
3 FR	0.00163	1.3338 (9)
4 KA	-0.12514	0.0034 (9)
5 KS	0.06420	0.0014 (9)
6 DIAG	0.11696	0.1138 (9)
7 DIG	0.70426	0.0693 (9)
8 PP	0.67364	0.0628 (9)
9 ALI	1.59043	0.0448 (9)
10 TANAL	3.70016	0.2081 (9)
11 QFIR/MRIQ	0.06233	0.4603 (9)

F-LEVEL OR TOLERANCE INSUFFICIENT FOR FURTHER COMPUTATION

Figure A-4A. SRAP Computer Results for $MTTR_{CO}$ (Sub No. 4)

82588-63

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	10 TANAL	[illegible]	[illegible]	[illegible]	[illegible]	1
[illegible]	3 FR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	11 OFIR/MRID	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6 DIAG	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7 MRID	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	8 ALI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	9 PF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	7 DIO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4 KA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	5 KS	[illegible]	[illegible]	0.0000	[illegible]	10

LIST OF RESIDUALS

CASE NUMBER	$MTTR_{CO}$ COMPUTED	$MTTR_{CO}$ ACTUAL
[illegible]	[illegible]	[illegible]

Figure A-4B. SRAP Computer Results for $MTTR_{CO}$ (Run No. 4)

APPENDIX B - DERIVATION OF $M_{max}(\Phi)$ FOR THE LOGNORMAL DISTRIBUTION

Let $y = \text{Log } x$ and be normally distributed (μ_y, σ_y). Then $x = e^y$ and is lognormally distributed and

$$E(x) = E(e^y)$$

$$E(y) = E(\ln x)$$

Since $E(e^y)$ is equal to the moment generating function of y evaluated at 1 and y is normally distributed

$$E(e^y) = \mu_x = e^{\mu_y + \frac{1}{2}\sigma_y^2} \tag{1}$$

The coefficient of variation for the lognormal distribution is

$$\eta = \frac{\sigma_x}{\mu_x} = (e^{\sigma_y^2} - 1)^{1/2}$$

Hence

$$\sigma_y^2 = \log \frac{\sigma_x^2 + \mu_x^2}{\mu_x^2} \tag{2}$$

and

$$\mu_y = \log \mu_x - \frac{1}{2} \log \frac{\sigma_x^2 + \mu_x^2}{\mu_x^2} = \log \frac{\mu_x^2}{\left[\sigma_x^2 + \mu_x^2\right]^{\frac{1}{2}}} \tag{3}$$

A simple relationship exists between the quantiles of the lognormal distribution f(x) and the standard normal distribution f(y). If $M_{max}(\Phi)$ and v_Φ represent the values of x and v, a standard normal variable, respectively for the qth quantile then;

$$M_{max}(\Phi) = e^{\mu_y + v_\Phi \sigma_y} \tag{4}$$

substituting (2) and (3) in (4) we find that

$$M_{max}(\Phi) = \frac{\mu_x^2}{\left[\mu_x^2 + \sigma_x^2\right]^{\frac{1}{2}}} \exp \left\{ v_\Phi \left[\log \frac{\sigma_x^2 + \mu_x^2}{\mu_x^2} \right]^{\frac{1}{2}} \right\}$$

Reference: J. Aitchison and J. Brown, The Lognormal Distribution, Cambridge, Mass. 1957

APPENDIX C – ESTIMATES OF M_{max} (Φ) FOR LOGNORMAL REPAIR DISTRIBUTIONS

This appendix provides estimates of M_{max} (Φ) for lognormally distributed repair times. The M_{max} (Φ) values are found by:

1. Selecting Table C-1 or C-2. Table C-1 is used for percentiles (Φ) of 60, 70, and 80 percent. Table C-2 is used for percentiles of 90, 95, and 99 percent.
2. Locate the mean repair time (MEAN) which most closely approximates the MTTR of the equipment/system in question. The repair times are provided from 0.1 to 2.6 in steps of 0.1.
3. Locate the corresponding repair times standard deviation (SIGMA) which is estimated for the subject equipment/system. Values are provided from 0.1 to 2.5 in steps of 0.1.
4. Read the value of M_{max} (Φ) under the appropriate percentile column.

TABLE C-1

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
.1	.1	.087315	.109419	.142493
.1	.2	.061674	.086984	.130081
.1	.3	.046447	.070079	.113406
.1	.4	.037152	.058630	.100002
.1	.5	.030983	.050535	.089592
.1	.6	.026606	.044532	.081369
.1	.7	.023342	.039899	.074723
.1	.8	.020814	.036212	.069236
.1	.9	.018796	.033203	.064622
.1	1.0	.017148	.030697	.060682
.1	1.1	.015775	.028575	.057273
.1	1.2	.014614	.026754	.054290
.1	1.3	.013618	.025171	.051654
.1	1.4	.012755	.023782	.049306
.1	1.5	.011998	.022552	.047199
.1	1.6	.011330	.021454	.045295
.1	1.7	.010735	.020469	.043565
.1	1.8	.010202	.019578	.041985
.1	1.9	.009721	.018769	.040536
.1	2.0	.009286	.018030	.039201
.1	2.1	.008889	.017353	.037966
.1	2.2	.008526	.016729	.036820
.1	2.3	.008193	.016153	.035753
.1	2.4	.007886	.015619	.034757
.1	2.5	.007602	.015123	.033824
.2	.1	.201628	.229170	.262217
.2	.2	.174630	.218639	.284986
.2	.3	.146064	.196038	.276636
.2	.4	.123348	.173968	.260163
.2	.5	.106102	.155384	.242835
.2	.6	.092895	.140157	.226812
.2	.7	.082564	.127649	.212556
.2	.8	.074303	.117259	.200004
.2	.9	.067563	.108518	.188953
.2	1.0	.061965	.101071	.179183
.2	1.1	.057245	.094652	.170501
.2	1.2	.053212	.089063	.162738
.2	1.3	.049727	.084151	.155757
.2	1.4	.046684	.079799	.149446
.2	1.5	.044005	.075914	.143709
.2	1.6	.041627	.072424	.138471
.2	1.7	.039502	.069271	.133668
.2	1.8	.037592	.066406	.129244
.2	1.9	.035865	.063791	.125156
.2	2.0	.034296	.061394	.121364
.2	2.1	.032864	.059188	.117837
.2	2.2	.031551	.057151	.114546
.2	2.3	.030343	.055262	.111467
.2	2.4	.029228	.053507	.108580
.2	2.5	.028196	.051871	.105866

TABLE C-1 (Continued)

60TH 70TH AND 80TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
.3	.1	.308999	.337417	.374011
.3	.2	.291067	.343064	.415832
.3	.3	.261946	.328258	.427478
.3	.4	.232534	.305822	.421424
.3	.5	.206706	.282530	.407281
.3	.6	.185022	.260952	.390244
.3	.7	.167000	.241768	.372778
.3	.8	.151974	.224948	.355961
.3	.9	.139342	.210236	.340218
.3	1.0	.128616	.197333	.325667
.3	1.1	.119418	.185964	.312288
.3	1.2	.111455	.175889	.300006
.3	1.3	.104500	.166909	.288725
.3	1.4	.098377	.158860	.278346
.3	1.5	.092948	.151606	.268775
.3	1.6	.088101	.145036	.259927
.3	1.7	.083748	.139058	.251727
.3	1.8	.079818	.133595	.244107
.3	1.9	.076252	.128582	.237007
.3	2.0	.073001	.123965	.230376
.3	2.1	.070026	.119698	.224168
.3	2.2	.067292	.115743	.218344
.3	2.3	.064772	.112065	.212867
.3	2.4	.062441	.108636	.207707
.3	2.5	.060278	.105432	.202836
.4	.1	.413035	.441541	.477410
.4	.2	.403256	.458339	.532433
.4	.3	.379013	.454249	.561473
.4	.4	.349261	.437678	.569971
.4	.5	.319492	.415575	.565313
.4	.6	.292127	.392076	.553272
.4	.7	.267876	.369238	.537551
.4	.8	.246695	.347936	.520326
.4	.9	.228265	.328447	.502814
.4	1.0	.212204	.310768	.485669
.4	1.1	.198151	.294778	.469222
.4	1.2	.185789	.280314	.453624
.4	1.3	.174855	.267207	.438923
.4	1.4	.165128	.255297	.425113
.4	1.5	.156428	.244443	.412158
.4	1.6	.148606	.234519	.400008
.4	1.7	.141539	.225415	.388609
.4	1.8	.135125	.217036	.377905
.4	1.9	.129279	.209302	.367841
.4	2.0	.123930	.202142	.358367
.4	2.1	.119017	.195493	.349435
.4	2.2	.114490	.189305	.341001
.4	2.3	.110305	.183529	.333027
.4	2.4	.106424	.178126	.325475
.4	2.5	.102816	.173061	.318315

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
.5	.1	.515518	.543947	.579215
.5	.2	.511835	.568172	.642030
.5	.3	.493416	.573439	.683724
.5	.4	.466591	.564587	.705714
.5	.5	.436576	.547097	.712464
.5	.6	.406623	.525254	.708736
.5	.7	.378393	.501846	.698370
.5	.8	.352557	.478493	.684094
.5	.9	.329253	.456050	.667720
.5	1.0	.308369	.434920	.650407
.5	1.1	.289687	.415246	.632878
.5	1.2	.272960	.397036	.615571
.5	1.3	.257951	.380223	.598744
.5	1.4	.244440	.364711	.582540
.5	1.5	.232236	.350393	.567030
.5	1.6	.221173	.337159	.552239
.5	1.7	.211108	.324909	.538165
.5	1.8	.201917	.313546	.524788
.5	1.9	.193497	.302985	.512081
.5	2.0	.185758	.293149	.500010
.5	2.1	.178622	.283968	.488540
.5	2.2	.172023	.275383	.477634
.5	2.3	.165904	.267337	.467257
.5	2.4	.160215	.259783	.457376
.5	2.5	.154913	.252677	.447959
.6	.1	.617183	.645504	.680304
.6	.2	.617998	.674833	.748023
.6	.3	.604883	.687509	.798650
.6	.4	.582133	.686129	.831664
.6	.5	.554038	.674565	.849315
.6	.6	.523891	.656516	.854957
.6	.7	.493830	.634874	.851889
.6	.8	.465067	.611644	.842848
.6	.9	.438191	.588114	.829908
.6	1.0	.413412	.565060	.814561
.6	1.1	.390732	.542917	.797851
.6	1.2	.370043	.521904	.780489
.6	1.3	.351190	.502107	.762952
.6	1.4	.334001	.483536	.745556
.6	1.5	.318306	.466152	.728504
.6	1.6	.303943	.449895	.711923
.6	1.7	.290784	.434694	.695887
.6	1.8	.278684	.420471	.680436
.6	1.9	.267533	.407153	.665585
.6	2.0	.257232	.394667	.651333
.6	2.1	.247692	.382946	.637669
.6	2.2	.238836	.371928	.624576
.6	2.3	.230595	.361556	.612032
.6	2.4	.222909	.351778	.600013
.6	2.5	.215727	.342547	.588494

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
.7	.1	.718373	.746589	.781022
.7	.2	.722570	.779571	.852016
.7	.3	.713944	.797999	.909022
.7	.4	.695388	.803159	.950680
.7	.5	.670232	.797639	.977825
.7	.6	.641427	.784357	.992571
.7	.7	.611206	.765936	.997449
.7	.8	.581076	.744451	.994874
.7	.9	.551961	.721416	.986892
.7	1.0	.524368	.697872	.975127
.7	1.1	.498529	.674502	.960815
.7	1.2	.474508	.651733	.944872
.7	1.3	.452267	.629817	.927964
.7	1.4	.431717	.608888	.910570
.7	1.5	.412740	.589003	.893030
.7	1.6	.395211	.570172	.875581
.7	1.7	.379003	.552370	.858387
.7	1.8	.363998	.535559	.841557
.7	1.9	.350084	.519689	.825164
.7	2.0	.337159	.504704	.809251
.7	2.1	.325131	.490550	.793842
.7	2.2	.313917	.477170	.778948
.7	2.3	.303443	.464512	.764568
.7	2.4	.293641	.452526	.750696
.7	2.5	.284453	.441165	.737321
.8	.1	.819263	.847385	.881526
.8	.2	.826070	.883082	.954821
.8	.3	.821164	.906002	1.016487
.8	.4	.806511	.916678	1.064867
.8	.5	.784635	.916780	1.099959
.8	.6	.758026	.908498	1.122945
.8	.7	.728788	.894042	1.135621
.8	.8	.698521	.875355	1.139942
.8	.9	.668344	.853997	1.137748
.8	1.0	.638985	.831150	1.130627
.8	1.1	.610877	.807670	1.119881
.8	1.2	.584254	.784153	1.106543
.8	1.3	.559210	.761001	1.091413
.8	1.4	.535753	.738477	1.075101
.8	1.5	.513838	.716737	1.058066
.8	1.6	.493391	.695872	1.040652
.8	1.7	.474321	.675921	1.023110
.8	1.8	.456531	.656093	1.005628
.8	1.9	.439924	.638774	.988339
.8	2.0	.424408	.621536	.971338
.8	2.1	.409895	.605144	.954692
.8	2.2	.396301	.589556	.938445
.8	2.3	.383552	.574732	.922625
.8	2.4	.371578	.560628	.907248
.8	2.5	.360317	.547202	.892322

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
.9	.1	.919954	.947994	.981897
.9	.2	.928822	.985773	1.056874
.9	.3	.926997	1.012250	1.122034
.9	.4	.915829	1.027526	1.175669
.9	.5	.897217	1.032642	1.217311
.9	.6	.873200	1.029193	1.247496
.9	.7	.845653	1.018963	1.267407
.9	.8	.816133	1.003661	1.278538
.9	.9	.785837	.984775	1.282435
.9	1.0	.755626	.963520	1.280545
.9	1.1	.726089	.940846	1.274135
.9	1.2	.697601	.917466	1.264272
.9	1.3	.670382	.893902	1.251827
.9	1.4	.644542	.870525	1.237500
.9	1.5	.620118	.847591	1.221842
.9	1.6	.597096	.825270	1.205285
.9	1.7	.575432	.803671	1.188163
.9	1.8	.555065	.782856	1.170733
.9	1.9	.535921	.762854	1.153192
.9	2.0	.517925	.743673	1.135688
.9	2.1	.501001	.725304	1.118333
.9	2.2	.485072	.707727	1.101210
.9	2.3	.470069	.690917	1.084380
.9	2.4	.455923	.674843	1.067884
.9	2.5	.442572	.659473	1.051753
1.0	.1	1.020504	1.048473	1.082180
1.0	.2	1.031035	1.087893	1.158430
1.0	.3	1.031779	1.117232	1.226270
1.0	.4	1.023670	1.136345	1.284060
1.0	.5	1.008139	1.145848	1.331084
1.0	.6	.986831	1.146879	1.367449
1.0	.7	.961365	1.140839	1.393870
1.0	.8	.933182	1.129174	1.411429
1.0	.9	.903469	1.113235	1.421364
1.0	1.0	.873152	1.094194	1.424928
1.0	1.1	.842916	1.073026	1.423285
1.0	1.2	.813247	1.050508	1.417471
1.0	1.3	.784468	1.027244	1.408375
1.0	1.4	.756787	1.003692	1.396740
1.0	1.5	.730318	.980191	1.383179
1.0	1.6	.705114	.956985	1.368189
1.0	1.7	.681184	.934249	1.352170
1.0	1.8	.658507	.912100	1.335441
1.0	1.9	.637043	.890615	1.318256
1.0	2.0	.616739	.869840	1.300815
1.0	2.1	.597536	.849797	1.283274
1.0	2.2	.579374	.830493	1.265756
1.0	2.3	.562189	.811922	1.248354
1.0	2.4	.545921	.794071	1.231142
1.0	2.5	.530510	.776920	1.214173

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
1.1	.1	1.120953	1.148859	1.182403
1.1	.2	1.132852	1.189603	1.259642
1.1	.3	1.135756	1.22179	1.329585
1.1	.4	1.130316	1.243608	1.390700
1.1	.5	1.117617	1.256921	1.442159
1.1	.6	1.098976	1.262014	1.483793
1.1	.7	1.075768	1.259966	1.51972
1.1	.8	1.049283	1.25172	1.539436
1.1	.9	1.020649	1.239213	1.555141
1.1	1.0	.990798	1.222777	1.564127
1.1	1.1	.960467	1.203613	1.567420
1.1	1.2	.930212	1.182518	1.565983
1.1	1.3	.900441	1.160141	1.560676
1.1	1.4	.871437	1.136998	1.552250
1.1	1.5	.843389	1.113493	1.541346
1.1	1.6	.816413	1.089934	1.528503
1.1	1.7	.790573	1.066554	1.514168
1.1	1.8	.765892	1.043522	1.498711
1.1	1.9	.742364	1.020961	1.482432
1.1	2.0	.719967	.998957	1.465578
1.1	2.1	.698665	.977566	1.448346
1.1	2.2	.678412	.956824	1.430896
1.1	2.3	.659162	.936747	1.413356
1.1	2.4	.640862	.917343	1.395828
1.1	2.5	.623461	.898606	1.378392
1.2	.1	1.221326	1.24917 8	1.282582
1.2	.2	1.234367	1.291009	1.360609
1.2	.3	1.239105	1.324622	1.432231
1.2	.4	1.235996	1.349667	1.496045
1.2	.5	1.225864	1.366284	1.551181
1.2	.6	1.209767	1.375017	1.597300
1.2	.7	1.188856	1.376685	1.634524
1.2	.8	1.164267	1.372257	1.663328
1.2	.9	1.137039	1.362746	1.684418
1.2	1.0	1.108076	1.349129	1.698630
1.2	1.1	1.078124	1.332297	1.706841
1.2	1.2	1.047782	1.313033	1.709913
1.2	1.3	1.017512	1.292000	1.708649
1.2	1.4	.987661	1.269748	1.703777
1.2	1.5	.958477	1.246725	1.695940
1.2	1.6	.930134	1.223288	1.685695
1.2	1.7	.902747	1.199717	1.673519
1.2	1.8	.876381	1.176229	1.659815
1.2	1.9	.851071	1.152989	1.644922
1.2	2.0	.826824	1.130121	1.629123
1.2	2.1	.803629	1.107715	1.612652
1.2	2.2	.781464	1.085834	1.595703
1.2	2.3	.760295	1.064523	1.578434
1.2	2.4	.740086	1.043808	1.560978
1.2	2.5	.720795	1.023703	1.543438

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
1.3	.1	1.321641	1.349445	1.382729
1.3	.2	1.335649	1.392184	1.461395
1.3	.3	1.341959	1.427423	1.534383
1.3	.4	1.340890	1.454780	1.600414
1.3	.5	1.333072	1.474268	1.658621
1.3	.6	1.319353	1.486246	1.708565
1.3	.7	1.300697	1.491326	1.750194
1.3	.8	1.278089	1.490285	1.783778
1.3	.9	1.252469	1.483978	1.809818
1.3	1.0	1.224686	1.473262	1.828966
1.3	1.1	1.195475	1.458955	1.841950
1.3	1.2	1.165447	1.441800	1.849520
1.3	1.3	1.135097	1.422452	1.852406
1.3	1.4	1.104816	1.401473	1.851290
1.3	1.5	1.074900	1.379334	1.846796
1.3	1.6	1.045571	1.356427	1.839480
1.3	1.7	1.016988	1.333069	1.829830
1.3	1.8	.989259	1.309516	1.818271
1.3	1.9	.962455	1.285968	1.805166
1.3	2.0	.936615	1.262586	1.790827
1.3	2.1	.911754	1.239489	1.775517
1.3	2.2	.887874	1.216772	1.759460
1.3	2.3	.864959	1.194502	1.742841
1.3	2.4	.842988	1.172728	1.725818
1.3	2.5	.821933	1.151484	1.708521
1.4	.1	1.421910	1.449672	1.482852
1.4	.2	1.436746	1.493179	1.562045
1.4	.3	1.444417	1.529800	1.636159
1.4	.4	1.445141	1.559142	1.704033
1.4	.5	1.439404	1.581134	1.764826
1.4	.6	1.427887	1.595997	1.818044
1.4	.7	1.411394	1.604187	1.863517
1.4	.8	1.390776	1.606317	1.901359
1.4	.9	1.366872	1.603099	1.931906
1.4	1.0	1.340465	1.595277	1.955650
1.4	1.1	1.312257	1.583585	1.973183
1.4	1.2	1.282855	1.568714	1.985141
1.4	1.3	1.252768	1.551290	1.992171
1.4	1.4	1.222412	1.531872	1.994899
1.4	1.5	1.192121	1.510939	1.993911
1.4	1.6	1.162153	1.488903	1.989748
1.4	1.7	1.132705	1.466106	1.982895
1.4	1.8	1.103923	1.442833	1.973784
1.4	1.9	1.075910	1.419316	1.962794
1.4	2.0	1.048736	1.395744	1.950254
1.4	2.1	1.022445	1.372267	1.936451
1.4	2.2	.997058	1.349004	1.921630
1.4	2.3	.972584	1.326046	1.906001
1.4	2.4	.949016	1.303466	1.889743
1.4	2.5	.926340	1.281315	1.873009

TABLE C-1 (Continued)

60 TH 70 TH AND 80TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
1.5	.1	1.522143	1.549867	1.582955
1.5	.2	1.537697	1.594032	1.662589
1.5	.3	1.546553	1.631840	1.737645
1.5	.4	1.548861	1.662899	1.807068
1.5	.5	1.544995	1.687084	1.870057
1.5	.6	1.535505	1.704517	1.926090
1.5	.7	1.521060	1.715528	1.974920
1.5	.8	1.502394	1.720600	2.016547
1.5	.9	1.480246	1.720318	2.051173
1.5	1.0	1.455333	1.715321	2.079160
1.5	1.1	1.428313	1.706259	2.100972
1.5	1.2	1.399773	1.693762	2.117143
1.5	1.3	1.370221	1.678420	2.128232
1.5	1.4	1.340088	1.660770	2.134800
1.5	1.5	1.309728	1.641291	2.137391
1.5	1.6	1.279428	1.620400	2.136516
1.5	1.7	1.249417	1.598455	2.132645
1.5	1.8	1.219870	1.575762	2.126207
1.5	1.9	1.190921	1.552576	2.117585
1.5	2.0	1.162668	1.529110	2.107119
1.5	2.1	1.135180	1.505538	2.095111
1.5	2.2	1.108502	1.482003	2.081821
1.5	2.3	1.082662	1.458619	2.067479
1.5	2.4	1.057671	1.435478	2.052283
1.5	2.5	1.033530	1.412651	2.036404
1.6	.1	1.622346	1.650036	1.683044
1.6	.2	1.638527	1.694771	1.763052
1.6	.3	1.648426	1.733607	1.838905
1.6	.4	1.652140	1.766163	1.909642
1.6	.5	1.649958	1.792279	1.974508
1.6	.6	1.642327	1.812004	2.032975
1.6	.7	1.629806	1.825571	2.084745
1.6	.8	1.613022	1.833356	2.129734
1.6	.9	1.592629	1.835838	2.168042
1.6	1.0	1.569271	1.833560	2.199918
1.6	1.1	1.543559	1.827089	2.225723
1.6	1.2	1.516052	1.816995	2.245890
1.6	1.3	1.487248	1.803824	2.260898
1.6	1.4	1.457577	1.788085	2.271241
1.6	1.5	1.427406	1.770242	2.277412
1.6	1.6	1.397043	1.750710	2.279884
1.6	1.7	1.366737	1.729856	2.279107
1.6	1.8	1.336689	1.707995	2.275496
1.6	1.9	1.307059	1.685399	2.269431
1.6	2.0	1.277969	1.662300	2.261254
1.6	2.1	1.249512	1.638893	2.251273
1.6	2.2	1.221755	1.615339	2.239762
1.6	2.3	1.194743	1.591773	2.226963
1.6	2.4	1.168508	1.568305	2.213087
1.6	2.5	1.143065	1.545025	2.198321

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES OF THE LOGNORMAL DISTRIBUTION
FOR MEANS AND SIGMAS FROM .1 TO 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
1.7	.1	1.722525	1.750185	1.783121
1.7	.2	1.739258	1.795417	1.863449
1.7	.3	1.750080	1.835152	1.939982
1.7	.4	1.755048	1.869022	2.011845
1.7	.5	1.754387	1.896846	2.078329
1.7	.6	1.748460	1.918621	2.138912
1.7	.7	1.737735	1.934503	2.193264
1.7	.8	1.722748	1.944783	2.241242
1.7	.9	1.704075	1.949850	2.282867
1.7	1.0	1.682292	1.950160	2.318298
1.7	1.1	1.657962	1.946208	2.347804
1.7	1.2	1.631609	1.938501	2.371732
1.7	1.3	1.603710	1.927538	2.390484
1.7	1.4	1.574692	1.913795	2.404439
1.7	1.5	1.544925	1.897716	2.414185
1.7	1.6	1.514724	1.879707	2.420008
1.7	1.7	1.484358	1.860130	2.422377
1.7	1.8	1.454046	1.839303	2.421688
1.7	1.9	1.423968	1.817523	2.418309
1.7	2.0	1.394267	1.795019	2.412580
1.7	2.1	1.365057	1.772006	2.404810
1.7	2.2	1.336425	1.748662	2.395278
1.7	2.3	1.308435	1.725139	2.384233
1.7	2.4	1.281134	1.701563	2.371898
1.7	2.5	1.254553	1.678039	2.358472
1.8	.1	1.822684	1.850317	1.883189
1.8	.2	1.839908	1.895987	1.963794
1.8	.3	1.851550	1.936513	2.040913
1.8	.4	1.857643	1.971545	2.113749
1.8	.5	1.858359	2.000888	2.181637
1.8	.6	1.853994	2.024500	2.244068
1.8	.7	1.844939	2.042482	2.300697
1.8	.8	1.831657	2.055053	2.351338
1.8	.9	1.814650	2.062526	2.395950
1.8	1.0	1.794434	2.065284	2.434622
1.8	1.1	1.771521	2.063755	2.467545
1.8	1.2	1.746400	2.058386	2.494991
1.8	1.3	1.719524	2.049630	2.517292
1.8	1.4	1.691306	2.037926	2.534814
1.8	1.5	1.662113	2.023694	2.547945
1.8	1.6	1.632267	2.007322	2.557075
1.8	1.7	1.602042	1.989166	2.562593
1.8	1.8	1.571673	1.969549	2.564870
1.8	1.9	1.541356	1.948757	2.564258
1.8	2.0	1.511252	1.927041	2.561089
1.8	2.1	1.481491	1.904622	2.555666
1.8	2.2	1.452178	1.881692	2.548269
1.8	2.3	1.423394	1.858416	2.539152
1.8	2.4	1.395202	1.834932	2.528543
1.8	2.5	1.367647	1.811362	2.516649

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
1.9	.1	1.922826	1.950434	1.983248
1.9	.2	1.940487	1.996493	2.064095
1.9	.3	1.952866	2.037721	2.141725
1.9	.4	1.959971	2.073785	2.215407
1.9	.5	1.961937	2.104485	2.284520
1.9	.6	1.959004	2.129751	2.348576
1.9	.7	1.951503	2.149640	2.407220
1.9	.8	1.939830	2.164313	2.460237
1.9	.9	1.924423	2.174021	2.507548
1.9	1.0	1.905745	2.179083	2.549166
1.9	1.1	1.884258	2.179867	2.585236
1.9	1.2	1.860415	2.176766	2.615959
1.9	1.3	1.834642	2.170186	2.641605
1.9	1.4	1.807336	2.160530	2.662481
1.9	1.5	1.778854	2.148189	2.678926
1.9	1.6	1.749516	2.133532	2.691289
1.9	1.7	1.719604	2.116905	2.699921
1.9	1.8	1.689359	2.098621	2.705168
1.9	1.9	1.658988	2.078969	2.707362
1.9	2.0	1.628667	2.058202	2.706821
1.9	2.1	1.598540	2.036550	2.703841
1.9	2.2	1.568727	2.014212	2.698697
1.9	2.3	1.539325	1.991362	2.691643
1.9	2.4	1.510409	1.968153	2.682910
1.9	2.5	1.482040	1.944716	2.672710
2.0	.1	2.022953	2.050538	2.083301
2.0	.2	2.041008	2.096945	2.164360
2.0	.3	2.054049	2.138800	2.242437
2.0	.4	2.062071	2.175786	2.316861
2.0	.5	2.065175	2.207704	2.387052
2.0	.6	2.063558	2.234464	2.452541
2.0	.7	2.057500	2.256087	2.512975
2.0	.8	2.047339	2.272690	2.568120
2.0	.9	2.033462	2.284471	2.617855
2.0	1.0	2.016278	2.291695	2.662167
2.0	1.1	1.996206	2.294676	2.701130
2.0	1.2	1.973662	2.293758	2.734898
2.0	1.3	1.949045	2.289303	2.763682
2.0	1.4	1.922731	2.281678	2.787740
2.0	1.5	1.895065	2.271244	2.807363
2.0	1.6	1.866363	2.258349	2.822857
2.0	1.7	1.836905	2.243322	2.834540
2.0	1.8	1.806938	2.226469	2.842729
2.0	1.9	1.776675	2.208075	2.847734
2.0	2.0	1.746304	2.188388	2.849855
2.0	2.1	1.715979	2.167646	2.849378
2.0	2.2	1.685832	2.146052	2.846570
2.0	2.3	1.655974	2.123788	2.841681
2.0	2.4	1.626493	2.101016	2.834942
2.0	2.5	1.597462	2.077876	2.826567

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
2.1	.1	2.123068	2.150633	2.183348
2.1	.2	2.141479	2.197352	2.264595
2.1	.3	2.155120	2.239768	2.343067
2.1	.4	2.163973	2.277584	2.418144
2.1	.5	2.168116	2.310599	2.489288
2.1	.6	2.167711	2.338713	2.556049
2.1	.7	2.162993	2.361917	2.618079
2.1	.8	2.154253	2.380293	2.675133
2.1	.9	2.141831	2.393996	2.727066
2.1	1.0	2.126089	2.403245	2.773827
2.1	1.1	2.107407	2.408305	2.815449
2.1	1.2	2.086164	2.409476	2.852039
2.1	1.3	2.062733	2.407081	2.883759
2.1	1.4	2.037467	2.401450	2.910823
2.1	1.5	2.010697	2.392916	2.933476
2.1	1.6	1.982730	2.381803	2.951983
2.1	1.7	1.953843	2.368423	2.966635
2.1	1.8	1.924282	2.353070	2.977712
2.1	1.9	1.894268	2.336019	2.985505
2.1	2.0	1.863992	2.317521	2.990293
2.1	2.1	1.833619	2.297807	2.992348
2.1	2.2	1.803291	2.277067	2.991028
2.1	2.3	1.773127	2.255547	2.989277
2.1	2.4	1.743229	2.233354	2.984622
2.1	2.5	1.713680	2.210656	2.978176
2.2	.1	2.223173	2.250716	2.283390
2.2	.2	2.241906	2.297719	2.364805
2.2	.3	2.256092	2.340642	2.443627
2.2	.4	2.265704	2.379207	2.519285
2.2	.5	2.270799	2.413216	2.591275
2.2	.6	2.271511	2.442559	2.659169
2.2	.7	2.268038	2.467209	2.722628
2.2	.8	2.260632	2.487216	2.781400
2.2	.9	2.249589	2.502702	2.835323
2.2	1.0	2.235233	2.513843	2.884318
2.2	1.1	2.217905	2.520865	2.928384
2.2	1.2	2.197953	2.524029	2.967586
2.2	1.3	2.175719	2.523618	3.002049
2.2	1.4	2.151537	2.519932	3.031943
2.2	1.5	2.125721	2.513274	3.057473
2.2	1.6	2.098566	2.503943	3.078872
2.2	1.7	2.070343	2.492234	3.096388
2.2	1.8	2.041298	2.478426	3.110283
2.2	1.9	2.011650	2.462784	3.120817
2.2	2.0	1.981597	2.445555	3.128253
2.2	2.1	1.951308	2.426966	3.132846
2.2	2.2	1.920934	2.407227	3.134841
2.2	2.3	1.890603	2.386527	3.134473
2.2	2.4	1.860424	2.365036	3.131966
2.2	2.5	1.830492	2.342909	3.127527

TABLE C-1 (Continued)

60TH 70TH AND 80TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
2.3	.1	2.323268	2.350796	2.383428
2.3	.2	2.342296	2.398052	2.464994
2.3	.3	2.356978	2.441434	2.544128
2.3	.4	2.367284	2.480678	2.620303
2.3	.5	2.373255	2.515590	2.693049
2.3	.6	2.374999	2.546055	2.761958
2.3	.7	2.372684	2.572029	2.826701
2.3	.8	2.366529	2.593540	2.887024←←
2.3	.9	2.356792	2.610678	2.942753
2.3	1.0	2.343763	2.623588	2.993788
2.3	1.1	2.327748	2.632459	3.040099
2.3	1.2	2.309063	2.637517	3.081721
2.3	1.3	2.288026	2.639012	3.118741
2.3	1.4	2.264947	2.637211	3.151293
2.3	1.5	2.240124	2.632390	3.179548
2.3	1.6	2.213839	2.624826	3.203703
2.3	1.7	2.186355	2.614793	3.223978
2.3	1.8	2.157913	2.602556	3.240604
2.3	1.9	2.128733	2.588368	3.253819
2.3	2.0	2.099011	2.572468	3.263864
2.3	2.1	2.068923	2.555079	3.270978
2.3	2.2	2.038624	2.536409	3.275393
2.3	2.3	2.008249	2.516646	3.277334
2.3	2.4	1.977915	2.495964	3.277014
2.3	2.5	1.947724	2.474520	3.274639
2.4	.1	2.423355	2.450867	2.483462
2.4	.2	2.442652	2.498356	2.565163
2.4	.3	2.457790	2.542156	2.644578
2.4	.4	2.468734	2.582018	2.721218
2.4	.5	2.475511	2.617754	2.794641
2.4	.6	2.478210	2.649245	2.864462
2.4	.7	2.476974	2.676435	2.930363
2.4	.8	2.471991	2.699334	2.992090
2.4	.9	2.463491	2.718006	3.049462
2.4	1.0	2.451728	2.732568	3.102362
2.4	1.1	2.436979	2.743180	3.150740
2.4	1.2	2.419533	2.750034	3.194600
2.4	1.3	2.399681	2.753352	3.234003
2.4	1.4	2.377712	2.753370	3.269049
2.4	1.5	2.353906	2.750339	3.299877
2.4	1.6	2.328533	2.744514	3.326655
2.4	1.7	2.301846	2.736149	3.349573
2.4	1.8	2.274079	2.725492	3.368835
2.4	1.9	2.245448	2.712786	3.384657
2.4	2.0	2.216151	2.698258	3.397259
2.4	2.1	2.186365	2.682127	3.406862
2.4	2.2	2.156248	2.664595	3.413683
2.4	2.3	2.125940	2.645850	3.417936
2.4	2.4	2.095564	2.626066	3.419826
2.4	2.5	2.065228	2.605401	3.419551

TABLE C-1 (Continued)

60 TH 70 TH AND 80 TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	60 PERCENT	70 PERCENT	80 PERCENT
2.5	.1	2.523436	2.550933	2.583494
2.5	.2	2.542960	2.598634	2.665317
2.5	.3	2.558537	2.642817	2.744985
2.5	.4	2.570067	2.683243	2.822043
2.5	.5	2.577589	2.719733	2.896076
2.5	.6	2.581174	2.752165	2.9667[illegible]1
2.5	.7	2.580944	2.780475	3.033669
2.5	.8	2.577063	2.804656	3.096671
2.5	.9	2.569730	2.824755	3.155540
2.5	1.0	2.559174	2.840862	3.210149
2.5	1.1	2.545644	2.853110	3.260429
2.5	1.2	2.529402	2.861666	3.306363
2.5	1.3	2.510715	2.866723	3.347984
2.5	1.4	2.489852	2.868491	3.385367
2.5	1.5	2.467077	2.867197	3.418622
2.5	1.6	2.442645	2.863074	3.447890
2.5	1.7	2.416797	2.856356	3.473333
2.5	1.8	2.389760	2.847277	3.495131
2.5	1.9	2.361748	2.836064	3.513477
2.5	2.0	2.332954	2.822936	3.528571
2.5	2.1	2.303556	2.808103	3.540616
2.5	2.2	2.273714	2.791764	3.549815
2.5	2.3	2.243571	2.774101	3.556370
2.5	2.4	2.213256	2.755289	3.560474
2.5	2.5	2.182879	2.735485	3.562319
2.6	.1	2.623510	2.650993	2.683523
2.6	.2	2.643282	2.698890	2.765458
2.6	.3	2.659225	2.743423	2.845354
2.6	.4	2.671297	2.784367	2.922790
2.6	.5	2.679509	2.821549	2.997375
2.6	.6	2.683918	2.854847	3.068765
2.6	.7	2.684628	2.884190	3.136664
2.6	.8	2.681780	2.909560	3.200827
2.6	.9	2.675551	2.930985	3.261065
2.6	1.0	2.666144	2.948537	3.317242
2.6	1.1	2.653783	2.962325	3.369275
2.6	1.2	2.638707	2.972491	3.417130
2.6	1.3	2.621161	2.979204	3.460817
2.6	1.4	2.601394	2.982651	3.500389
2.6	1.5	2.579653	2.983036	3.535930
2.6	1.6	2.556177	2.980571	3.567556
2.6	1.7	2.531199	2.975471	3.595406
2.6	1.8	2.504938	2.967955	3.619636
2.6	1.9	2.477599	2.958237	3.640418
2.6	2.0	2.449373	2.946524	3.657931
2.6	2.1	2.420436	2.933018	3.672363
2.6	2.2	2.390950	2.917910	3.683900
2.6	2.3	2.361059	2.901381	3.692731
2.6	2.4	2.330894	2.883601	3.699041
2.6	2.5	2.300571	2.864726	3.703009

TABLE C-2

90TH 95TH AND 99TH PERCENTILES OF THE LOGNORMAL DISTRIBUTION FOR MEANS AND SIGMAS FROM .1 TO 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
.1	.1	.205523	.278112	.490493
.1	.2	.227300	.360383	.855549
.1	.3	.221083	.383683	1.079166
.1	.4	.209702	.386526	1.217203
.1	.5	.198214	.381881	1.306660
.1	.6	.187723	.374400	1.366951
.1	.7	.178380	.365944	1.408679
.1	.8	.170094	.357316	1.438011
.1	.9	.162725	.348874	1.458740
.1	1.0	.156138	.340772	1.473312
.1	1.1	.150215	.333071	1.483370
.1	1.2	.144859	.325783	1.490047
.1	1.3	.139988	.318901	1.494154
.1	1.4	.135536	.312402	1.496277
.1	1.5	.131448	.306265	1.496854
.1	1.6	.127678	.300461	1.496214
.1	1.7	.124188	.294968	1.494610
.1	1.8	.120945	.289760	1.492239
.1	1.9	.117921	.284816	1.489253
.1	2.0	.115094	.280116	1.485775
.1	2.1	.112444	.275641	1.481902
.1	2.2	.109952	.271375	1.477713
.1	2.3	.107605	.267301	1.473272
.1	2.4	.105388	.263407	1.468630
.1	2.5	.103290	.259679	1.463830
.2	.1	.327709	.389063	.536823
.2	.2	.411046	.556224	.980985
.2	.3	.445999	.661649	1.386603
.2	.4	.454601	.720766	1.711098
.2	.5	.451048	.752131	1.962764
.2	.6	.442165	.767367	2.158333
.2	.7	.431120	.773082	2.312036
.2	.8	.419404	.773053	2.434407
.2	.9	.407728	.769498	2.533017
.2	1.0	.396427	.763762	2.613321
.2	1.1	.385649	.756684	2.679299
.2	1.2	.375445	.748799	2.733902
.2	1.3	.365822	.740457	2.779355
.2	1.4	.356760	.731888	2.817359
.2	1.5	.348227	.723246	2.849234
.2	1.6	.340188	.714633	2.876022
.2	1.7	.332608	.706118	2.898548
.2	1.8	.325451	.697748	2.917479
.2	1.9	.318684	.689550	2.933357
.2	2.0	.312277	.681544	2.946625
.2	2.1	.306201	.673739	2.957650
.2	2.2	.300431	.666141	2.966739
.2	2.3	.294944	.658751	2.974148
.2	2.4	.289718	.651567	2.980094
.2	2.5	.284735	.644585	2.984762

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
.3	.1	.431421	.485417	.605599
.3	.2	.542971	.676791	1.023134
.3	.3	.616568	.834336	1.471478
.3	.4	.657409	.949104	1.890045
.3	.5	.676336	1.028166	2.255711
.3	.6	.681901	1.081149	2.566646
.3	.7	.679587	1.115870	2.828878
.3	.8	.672710	1.137896	3.050107
.3	.9	.663248	1.151050	3.237499
.3	1.0	.652392	1.157941	3.397100
.3	1.1	.640865	1.160366	3.533822
.3	1.2	.629106	1.159579	3.651610
.3	1.3	.617385	1.156468	3.753622
.3	1.4	.605864	1.151668	3.842395
.3	1.5	.594641	1.145643	3.919981
.3	1.6	.583768	1.138732	3.988047
.3	1.7	.573274	1.131187	4.047962
.3	1.8	.563168	1.123199	4.100853
.3	1.9	.553450	1.114909	4.147660
.3	2.0	.544111	1.106426	4.189168
.3	2.1	.535140	1.097832	4.226038
.3	2.2	.526522	1.089191	4.258831
.3	2.3	.518241	1.080551	4.288026
.3	2.4	.510282	1.071949	4.314032
.3	2.5	.502629	1.063414	4.337203
.4	.1	.532028	.581813	.688109
.4	.2	.655417	.778126	1.073646
.4	.3	.753295	.960216	1.513882
.4	.4	.822091	1.112448	1.961970
.4	.5	.866214	1.232190	2.386617
.4	.6	.891997	1.323299	2.773206
.4	.7	.904959	1.391347	3.117876
.4	.8	.909201	1.441532	3.422195
.4	.9	.907593	1.478084	3.689952
.4	1.0	.902096	1.504263	3.925528
.4	1.1	.894039	1.522530	4.133161
.4	1.2	.884330	1.534733	4.316666
.4	1.3	.873589	1.542261	4.479358
.4	1.4	.862240	1.546164	4.624072
.4	1.5	.850579	1.547240	4.753212
.4	1.6	.838808	1.546105	4.868813
.4	1.7	.827069	1.543234	4.972600
.4	1.8	.815457	1.538995	5.066033
.4	1.9	.804037	1.533682	5.150359
.4	2.0	.792854	1.527524	5.226641
.4	2.1	.781935	1.520703	5.295792
.4	2.2	.771297	1.513367	5.358598
.4	2.3	.760948	1.505634	5.415738
.4	2.4	.750891	1.497598	5.467805
.4	2.5	.741124	1.489337	5.515312

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
.5	.1	.631943	.679086	.777212
.5	.2	.760609	.874876	1.137550
.5	.3	.872622	1.067374	1.557531
.5	.4	.961634	1.241604	2.005182
.5	.5	1.027614	1.390560	2.452463
.5	.6	1.073820	1.513376	2.880576
.5	.7	1.104375	1.612423	3.279442
.5	.8	1.123074	1.691219	3.645118
.5	.9	1.132997	1.753329	3.977331
.5	1.0	1.136501	1.801915	4.277744
.5	1.1	1.135348	1.839619	4.548896
.5	1.2	1.130831	1.868578	4.793601
.5	1.3	1.123902	1.890505	5.014637
.5	1.4	1.115258	1.906757	5.214599
.5	1.5	1.105413	1.918417	5.395832
.5	1.6	1.094746	1.926344	5.560427
.5	1.7	1.083539	1.931227	5.710226
.5	1.8	1.072000	1.933619	5.846844
.5	1.9	1.060286	1.933967	5.971695
.5	2.0	1.048510	1.932632	6.086017
.5	2.1	1.036761	1.929910	6.190892
.5	2.2	1.025102	1.926043	6.287273
.5	2.3	1.013579	1.921231	6.375992
.5	2.4	1.002226	1.915639	6.457785
.5	2.5	.991068	1.909404	6.533301
.6	.1	.731693	.777043	.869834
.6	.2	.862842	.970834	1.211199
.6	.3	.983126	1.167189	1.610469
.6	.4	1.085942	1.353582	2.046269
.6	.5	1.169000	1.521922	2.496460
.6	.6	1.233137	1.668672	2.942955
.6	.7	1.280780	1.793573	3.373288
.6	.8	1.314818	1.898207	3.780091
.6	.9	1.337996	1.984948	4.159809
.6	1.0	1.352672	2.056332	4.511422
.6	1.1	1.360767	2.114745	4.835455
.6	1.2	1.363802	2.162298	5.133293
.6	1.3	1.362965	2.200793	5.406740
.6	1.4	1.359175	2.231740	5.657756
.6	1.5	1.353143	2.256394	5.888292
.6	1.6	1.345419	2.275793	6.100214
.6	1.7	1.336427	2.290793	6.295254
.6	1.8	1.326496	2.302100	6.474999
.6	1.9	1.315882	2.310301	6.640883
.6	2.0	1.304785	2.315881	6.794200
.6	2.1	1.293360	2.319246	6.936107
.6	2.2	1.281730	2.320731	7.067644
.6	2.3	1.269989	2.320623	7.189738
.6	2.4	1.258213	2.319158	7.303220
.6	2.5	1.246458	2.316539	7.408833

90TH 95TH AND 99TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
.7	.1	.831419	.875479	.964527
.7	.2	.963760	1.067007	1.291449
.7	.3	1.089006	1.264213	1.672466
.7	.4	1.201145	1.457022	2.093129
.7	.5	1.296980	1.637712	2.536704
.7	.6	1.375820	1.801616	2.987628
.7	.7	1.438660	1.946784	3.433448
.7	.8	1.487353	2.073190	3.865316
.7	.9	1.524034	2.181956	4.277615
.7	1.0	1.550769	2.274767	4.667249
.7	1.1	1.569406	2.353490	5.032927
.7	1.2	1.581513	2.419955	5.374563
.7	1.3	1.588392	2.475851	5.692829
.7	1.4	1.591102	2.522681	5.988842
.7	1.5	1.590498	2.561793	6.263945
.7	1.6	1.587266	2.594189	6.519580
.7	1.7	1.581958	2.620949	6.757189
.7	1.8	1.575015	2.642847	6.978172
.7	1.9	1.566790	2.660576	7.183855
.7	2.0	1.557569	2.674722	7.375472
.7	2.1	1.547578	2.685784	7.554165
.7	2.2	1.537004	2.694184	7.720981
.7	2.3	1.525994	2.700284	7.876875
.7	2.4	1.514670	2.704394	8.022721
.7	2.5	1.503128	2.706777	8.159309
.8	.1	.931162	.974251	1.060533
.8	.2	1.064056	1.163625	1.376219
.8	.3	1.192355	1.360309	1.741794
.8	.4	1.310835	1.556252	2.147292
.8	.5	1.416089	1.744592	2.580199
.8	.6	1.506590	1.920432	3.027765
.8	.7	1.582306	2.080917	3.478686
.8	.8	1.644182	2.224896	3.923940
.8	.9	1.693677	2.352439	4.356931
.8	1.0	1.732427	2.464379	4.773235
.8	1.1	1.762041	2.561961	5.170179
.8	1.2	1.783995	2.646597	5.546412
.8	1.3	1.799583	2.719721	5.901525
.8	1.4	1.809918	2.782694	6.235752
.8	1.5	1.815931	2.836768	6.549739
.8	1.6	1.818402	2.883065	6.844390
.8	1.7	1.817977	2.922575	7.120745
.8	1.8	1.815187	2.956168	7.379905
.8	1.9	1.810471	2.984599	7.622980
.8	2.0	1.804191	3.008525	7.851056
.8	2.1	1.796645	3.028515	8.065175
.8	2.2	1.788078	3.045060	8.266322
.8	2.3	1.778694	3.058588	8.455421
.8	2.4	1.768661	3.069467	8.633332
.8	2.5	1.758117	3.078019	8.800851

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES OF THE LOGNORMAL DISTRIBUTION
FOR MEANS AND SIGMAS FROM .1 TO 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
.9	.1	1.030931	1.073265	1.157422
.9	.2	1.164047	1.260697	1.464169
.9	.3	1.294263	1.456252	1.816798
.9	.4	1.417110	1.653454	2.208278
.9	.5	1.529301	1.846392	2.629223
.9	.6	1.628913	2.030373	3.069403
.9	.7	1.715256	2.202172	3.519040
.9	.8	1.788571	2.359954	3.969652
.9	.9	1.849705	2.503008	4.414433
.9	1.0	1.899831	2.631441	4.848279
.9	1.1	1.940243	2.745891	5.267616
.9	1.2	1.972227	2.847311	5.670136
.9	1.3	1.996983	2.936797	6.054523
.9	1.4	2.015593	3.015489	6.420201
.9	1.5	2.029008	3.084498	6.767133
.9	1.6	2.038047	3.144868	7.095653
.9	1.7	2.043413	3.197562	7.406342
.9	1.8	2.045703	3.243448	7.699939
.9	1.9	2.045418	3.283303	7.977272
.9	2.0	2.042986	3.317820	8.259211
.9	2.1	2.038762	3.347610	8.486634
.9	2.2	2.033049	3.373211	8.720407
.9	2.3	2.026100	3.395098	8.941369
.9	2.4	2.018129	3.413689	9.150321
.9	2.5	2.009314	3.429353	9.348023
1.0	.1	1.130727	1.172456	1.254932
1.0	.2	1.263885	1.358172	1.554424
1.0	.3	1.395320	1.552356	1.896169
1.0	.4	1.521218	1.749751	2.275099
1.0	.5	1.638543	1.945314	2.684115
1.0	.6	1.745243	2.134748	3.115062
1.0	.7	1.840237	2.314778	3.559686
1.0	.8	1.923267	2.483208	4.010364
1.0	.9	1.994683	2.638807	4.460544
1.0	1.0	2.055228	2.781120	4.904925
1.0	1.1	2.105864	2.910267	5.339443
1.0	1.2	2.147639	3.026752	5.761151
1.0	1.3	2.181603	3.131322	6.168049
1.0	1.4	2.208751	3.224847	6.558884
1.0	1.5	2.229993	3.308247	6.933019
1.0	1.6	2.246149	3.382438	7.290236
1.0	1.7	2.257939	3.448300	7.630667
1.0	1.8	2.265993	3.506658	7.954661
1.0	1.9	2.270858	3.558270	8.262731
1.0	2.0	2.273003	3.603831	8.555488
1.0	2.1	2.272833	3.643965	8.833607
1.0	2.2	2.270696	3.679237	9.097791
1.0	2.3	2.266887	3.710151	9.348754
1.0	2.4	2.261662	3.737157	9.587201
1.0	2.5	2.255239	3.760657	9.813820

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES OF THE LOGNORMAL DISTRIBUTION
FOR MEANS AND SIGMAS FROM .1 TO 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
1.1	.1	1.230548	1.271782	1.352894
1.1	.2	1.363651	1.455987	1.646393
1.1	.3	1.495861	1.648741	1.978922
1.1	.4	1.623918	1.845723	2.346761
1.1	.5	1.745074	2.042640	2.744475
1.1	.6	1.857291	2.235643	3.165563
1.1	.7	1.959287	2.421583	3.603139
1.1	.8	2.050469	2.598125	4.050524
1.1	.9	2.130808	2.763723	4.501666
1.1	1.0	2.200685	2.917525	4.951377
1.1	1.1	2.260751	3.059232	5.395418
1.1	1.2	2.311807	3.188965	5.830477
1.1	1.3	2.354720	3.307132	6.254084
1.1	1.4	2.390363	3.414030	6.664489
1.1	1.5	2.419569	3.511263	7.060537
1.1	1.6	2.443116	3.598687	7.441553
1.1	1.7	2.461714	3.677363	7.807232
1.1	1.8	2.475997	3.748038	8.157552
1.1	1.9	2.486530	3.811420	8.492704
1.1	2.0	2.493810	3.868174	8.813026
1.1	2.1	2.498274	3.918917	9.118965
1.1	2.2	2.500303	3.964214	9.411037
1.1	2.3	2.500228	4.004578	9.689801
1.1	2.4	2.498338	4.040479	9.955838
1.1	2.5	2.494884	4.072338	10.209739
1.2	.1	1.330390	1.371212	1.451197
1.2	.2	1.463385	1.554087	1.739668
1.2	.3	1.596084	1.745438	2.064328
1.2	.4	1.725684	1.941669	2.422398
1.2	.5	1.849723	2.139120	2.809670
1.2	.6	1.966252	2.334377	3.220938
1.2	.7	2.073906	2.524504	3.650483
1.2	.8	2.171884	2.707163	4.092537
1.2	.9	2.259885	2.880649	4.541647
1.2	1.0	2.337999	3.043844	4.992921
1.2	1.1	2.406606	3.196142	5.442162
1.2	1.2	2.466274	3.337344	5.885910
1.2	1.3	2.517682	3.467567	6.321415
1.2	1.4	2.561560	3.587146	6.746575
1.2	1.5	2.598641	3.696569	7.159852
1.2	1.6	2.629635	3.796415	7.560182
1.2	1.7	2.655213	3.887310	7.946891
1.2	1.8	2.675992	3.969896	8.319618
1.2	1.9	2.692533	4.044809	8.678246
1.2	2.0	2.705344	4.112663	9.022845
1.2	2.1	2.714876	4.174042	9.353627
1.2	2.2	2.721533	4.229491	9.670910
1.2	2.3	2.725671	4.279519	9.975083
1.2	2.4	2.727603	4.324597	10.266586
1.2	2.5	2.727608	4.365154	10.545889

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES OF THE LOGNORMAL DISTRIBUTION
FOR MEANS AND SIGMAS FROM .1 TO 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
1.3	.1	1.430251	1.470724	1.549761
1.3	.2	1.563110	1.652424	1.833959
1.3	.3	1.696108	1.842438	2.151840
1.3	.4	1.826818	2.037742	2.501300
1.3	.5	1.953044	2.235197	2.879044
1.3	.6	2.072962	2.431792	3.280874
1.3	.7	2.185194	2.624832	3.702044
1.3	.8	2.288825	2.812061	4.137609
1.3	.9	2.383362	2.991715	4.582731
1.3	1.0	2.468677	3.162523	5.032906
1.3	1.1	2.544924	3.323659	5.484117
1.3	1.2	2.612463	3.474680	5.932908
1.3	1.3	2.671796	3.615456	6.376403
1.3	1.4	2.723505	3.746094	6.812281
1.3	1.5	2.768209	3.866876	7.238733
1.3	1.6	2.806536	3.978205	7.654398
1.3	1.7	2.839098	4.080565	8.058299
1.3	1.8	2.866474	4.174482	8.449781
1.3	1.9	2.889208	4.260502	8.828452
1.3	2.0	2.907798	4.339169	9.194131
1.3	2.1	2.922699	4.411019	9.546804
1.3	2.2	2.934323	4.476564	9.886589
1.3	2.3	2.943042	4.536290	10.213701
1.3	2.4	2.949186	4.590655	10.528428
1.3	2.5	2.953052	4.640087	10.831113
1.4	.1	1.530127	1.570301	1.648530
1.4	.2	1.662838	1.750959	1.929053
1.4	.3	1.796007	1.939720	2.241048
1.4	.4	1.927520	2.134014	2.582898
1.4	.5	2.055418	2.331134	2.951994
1.4	.6	2.178012	2.528426	3.344931
1.4	.7	2.293961	2.723440	3.757761
1.4	.8	2.402290	2.914045	4.186258
1.4	.9	2.502388	3.098490	4.626168
1.4	1.0	2.593960	3.275423	5.073409
1.4	1.1	2.676983	3.443878	5.524221
1.4	1.2	2.751641	3.603232	5.975256
1.4	1.3	2.818272	3.753158	6.423623
1.4	1.4	2.877319	3.893569	6.866895
1.4	1.5	2.929286	4.024562	7.303090
1.4	1.6	2.974707	4.146380	7.730632
1.4	1.7	3.014124	4.259361	8.148311
1.4	1.8	3.048067	4.363913	8.555230
1.4	1.9	3.077046	4.460482	8.950761
1.4	2.0	3.101539	4.549535	9.334499
1.4	2.1	3.121990	4.631545	9.706221
1.4	2.2	3.138811	4.706979	10.065855
1.4	2.3	3.152376	4.776289	10.413444
1.4	2.4	3.163026	4.839909	10.749126
1.4	2.5	3.171070	4.898251	11.073110

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
1.5	.1	1.630016	1.669932	1.747464
1.5	.2	1.762574	1.849661	2.024796
1.5	.3	1.895828	2.037257	2.331636
1.5	.4	2.027922	2.230515	2.666732
1.5	.5	2.157104	2.427086	3.027997
1.5	.6	2.281827	2.624627	3.412649
1.5	.7	2.400803	2.820923	3.817390
1.5	.8	2.513045	3.013986	4.238612
1.5	.9	2.617865	3.202121	4.672593
1.5	1.0	2.714855	3.383954	5.115672
1.5	1.1	2.803854	3.558434	5.564381
1.5	1.2	2.884901	3.724812	6.015945
1.5	1.3	2.958193	3.882612	6.466339
1.5	1.4	3.024042	4.031587	6.914311
1.5	1.5	3.082842	4.171681	7.357388
1.5	1.6	3.135033	4.302984	7.793854
1.5	1.7	3.181081	4.425703	8.222329
1.5	1.8	3.221459	4.540129	8.641727
1.5	1.9	3.256630	4.646606	9.051225
1.5	2.0	3.287044	4.745518	9.450227
1.5	2.1	3.313126	4.837270	9.838325
1.5	2.2	3.335274	4.922272	10.215272
1.5	2.3	3.353859	5.000934	10.580951
1.5	2.4	3.369223	5.073657	10.935353
1.5	2.5	3.381680	5.140829	11.278556
1.6	.1	1.729916	1.769607	1.846532
1.6	.2	1.862323	1.948503	2.121066
1.6	.3	1.995601	2.135021	2.423362
1.6	.4	2.128112	2.327250	2.752437
1.6	.5	2.258289	2.523141	3.106610
1.6	.6	2.384711	2.720619	3.483589
1.6	.7	2.506163	2.917685	3.880608
1.6	.8	2.621670	3.112503	4.294584
1.6	.9	2.730503	3.303456	4.722269
1.6	1.0	2.832178	3.489185	5.160398
1.6	1.1	2.926430	3.668597	5.605807
1.6	1.2	3.013180	3.840865	6.055529
1.6	1.3	3.092508	4.005401	6.506855
1.6	1.4	3.164612	4.161834	6.957372
1.6	1.5	3.229781	4.309977	7.404978
1.6	1.6	3.288365	4.449793	7.847880
1.6	1.7	3.340753	4.581367	8.284583
1.6	1.8	3.387355	4.704879	8.713863
1.6	1.9	3.428585	4.820576	9.134743
1.6	2.0	3.464854	4.928758	9.546469
1.6	2.1	3.496560	5.029756	9.948475
1.6	2.2	3.524082	5.123921	10.340358
1.6	2.3	3.547780	5.211613	10.721856
1.6	2.4	3.567989	5.293195	11.092824
1.6	2.5	3.585022	5.369022	11.453212

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
1.7	.1	1.829827	1.869318	1.945710
1.7	.2	1.962086	2.047465	2.217773
1.7	.3	2.095347	2.232987	2.516034
1.7	.4	2.228155	2.424214	2.839719
1.7	.5	2.359102	2.619348	3.187459
1.7	.6	2.486889	2.816547	3.557354
1.7	.7	2.610375	3.014007	3.947076
1.7	.8	2.728613	3.210038	4.353981
1.7	.9	2.840861	3.403117	4.775237
1.7	1.0	2.946585	3.591923	5.207944
1.7	1.1	3.045443	3.775356	5.649235
1.7	1.2	3.137267	3.952539	6.096367
1.7	1.3	3.222039	4.122810	6.546778
1.7	1.4	3.299859	4.285703	6.998136
1.7	1.5	3.370922	4.440926	7.448358
1.7	1.6	3.435493	4.588333	7.895625
1.7	1.7	3.493888	4.727905	8.338373
1.7	1.8	3.546450	4.859718	8.775282
1.7	1.9	3.593544	4.983931	9.205264
1.7	2.0	3.635536	5.100759	9.627437
1.7	2.1	3.672792	5.210460	10.041102
1.7	2.2	3.705666	5.313325	10.445728
1.7	2.3	3.734500	5.409660	10.840922
1.7	2.4	3.759617	5.499782	11.226415
1.7	2.5	3.781324	5.584013	11.602041
1.8	.1	1.929746	1.969059	2.044980
1.8	.2	2.061862	2.146530	2.314844
1.8	.3	2.195078	2.331130	2.609502
1.8	.4	2.328093	2.521394	2.928338
1.8	.5	2.459639	2.715733	3.270231
1.8	.6	2.588525	2.912503	3.633597
1.8	.7	2.713689	3.110079	4.016462
1.8	.8	2.834220	3.306909	4.416555
1.8	.9	2.949378	3.501566	4.831407
1.8	1.0	3.058602	3.692784	5.258445
1.8	1.1	3.161497	3.879476	5.695085
1.8	1.2	3.257826	4.060745	6.138806
1.8	1.3	3.347492	4.235880	6.587213
1.8	1.4	3.430512	4.404345	7.038080
1.8	1.5	3.506999	4.565766	7.489381
1.8	1.6	3.577142	4.719909	7.939304
1.8	1.7	3.641184	4.866663	8.386257
1.8	1.8	3.699410	5.006017	8.828865
1.8	1.9	3.752129	5.138043	9.265958
1.8	2.0	3.799662	5.262881	9.696557
1.8	2.1	3.842339	5.380719	10.119863
1.8	2.2	3.880486	5.491783	10.535232
1.8	2.3	3.914422	5.596327	10.942161
1.8	2.4	3.944453	5.694622	11.340273
1.8	2.5	3.970875	5.786949	11.729294

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES OF THE LOGNORMAL DISTRIBUTION
FOR MEANS AND SIGMAS FROM .1 TO 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
1.9	.1	2.029672	2.068827	2.144327
1.9	.2	2.161652	2.245683	2.412223
1.9	.3	2.294803	2.429432	2.703645
1.9	.4	2.427958	2.618776	3.018101
1.9	.5	2.559968	2.812304	3.354667
1.9	.6	2.689744	3.008547	3.712012
1.9	.7	2.816297	3.206033	4.088458
1.9	.8	2.938758	3.403342	4.482047
1.9	.9	3.056402	3.599144	4.890622
1.9	1.0	3.168655	3.792234	5.311902
1.9	1.1	3.275087	3.981554	5.743564
1.9	1.2	3.375412	4.166206	6.183305
1.9	1.3	3.469467	4.345450	6.628900
1.9	1.4	3.557202	4.518704	7.078249
1.9	1.5	3.638660	4.685530	7.529403
1.9	1.6	3.713962	4.845625	7.980587
1.9	1.7	3.783286	4.998800	8.430213
1.9	1.8	3.846857	5.144969	8.876876
1.9	1.9	3.904933	5.284129	9.319358
1.9	2.0	3.957791	5.416346	9.756613
1.9	2.1	4.005720	5.541744	10.187760
1.9	2.2	4.049016	5.660490	10.612068
1.9	2.3	4.087972	5.772782	11.028943
1.9	2.4	4.122875	5.878845	11.437912
1.9	2.5	4.154005	5.978920	11.838609
2.0	.1	2.129604	2.168618	2.243739
2.0	.2	2.261455	2.344912	2.509864
2.0	.3	2.394528	2.527873	2.798364
2.0	.4	2.527771	2.716343	3.108848
2.0	.5	2.660141	2.909063	3.440546
2.0	.6	2.790639	3.104712	3.792337
2.0	.7	2.918344	3.301960	4.162786
2.0	.8	3.042436	3.499503	4.550199
2.0	.9	3.162209	3.696105	4.952687
2.0	1.0	3.277087	3.890629	5.368230
2.0	1.1	3.386621	4.082055	5.794741
2.0	1.2	3.490486	4.269495	6.230124
2.0	1.3	3.588472	4.452200	6.672324
2.0	1.4	3.680474	4.629556	7.119371
2.0	1.5	3.766475	4.801081	7.569411
2.0	1.6	3.846535	4.966416	8.020727
2.0	1.7	3.920775	5.125311	8.471755
2.0	1.8	3.989366	5.277614	8.921088
2.0	1.9	4.052515	5.423256	9.367483
2.0	2.0	4.110456	5.562241	9.809850
2.0	2.1	4.163439	5.694630	10.247251
2.0	2.2	4.211727	5.820534	10.678886
2.0	2.3	4.255585	5.940099	11.104087
2.0	2.4	4.295278	6.053505	11.522302
2.0	2.5	4.331068	6.160948	11.933087

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
2.1	.1	2.229543	2.268427	2.343207
2.1	.2	2.361270	2.444209	2.607729
2.1	.3	2.494256	2.626438	2.893580
2.1	.4	2.627548	2.814081	3.200446
2.1	.5	2.760195	3.006004	3.527686
2.1	.6	2.891280	3.201021	3.874346
2.1	.7	3.019946	3.397921	4.239196
2.1	.8	3.145418	3.595509	4.620765
2.1	.9	3.267018	3.792639	5.017397
2.1	1.0	3.384176	3.988242	5.427299
2.1	1.1	3.496432	4.181340	5.848597
2.1	1.2	3.603436	4.371067	6.279387
2.1	1.3	3.704941	4.556676	6.717781
2.1	1.4	3.800797	4.737536	7.161940
2.1	1.5	3.890940	4.913135	7.610113
2.1	1.6	3.975376	5.083070	8.060654
2.1	1.7	4.054176	5.247043	8.512040
2.1	1.8	4.127461	5.404848	8.962883
2.1	1.9	4.195392	5.556361	9.411934
2.1	2.0	4.258160	5.701526	9.858080
2.1	2.1	4.315979	5.840353	10.300343
2.1	2.2	4.369076	5.972897	10.737874
2.1	2.3	4.417690	6.099259	11.169948
2.1	2.4	4.462060	6.219570	11.595948
2.1	2.5	4.502428	6.333988	12.015363
2.2	.1	2.329486	2.368253	2.442724
2.2	.2	2.461097	2.543564	2.705789
2.2	.3	2.593991	2.725115	2.989227
2.2	.4	2.727302	2.911974	3.292786
2.2	.5	2.860160	3.103121	3.615929
2.2	.6	2.991722	3.297483	3.957844
2.2	.7	3.121191	3.493956	4.317468
2.2	.8	3.247836	3.691445	4.693522
2.2	.9	3.371008	3.888889	5.084546
2.2	1.0	3.490148	4.085280	5.488951
2.2	1.1	3.604796	4.279692	5.905053
2.2	1.2	3.714583	4.471285	6.331127
2.2	1.3	3.819237	4.659322	6.765437
2.2	1.4	3.918574	4.843166	7.206278
2.2	1.5	4.012486	5.022286	7.652004
2.2	1.6	4.100938	5.196250	8.101049
2.2	1.7	4.183956	5.364720	8.551944
2.2	1.8	4.261616	5.527446	9.003333
2.2	1.9	4.334037	5.684257	9.453976
2.2	2.0	4.401371	5.835049	9.902754
2.2	2.1	4.463794	5.979782	10.348668
2.2	2.2	4.521501	6.118465	10.790835
2.2	2.3	4.574703	6.251151	11.228486
2.2	2.4	4.623613	6.377930	11.660955
2.2	2.5	4.668453	6.498920	12.087674

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES OF THE LOGNORMAL DISTRIBUTION
FOR MEANS AND SIGMAS FROM .1 TO 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
2.3	.1	2.429433	2.468094	2.542284
2.3	.2	2.560934	2.642971	2.804017
2.3	.3	2.693734	2.823890	3.085248
2.3	.4	2.827041	3.010009	3.385775
2.3	.5	2.960058	3.200404	3.705145
2.3	.6	3.092007	3.394101	4.042662
2.3	.7	3.222147	3.590093	4.397407
2.3	.8	3.349791	3.787374	4.768260
2.3	.9	3.474318	3.984958	5.153937
2.3	1.0	3.595188	4.181905	5.553021
2.3	1.1	3.711939	4.377334	5.964001
2.3	1.2	3.824197	4.570438	6.385313
2.3	1.3	3.931671	4.760495	6.815366
2.3	1.4	4.034147	4.946873	7.252584
2.3	1.5	4.131487	5.129030	7.695425
2.3	1.6	4.223619	5.306513	8.142406
2.3	1.7	4.310531	5.478955	8.592123
2.3	1.8	4.392259	5.646072	9.043260
2.3	1.9	4.468883	5.807653	9.494601
2.3	2.0	4.540519	5.963553	9.945033
2.3	2.1	4.607309	6.113688	10.393549
2.3	2.2	4.669417	6.258025	10.839248
2.3	2.3	4.727024	6.396577	11.281328
2.3	2.4	4.780320	6.529392	11.719086
2.3	2.5	4.829503	6.656553	12.151913
2.4	.1	2.529385	2.567948	2.641880
2.4	.2	2.660781	2.742424	2.902393
2.4	.3	2.793485	2.922754	3.181599
2.4	.4	2.926770	3.108173	3.479336
2.4	.5	3.059905	3.297844	3.795221
2.4	.6	3.192169	3.490875	4.128656
2.4	.7	3.322871	3.686349	4.478841
2.4	.8	3.451367	3.883338	4.844796
2.4	.9	3.577066	4.080928	5.225383
2.4	1.0	3.699445	4.278240	5.619341
2.4	1.1	3.818051	4.474439	6.025312
2.4	1.2	3.932504	4.668755	6.441876
2.4	1.3	4.042502	4.860486	6.867580
2.4	1.4	4.147811	5.049008	7.300966
2.4	1.5	4.248268	5.233777	7.740597
2.4	1.6	4.343769	5.414327	8.185074
2.4	1.7	4.434268	5.590271	8.633062
2.4	1.8	4.519770	5.761297	9.083294
2.4	1.9	4.600320	5.927162	9.534585
2.4	2.0	4.675998	6.087688	9.985841
2.4	2.1	4.746918	6.242751	10.436058
2.4	2.2	4.813211	6.392283	10.884324
2.4	2.3	4.875033	6.536258	11.329821
2.4	2.4	4.932547	6.674689	11.771820
2.4	2.5	4.985930	6.807623	12.209677

TABLE C-2 (Continued)

90TH 95TH AND 99TH PERCENTILES ØF THE LØGNØRMAL DISTRIBUTIØN
FØR MEANS AND SIGMAS FRØM .1 TØ 2.5

MEAN	SIGMA	90 PERCENT	95 PERCENT	99 PERCENT
2.5	.1	2.629340	2.667813	2.741508
2.5	.2	2.760637	2.841918	3.000900
2.5	.3	2.893245	3.021698	3.278240
2.5	.4	3.026496	3.206456	3.573402
2.5	.5	3.159713	3.395429	3.886060
2.5	.6	3.292232	3.587802	4.215698
2.5	.7	3.423407	3.782733	4.561619
2.5	.8	3.552631	3.979367	4.922959
2.5	.9	3.679345	4.176857	5.298711
2.5	1.0	3.803044	4.374378	5.687748
2.5	1.1	3.923286	4.571145	6.088849
2.5	1.2	4.039693	4.766421	6.500724
2.5	1.3	4.151953	4.959530	6.922045
2.5	1.4	4.259820	5.149860	7.351468
2.5	1.5	4.363108	5.336869	7.787655
2.5	1.6	4.461690	5.520086	8.229293
2.5	1.7	4.555493	5.699111	8.675113
2.5	1.8	4.644491	5.873610	9.123910
2.5	1.9	4.728699	6.043316	9.574531
2.5	2.0	4.808169	6.208020	10.025909
2.5	2.1	4.882981	6.367570	10.477052
2.5	2.2	4.953244	6.521862	10.927051
2.5	2.3	5.019083	6.670839	11.375079
2.5	2.4	5.080640	6.814480	11.820388
2.5	2.5	5.138070	6.952801	12.262313
2.6	.1	2.729298	2.767688	2.841165
2.6	.2	2.860502	2.941448	3.099521
2.6	.3	2.993014	3.120714	3.375139
2.6	.4	3.126220	3.304848	3.667917
2.6	.5	3.259494	3.493150	3.977580
2.6	.6	3.392217	3.684876	4.303681
2.6	.7	3.523788	3.879250	4.645608
2.6	.8	3.653637	4.075484	5.002601
2.6	.9	3.781231	4.272788	5.373764
2.6	1.0	3.906088	4.470394	5.758088
2.6	1.1	4.027777	4.667560	6.154472
2.6	1.2	4.145924	4.863584	6.561748
2.6	1.3	4.260213	5.057818	6.978699
2.6	1.4	4.370388	5.249664	7.404088
2.6	1.5	4.476249	5.438590	7.836670
2.6	1.6	4.577649	5.624122	8.275218
2.6	1.7	4.674491	5.805851	8.718534
2.6	1.8	4.766724	5.983431	9.165462
2.6	1.9	4.854337	6.156573	9.614901
2.6	2.0	4.937354	6.325046	10.065812
2.6	2.1	5.015831	6.488671	10.517223
2.6	2.2	5.089848	6.647317	10.968234
2.6	2.3	5.159507	6.800897	11.418017
2.6	2.4	5.224927	6.949361	11.865817
2.6	2.5	5.286241	7.092695	12.310950

APPENDIX D – MAINTENANCE TIME STANDARD DATA

The data collected for establishment of the maintenance time standards described in section 4 is presented in this appendix. Table D-1 provides a listing of the task categories for which data was collected. Table D-2 presents the data collected. Each column in table D-2 presents the data collected for the corresponding task type of Table D-1. Also included in Table D-2 is the quantity of task data (N) collected for each type, the mean of the data (θ), and the standard deviation of the data (σ). All times are in seconds.

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TABLE D-1. DEFINITION OF DATA SET CODES

Data Set Code #	Applicable Time Standard Number	Description	
1	1A	Remove Screws (phillips)	
2	1B	Replace Screws (phillips)	
3	1A	Remove slot head screws	
4	1B	Replace slot head screws	
5	7A	Remove machine screws (w/washer & nut)	
6	7B	Replace machine screws (w/washer & nut)	
7	3A	Remove captive fasteners	
8	3B	Replace captive fasteners	
9	8A	Remove nuts or bolts	With a wrench
10	8B	Replace nuts or bolts	With a wrench
11	10A	Disengage drawhook latch	
12	10B	Engage drawhook latch	
13	46A	Remove adhesive from a PCB or component	
14	46B	Apply adhesive to a PCB or component	
15	16A	Remove a lead from a turret terminal	No soldering time
16	16B	Connect a lead to a turret terminal	No soldering time
17	21A	Remove discretes from a PCB	No soldering time
18	21B	Replace discretes on a PCB	No soldering time
19	23A	Remove an 8 pin IC from a PCB (DIP)	No soldering time
20	23B	Replace an 8 pin IC on a PCB (DIP)	No soldering time
21	25A	Demate a BNC connector	single pin
22	25B	Mate a BNC connector	single pin
23	29A	Demate a friction locking connector with jackscrew	
24	29B	Mate a friction locking connector with jackscrew	
25	32A	Remove a DIP IC from a socket	
26	32B	Replace a DIP IC in a socket	
27	34A	Remove a PCB (guided)	No tool used (80 pin)
28	34B	Replace a PCB (guided)	No tool used (80 pin)
29	37A	Remove a PCB (not guided)	No tool used (80 pin)
30	37B	Replace a PCB (not guided)	No tool used (80 pin)
31	40A	Hand prepare a wire (strip leads)	
32	41	Cut sleeving	
33	42	Dress wire with sleeving	
34	43	Crimp lugs	
35	49	Soldering a lead on a PCB	
36	48	Soldering a lead on a terminal post	
37	52	Desoldering with braided copper	
38	53	Desoldering with a solder sucker	
39	9A	Remove a retaining ring	
40	9B	Replace a retaining ring	
41	18A	Remove a termipoint clip	
42	18B	Replace a termipoint clip	

TABLE D-1. DEFINITION OF DATA SET CODES (Cont)

Data Set Code #	Applicable Time Standard Number	Description
43	39	Cut Wire
44	19B	Wire wrap using a hand gun
45	19A	Unwrap using a hand tool
46	12A	Open butterfly latch
47	12B	Close butterfly latch
48	13A	Remove an ATR latch (pair) } Spring loaded
49	13B	Replace an ATR latch (pair) } Spring loaded
50	57A	Remove a threaded cover
51	57B	Replace a threaded cover
52	34A	Remove 40 pin card with tool
53	34B	Replace 40 pin card with tool
54	55A	Open drawer
55	55B	Close drawer
56	35A	Remove 80 pin card with tool
57	35B	Replace 80 pin card with tool
58	14A	Disengage a lift & turn latch
59	14B	Engage a lift & turn latch
60	54A	Open panel
61	54B	Close panel
62	53	Clean small surface with alcohol or any other solution
63	43	Trim leads
64	42	Form leads with pliers
65	49	Tin leads of a flatpack IC by dipping process
66	52	Form leads of a flatpack IC by using a die
67	22B	Position flatpack IC on PCB
68	48	Reflow solder
69	27A	Remove quick disconnect coax connector
70	27B	Replace quick disconnect coax connector
71	26A	Demate multipin BNC
72	26B	Mate multipin BNC
73	30A	Demate a threaded connector (single pin)
74	30B	Mate a threaded connector (single pin)
75	5A	Remove a TRIDAIR fastener
76	5B	Replace a TRIDAIR fastener
77	56A	Remove a display light
78	56B	Replace a display lamp
79	37A	Remove a module (guided)
80	37B	Replace a module (guided
81	31A	Demate a slide locking connector
82	31B	Mate a slide locking connector

TABLE D-1. DEFINITION OF DATA SET CODES (Cont)

Data Set Code #	Applicable Time Standard Number	Description	
83	45A	Remove conformal coating	
84	45B	Replace conformal coating	
85	24A	Remove a 16 pin IC from a PCB (DIP)	No soldering
86	24B	Replace a 16 pin IC on a PCB (DIP)	

TABLE D-2. DATA COLLECTED

Data Set Number	1		2		3		4		5		6		7		8		9		10		11		12		13	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	11.0	1	20.0	1	27.0	3	56.0	4	No Data		43.0	2	10.0	1	14.0	1	No		44.0	2	3.0	2	3.2	2	30	1
	12.0	1	24.0	1	11.0	1	17.0	1	Avail-		95.0	4	10.0	1	11.0	1	Data		54.0	2	3.5	2	3.4	2	85	1
	20.0	1	17.0	1	10.0	1	17.0	1	able		19.0	1	32.0	4	9.0	1	Avail-		67.0	2	3.8	2	3.8	2	16	1
	14.0	1	54.0	3	23.0	2	11.0	1			30.0	1	12.0	1	40.0	3	able		31.0	1	3.2	2	3.2	2	33	1
	25.0	3	24.0	2	17.0	2	33.0	2			63.0	3	21.0	2	52.0	4			25.0	1	3.4	2	3.2	2	16	1
	15.0	2	12.0	1	57.0	6	50.0	3			130.0	4	9.0	1	38.0	4			19.0	1	3.4	2	3.1	2	17	1
	19.0	2	8.0	1	24.0	2	16.0	1			145.0	4	9.0	1	57.0	5			39.0	2	3.2	2	3.2	2		
	22.0	2	10.0	1	9.0	1	13.0	1			23.0	1	43.0	5	48.0	4					3.4	2	3.0	2		
	40.0	4	41.0	4	7.0	1	31.0	2			25.0	1	11.0	1	46.0	4					3.6	2	2.9	2		
	26.0	3	43.0	3	17.0	2	27.0	2			26.5	1			47.0	4					3.0	2	3.4	2		
	10.0	1	26.0	1	8.0	1					35.0	1			14.0	1					3.2	2	3.2	2		
	11.0	1	17.0	1											15.0	1					3.2	2	3.2	2		
	10.0	1	15.9	1																	3.4	2	3.1	2		
	12.0	1	11.0	1																	3.6	2	3.9	2		
	8.0	1	25.0	1																	3.7	2	3.5	2		
	11.0	1	25.0	1																	4.0	2	3.6	2		
	9.0	1	89.0	5																	3.8	2	3.6	2		
	7.0	1	30.0	1																	3.8	2	3.6	2		
	17.0	2	45.0	4																	3.4	2	3.8	2		
	26.0	3	40.0	3																	3.4	2	3.8	2		
	33.0	4	38.0	3																						
	10.0	1	43.0	3																						
	17.0	2	36.0	3																						
	26.0	3	15.0	1																						
	34.0	4	57.0	4																						
	44.0	5	14.0	1																						
	53.0	6	21.0	1																						
			57.0	5																						
N	58		68		22		18				23		17		33				11		40		40		6	
θ	9.51		15.54		9.55		15.06				27.59		9.24		11.88				26.27		1.73		1.67		32.83	
σ	2.14		4.16		1.52		1.73				6.12		1.21		1.42				7.11		0.14		0.15		26.63	

TABLE D-2. DATA COLLECTED (Cont)

Data Set Number	14		15		16		16	
	time	qty	time	qty	time	qty	time	qty
	5.0	1	8.5	1	20.0	1	77.0	2
	8.0	1	30.0	1	43.0	1	55.0	1
	12.0	1	8.0	1	21.0	1	70.0	1
	7.0	1	14.5	1	22.0	1	80.0	2
	6.0	1	16.0	1	27.0	1	57.0	1
	7.0	1	18.0	1	57.0	1	34.0	1
	9.0	1	16.0	1	23.0	1	21.0	1
			23.0	1	62.0	1	47.0	1
			15.0	1	39.0	1	39.0	1
			10.0	1	28.0	1	41.0	1
			13.0	1	17.0	1	43.0	1
			17.0	1	45.0	1	19.0	1
			19.0	1	65.0	2		
			11.0	1	18.0	1		
			16.0	1	22.0	1		
			25.0	3	60.0	1		
			22.0	2	70.0	1		
					56.0	1		
					29.0	1		
					28.0	1		
					21.0	1		
					50.0	1		
					52.0	1		
					23.0	1		
					39.0	1		
N	7		21		-		40	
θ	7.71		13.43		-		38.25	
σ	2.29		5.96		-		14.98	

Data Set Number	17		18		19		20	
	time	qty	time	qty	time	qty	time	qty
	40.0	2	10.0	2	5.0	1	19.0	1
	14.0	3	[illegible]2.0	2	21.0	1	30.0	1
	5.0	5	24.0	2	18.0	1	17.0	1
	22.0	2	70.0	4	30.0	1	25.0	1
	16.0	3	24.0	2	50.0	1	45.0	1
	12.0	2	17.0	2	[illegible]	[illegible]	36.0	1
	17.0	2	30.0	4	32.0	1	26.0	1
	19.0	3	31.0	3	30.0	1	4[illegible]	1
	11.0	2	32.0	3	20.0	1	5[illegible]	1
	17.0	2	19.0	2	29.0	1	11.0	1
	29.0	2	33.0	3	26.0	1	45.0	1
	20.0	2	17.0	2	17.0	1	42.0	1
	34.0	3	18.0	2	65.0	1	23.0	1
	18.0	2			21.0	1	18.0	1
					29.0	1		
N	33		33		15		14	
θ	8.39		10.21		27.87		31.07	
σ	4.46		3.3[illegible]		14.00		13.36	

Data Set Number	21		22		22		23		24	
	time	qty	time	qty	time	qty	time	qty	time	qty
	3.0	1	11.0	[illegible]	7.0	1	15.0	1	10.0	1
	2.5	1	10.0	1	6.0	1	10.0	1	15.0	1
	7.0	1	8.0	1	6.0	1	7.0	1	12.0	1
	6.0	1	6.0	1	6.0	1	12.0	1	11.0	1
	4.0	1	7.6	1	4.0	1	9.0	1	17.0	1
	3.2	1	7.6	1	9.0	1	14.0	1	16.5	1
	5.3	1	13.0	2	4.0	1	9.0	1	12.0	1
	4.0	1	6.0	1	7.0	1	11.0	1	9.0	1
	[illegible].5	1	4.0	1	9.0	2	10.0	1	10.0	1
			6.0	1	9.0	2	14.0	1	8.0	1
			4.0	1	5.0	1	10.0	1	11.0	1
			4.0	1	4.0	1	8.0	1	12.0	1
			6.0	1					11.0	1
			4.0	1					15.0	1
			6.0	1					13.0	1
			5.0	1					10.0	1
			8.0	1					16.0	1
			5.0	1						
			4.0	1						
			4.0	1						
			7.0	1						
			5.0	1						
			7.0	1						
			5.0	1						
			8.0	1						
N	9		-		40		12		17	
θ	4.28		-		5.90		10.75		12.26	
σ	1.51		-		1.74		2.53		2.73	

TABLE 3-2. DATA COLLECTED (Cont)

Data Set Number	25		25		26		26		27		28		29		30		31		32		33		34		35	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	4.0	1	3.8	1	5.5	1	8.0	1	26.0	9	54.0	17	26.0	9	10.0	1	5.0	1	7.0	3	20.0	1	12.0	1	6.0	2
	3.8	1	3.8	1	7.0	1	18.0	1	24.0	7	12.0	2	24.0	7	8.0	1	6.0	1			8.0	1	13.0	1	7.5	2
	4.4	1	3.8	1	9.8	1	7.8	1			5.0	1			9.0	1	5.0	1			12.0	1	23.0	1	45.0	11
	3.2	1	4.0	1	5.4	1	6.9	1			72.0	17			11.0	1	4.0	1			11.0	1	16.0	1	10.0	2
	3.8	1	4.2	1	6.6	1	13.4	1			10.0	1					5.0	2			13.0	1	17.0	1	26.0	7
	4.0	1	5.4	1	7.5	1	10.4	1			4.0	1					12.0	1					17.0	1	34.0	8
	4.6	1	4.4	1	6.2	1	6.8	1			8.0	1					3.0	1					14.0	1	9.0	2
	4.5	1	2.9	1	8.2	1	9.5	1			29.0	8					5.0	1					19.0	1	6.0	2
	4.6	1	3.6	1	6.6	1	8.6	1			9.0	1					12.0	3					10.0	1	30.0	14
	4.0	1	3.8	1	7.8	1	10.8	1			30.0	7					12.0	2					16.0	1	32.0	14
	4.2	1	4.8	1	8.0	1	14.6	1			6.0	1					5.0	1					15.0	1	36.0	14
	3.8	1	3.2	1	5.0	1	8.6	1			[illegible]5.0	25					4.5	1					16.0	1	43.0	14
	3.8	1	4.0	1	6.2	1	11.0	1			8.0	1					8.0	1							14.0	8
	5.0	1	3.6	1	11.0	1	6.9	1									4.0	1							25.0	5
	4.8	1	4.0	1	6.4	1	11.9	1									14.0	2							55.0	14
	3.4	1			6.4	1											4.8	1							15.0	3
	4.2	1			8.0	1											7.0	1							11.0	2
	4.2	1			7.5	1											12.0	2							11.5	2
	4.1	1			6.0	1											5.0	1							16.0	7
	4.2	1			7.0	1											4.0	1							8.0	3
	3.9	1			8.0	1											3.0	1							15.0	7
	3.4	1			7.0	1											5.0	1							23.0	8
	5.0	1			7.8	1											8.0	1							10.0	2
	4.0	1			9.2	1											7.0	1							14.0	4
	3.9	1			6.0	1											20.0	2							17.0	3
																	6.0	1							25.0	3
																	9.0	1								
N	-		40		-		40		16		68		16		4		34		3		5		12		166	
θ	-		4.05		-		8.33		2.22		4.31		2.22		9.5		5.74		2.33		12.80		16.17		3.29	
σ	-		0.52		-		2.66		1.56		1.24		1.56		1.29		1.77		-		4.44		3.38		1.20	

TABLE D-2. DATA COLLECTED (Cont)

Data Set Number	36		37		38		39		40		41	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	7.0	1	30.0	2	117.0	25			30.0	2	15.0	1
	12.0	1	50.0	4	24.0	4			26.0	2	16.0	1
	19.0	2	24.0	2	12.0	2			38.0	2	22.0	1
	7.0	1	28.0	2	27.0	4			36.0	2	6.0	1
	10.0	1	12.5	1	20.0	3					9.0	1
	11.5	1	18.0	1	39.0	8					4.0	1
	9.0	2	23.0	1	11.0	1					7.0	1
	20.0	1	26.0	1	70.0	15					7.0	1
	21.0	1	22.0	2	62.0	13					5.0	1
	22.0	1	28.0	2	180.0	28					10.0	1
	16.0	1	30.0	2	33.0	8					7.5	1
	11.0	1	36.0	3	13.0	2					16.0	1
	14.0	1	18.0	2	15.0	3					20.0	1
	19.0	2	9.0	1	18.0	2					7.0	1
	53.0	4	22.0	1	22.0	4					30.0	1
	26.0	3	23.0	1							8.5	1
	33.0	2	15.0	1							14.0	1
	30.0	1	19.0	2							7.0	1
	22.0	1	12.0	1							41.0	1
	16.0	1	11.5	1							32.0	1
	17.0	1	27.0	2							6.0	1
	22.0	1	25.0	2							17.0	1
	9.0	1	24.0	2							5.0	1
	11.0	1	19.0	1							7.0	1
	10.0	1	38.0	8							17.0	1
	12.5	1	77.0	14							17.0	1
											8.0	1
N	35		62		122		-		8		27	
θ	13.14		9.60		5.43		-		16.25		13.37	
σ	5.61		6.67		1.11		-		2.55		9.24	

Data Set Number	42		42		43		44		45		46		47	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	26.0	1	24.0	1	2.0	1	32.0	1	6.0	1	7.0	2	7.6	2
	12.0	1	16.0	1	4.0	1	18.0	1	6.0	1	7.1	2	7.5	2
	17.0	1	17.2	1	2.2	1	21.0	1	7.0	1	5.8	2	7.1	2
	14.0	1	15.0	1	2.3	1	7.0	1	7.5	1	5.9	2	6.6	2
	11.5	1	26.0	1	2.5	1	11.0	1	4.5	1	6.0	2	9.6	2
	24.0	1	16.0	1	2.5	1	11.0	1	5.0	1	5.1	2	7.6	2
	13.0	1	17.5	1	2.0	1	17.0	1	8.0	1	5.0	2	5.6	2
	10.5	1	14.0	1	2.2	1	15.0	1	3.0	1	5.5	2	7.8	2
	14.0	1	19.0	1	3.0	1	22.0	1	4.5	1	5.6	2	7.0	2
	17.0	1	14.0	1	1.5	1	15.4	1	7.0	1	6.0	2	6.9	2
	19.0	1	23.0	1	2.0	1	13.0	1	3.0	1	6.5	2	6.0	2
	14.0	1	21.0	1	3.0	1	15.0	1	5.0	1	6.0	2	5.0	2
	12.2	1	21.0	1	7.0	2	10.0	1	3.0	1	4.9	2	6.0	2
	17.5	1	20.0	1	9.0	4	13.0	1	2.0	1	5.8	2	5.0	2
	17.0	1	24.0	1	5.0	3	11.8	1	4.0	1	5.8	2	6.6	2
	16.8	1	19.0	1			18.8	1	7.0	1	5.2	2	7.0	2
	13.0	1	14.0	1			8.9	1	5.0	1	4.4	2	4.4	2
	13.[illegible]	1	17.0	1			9.0	1	6.0	1	5.0	2	5.3	2
	30.0	1	21.0	1			14.0	1			5.9	2	5.6	2
	14.0	1	24.0	1			13.0	1			4.9	2	6.5	2
	27.0	1					10.0	1						
	14.5	1					14.5	1						
	19.0	1					13.0	1						
	17.0	1					9.0	1						
	15.2	1					15.0	1						
N	-		45		21		25		18		40		40	
θ	-		17.80		2.39		14.30		5.47		2.84		3.27	
σ	-		4.66		0.65		5.29		1.94		0.35		0.61	

TABLE D-2. DATA COLLECTED (Cont)

Data Set Number	48		49		50		51		52		53		54		55		56		57		58		59		60	
	time	qty	time	qty	time	qty	time	qt.	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	28.5	1	51.6	1	6.5	1	8.2	1	2.5	1	3.5	1	5.1	1	5.0	1	4.8	1	8.6	1	15.0	7	17.0	7	4.0	1
	23.0	1	48.8	1	6.6	1	8.6	1	3.9	1	4.5	1	5.0	1	7.0	1	4.0	1	5.0	1	14.0	7	16.8	7	3.4	1
	25.4	1	41.0	1	6.2	1	8.0	1	4.2	1	4.4	1	5.6	1	6.0	1	6.0	1	6.0	1	14.0	7	15.5	7	2.5	1
	22.0	1	49.0	1	5.6	1	6.0	1	2.9	1	3.4	1	4.2	1	5.0	1	7.4	1	6.0	1	13.0	7	16.6	7	2.8	1
	29.8	1	40.3	1	6.4	1	7.5	1	4.1	1	4.0	1	4.8	1	5.2	1	4.2	1	5.2	1	13.2	7	16.2	7	3.0	1
	31.8	1	38.4	1	5.6	1	8.9	1	3.4	1	3.6	1	5.2	1	7.6	1	4.1	1	5.1	1	12.0	7	16.8	7	2.0	1
	27.8	1	39.5	1	7.2	1	8.0	1	3.2	1	3.8	1	5.9	1	8.0	1	6.8	1	4.0	1	12.0	7	16.5	7	2.0	1
	28.5	1	34.3	1	5.9	1	7.8	1	3.4	1	5.8	1	5.2	1	4.6	1	6.0	1	5.0	1	13.0	7	14.8	7	1.8	1
	25.2	1	42.5	1	6.4	1	8.2	1	3.0	1	3.6	1	6.0	1	6.0	1	4.0	1	6.0	1	11.5	7	15.0	7	1.9	1
	26.0	1	33.8	1	6.2	1	8.5	1	3.9	1	3.2	1	6.0	1	7.0	1	4.2	1	4.8	1	11.0	7	15.0	7	2.4	1
	27.7	1	33.1	1	6.0	1	8.3	1	4.2	1	4.9	1			7.2	1	8.2	1	4.5	1						
					5.9	1	8.0	1	4.0	1	3.2	1					4.0	1	3.5	1						
					6.5	1	7.8	1	4.2	1	4.0	1					5.8	1	3.8	1						
					7.0	1	9.2	1	4.2	1	4.5	1					3.8	1	3.8	1						
					6.8	1	8.4	1	3.0	1	5.0	1					4.0	1	4.9	1						
					7.2	1	8.7	1	4.5	1	8.0	1					4.2	1	3.9	1						
					6.6	1	8.8	1	4.4	1	3.6	1					4.6	1	3.0	1						
					6.5	1	7.6	1	3.2	1	4.2	1					7.2	1	6.2	1						
					6.6	1	8.2	1	3.4	1	5.1	1					5.4	1	5.9	1						
					6.4	1	8.2	1	5.4	1	4.8	1					5.6	1	4.8	1						
											4.0	1							6.2	1						
											3.0	1														
											4.0	1														
N	11		11		20		20		20		23		10		11		20		21		70		70		10	
θ	26.88		41.12		6.46		8.15		3.75		4.27		5.30		6.24		5.22		5.06		1.84		2.29		2.58	
σ	2.90		6.39		0.42		0.67		0.69		1.07		0.58		1.18		1.35		1.25		0.18		0.12		0.72	

TABLE D-2. DATA COLLECTED (Cont)

Data Set Number	61		62		63		64		65		66		67	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	3.0	1	17.0	1	9.0	4	3.0	1	20.0	1	6.0	1	49.0	5
	2.2	1	16.0	1	5.0	3	9.0	2	19.0	1	8.5	1	15.0	2
	2.0	1	33.0	1	7.0	2	7.0	2	18.5	1	8.0	1	10.0	2
	2.0	1	16.0	1	25.0	14	5.0	2	16.0	1	6.0	1	39.0	5
	2.4	1	14.0	1	32.0	14	7.0	2	21.0	1	10.0	1	25.0	4
	1.5	1	16.0	1	9.0	8			18.0	1	6.6	1		
	1.8	1	12.0	1	9.0	8			17.5	1	5.0	1		
	1.4	1	14.0	1					16.5	1	4.8	1		
	1.5	1	5.0	1					17.0	1	5.0	1		
	2.0	1	29.0	1					15.0	1	6.5	1		
N	10		10		53		9		10		10		18	
θ	1.98		17.2		1.8		3.44		17.90		6.64		7.67	
σ	0.48		5.78		0.60		0.73		1.84		1.71		1.63	

Data Set Number	68		69		70		71		72		73	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	15.0	1	19.0	7	18.0	7	4.0	1	6.0	1	7.0	1
	16.0	1	24.0	10	25.0	10	17.0	4	30.0	4	35.0	6
	12.0	1					16.5	4	25.0	4	20.0	4
	14.0	1					15.0	4	32.0	4		
	16.0	1										
	11.5	1										
	16.0	1										
	19.0	1										
	18.5	1										
	11.0	1										
N	10		17		17		13		13		11	
θ	14.90		2.53		2.53		4.04		7.15		5.60	
σ	2.78		0.16		0.04		0.07		0.81		0.61	

TABLE D-2. DATA COLLECTED (Cont)

Data Set Number	74		75		76		77		78		79		80	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	8.0	1	29.0	8	45.0	10	6.0	1	6.5	1	5.0	1	7.0	1
	43.0	4	77.0	24	81.0	23	13.5	2	14.0	2	4.0	1	7.0	1
	11.0	1					10.5	2	15.0	2	5.5	1	7.0	1
	41.0	4					13.0	2	13.0	2	6.0	1	5.0	1
							12.5	2	14.5	2	4.5	1	5.5	1
							19.0	3	19.5	3	7.0	1	6.0	1
											6.0	1	6.5	1
											5.5	1	6.0	1
											4.0	1	10.0	1
											6.6	1	8.0	1
N	10		32		33		12		12		10		10	
θ	10.30		3.31		5.82		6.21		6.71		5.41		6.80	
σ	0.86		0.18		0.46		0.49		0.64		1.03		1.42	

Data Set Number	81		82		83		84		85		86	
	time	qty	time	qty	time	qty	time	qty	time	qty	time	qty
	11.0	2	9.5	1	105.0	1	12.0	1	47.0	1	32.0	[illegible]
	51.0	10	71.0	10	80.0	1	12.5	1	67.0	1	75.0	[illegible]
					314.0	1	14.0	1	92.0	1	28.0	[illegible]
					135.0	1	22.0	1	51.0	1	55.0	1
					95.0	1	15.0	1	34.0	1	96.0	1
					140.0	1	10.5	1	43.0	1	49.0	1
					105.0	1	12.0	1	49.0	1	45.0	1
					90.0	1	12.5	1	52.0	1	33.0	1
					140.0	1	13.0	1	40.0	1		
					144.0	1	17.0	1	45.0	1		
					101.0	1			75.0	1		
N	12		11		11		10		11		8	
θ	5.67		7.32		131.73		14.05		54.07		51.63	
σ	0.08		0.72		64.54		3.33		17.00		23.00	

APPENDIX E — REGRESSION ANALYSIS FOR LOW TEMPERATURE WORK FACTORS

The data obtained from Test Methodology Research Investigation of Maintenance Performance in an Arctic Environment was analyzed using a linear regression program. The program implemented uses Newton's least squares approximation to fit the best possible line to a set of data points. In order to fit curves such as; exponential, hyberbolas, and power functions, the data was transformed so that the linear forms of the models could be fitted.

The various models that the data points were fitted against were:

	Function	General Form	Linear Form
1	LINEAR	$Y = A_1X + A_0$	$Y = A_1X + A_0$
2	EXPONENTIAL	$Y = Ae^{BX}$	$LN(Y) = BX + LN(A)$
3	POWER FUNCTION	$Y = AX^B$	$LN(Y) = B(LN(X)) + LN(A)$
4	INVERSE	$Y = \frac{A}{(X+C)} + B$	$1/(Y-B) = \frac{1}{A}(X) + C/A$

The above models were run for each data set obtained from the previously mentioned document. The program set up transformed the data by the following transformation equations:

LINEAR	$Y' = Y$	$X' = X$	$B_0 = B_0$	$B_1 = B_1$
EXPONENTIAL	$Y' = LN(Y)$	$X' = X$	$B_0 = LN(A)$	$B_1 = B$
POWER FUNCTION	$Y' = LN(Y)$	$X' = LN(X)$	$B_0 = LN(A)$	$B_1 = B$
INVERSE	$Y' = 1/(Y-B)$*	$X' = X$	$B_0 = C/A$	$B_1 = 1/A$

*B is a constant that translates the curve up and down the Y axis.

The results of each model are tabulated on the following pages. The model that exhibited the best results was the inverse model. The data sets with high correlation were averaged together (weighted by the correlation coefficient) to produce the model

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shown below.

$$Y = \frac{52.07}{(X + 72.43)} + 0.715$$

where Y = the multiplication factor for the repair time
X = the temperature in (°F)

CORRELATION ANALYSES RESULTS

LINEAR MODEL ~ $Y = A_1X + A_0$

Data Set Number	A_0	A_1	R
1	8.706	0.114	0.505
2	1.543	0.884	0.698
3	9.358	0.740	0.451
4	5.794	0.029	0.393
5	7.441	0.060	0.293
6	16.15	0.113	0.459
7	12.25	0.139	0.574
8	12.38	0.116	0.513

EXPONENTIAL MODEL ~ $Y = Ae^{Bx}$

Data Set Number	A_0	A_1	R
1	2.410	0.005	0.482
2	1.204	0.011	0.826
3	2.240	0.006	0.505
4	1.735	0.004	0.459
5	2.065	0.004	0.333
6	2.842	0.004	0.472
7	2.611	0.006	0.639
8	2.604	0.005	0.554

POWER FUNCTION MODEL ~ $Y = Ax^B$

Data Set Number	A_0	A_1	R
1	2.207	0.150	0.329
2	0.339	0.417	0.767
3	1.674	0.239	0.529
4	1.322	0.177	0.507
5	1.642	0.188	0.333
6	2.615	0.140	0.362
7	2.159	0.229	0.564
8	2.280	0.182	0.452

INVERSE MODEL

Data Set Number	A_0	A_1	B	R	MODEL
1	0.033	0.00009	-14.3	0.478	$Y = \frac{-11417}{X - 375} - 14.3$
2	0.374	0.00881	2.93	0.920	$Y = \frac{-113}{X - 42.5} + 2.93$
3	0.339	0.00672	8.14	0.770	$Y = \frac{-149}{X - 50.5} + 8.14$
4	0.612	0.01208	4.81	0.802	$Y = \frac{-83}{X - 50.6} + 4.81$
5	0.223	0.00152	7.18	0.385	$Y = \frac{-656}{X - 146.6} + 7.18$
6	0.229	0.00005	-20.4	0.475	$Y = \frac{-18986}{X - 435} - 20.4$
7	0.244	0.00434	13.74	0.786	$Y = \frac{-230}{X - 56} + 13.74$
8	0.052	0.00026	0.0	0.574	$Y = \frac{-3865.5}{X - 202.8}$

MODEL:

$$Y = \frac{A}{X+C} + B$$

LINEARIZED MODEL:

$$\frac{1}{Y-B} = \frac{1}{A}X + C/A$$

$$A_0 = 1/A$$

$$A_1 = C/A$$

DATA OBTAINED FROM MAINTENANCE PERFORMANCE IN AN ARCTIC ENVIRONMENT

Repair Action #1

Temp* (°F)	Time (Min.)
	11.75**
-20.00	15.00
-20.00	13.00
-27.00	13.50
-24.00	17.00
-51.00	34.00
-32.00	22.00
- 1.00	21.00
- 1.00	15.50
- 2.00	12.00
-20.00	22.00

Repair Action #3

Temp* (°F)	Time (Min.)
	8.50**
-28.00	17.00
-45.00	14.00
-29.00	19.50
-13.00	10.00
- 1.00	12.50
-16.00	21.00
- 9.00	20.50
- 5.00	14.00
-34.00	22.00
-34.00	11.50

Repair Action #2

Temp* (°F)	Time (Min.)
	3.43**
-20.00	10.50
-16.00	7.00
-27.00	9.50
-14.00	10.00
-26.00	6.50
-23.00	6.50
-13.50	9.00
- 9.00	8.50
-47.50	18.00
- 5.00	8.00
-36.00	9.00

Repair Action #4

Temp* (°F)	Time (Min.)
	5.13**
-20.00	6.00
-29.00	7.00
-25.00	11.00
-22.00	7.00
-24.00	8.00
-10.00	8.00
-18.00	10.00
- 5.00	11.00
-34.00	9.50
-21.00	7.50

*The temperature given is the equivalent windchill temperature.
**This time is the average time to perform the task indoors.

Repair Action #5

Temp*(°F)	Time (Min.)
	7.50**
-24.00	15.00
-29.00	9.00
-25.00	12.00
-11.00	10.00
-54.00	9.00
-27.50	27.00
-14.00	7.50
-19.00	12.00
- 4.00	10.00
-32.00	19.00

Repair Action #6

Temp*(°F)	Time (Min.)
	15.38**
-20.00	28.00
-25.00	24.00
-11.00	20.00
-54.00	27.00
-27.50	38.00
-14.00	16.00
-19.00	26.00
- 4.00	21.00
-32.00	38.00

Repair Action #7

Temp*(°F)	Time (Min.)
	14.80**
-29.00	27.00
-25.00	24.00
-11.00	19.00
-54.00	25.00
-27.50	37.00
-14.00	16.00
-19.00	23.00
- 4.00	20.00
-32.00	35.00

Repair Action #8

Temp*(°F)	Time (Min.)
	15.10**
-29.00	24.00
-25.00	22.00
-11.00	17.00
-54.00	24.00
-27.50	36.00
-14.00	14.00
-19.00	21.50
- 4.00	18.00
-32.00	30.00

*The temperature given is the equivalent windchill temperature.
**This time is the average time to perform the task indoors.

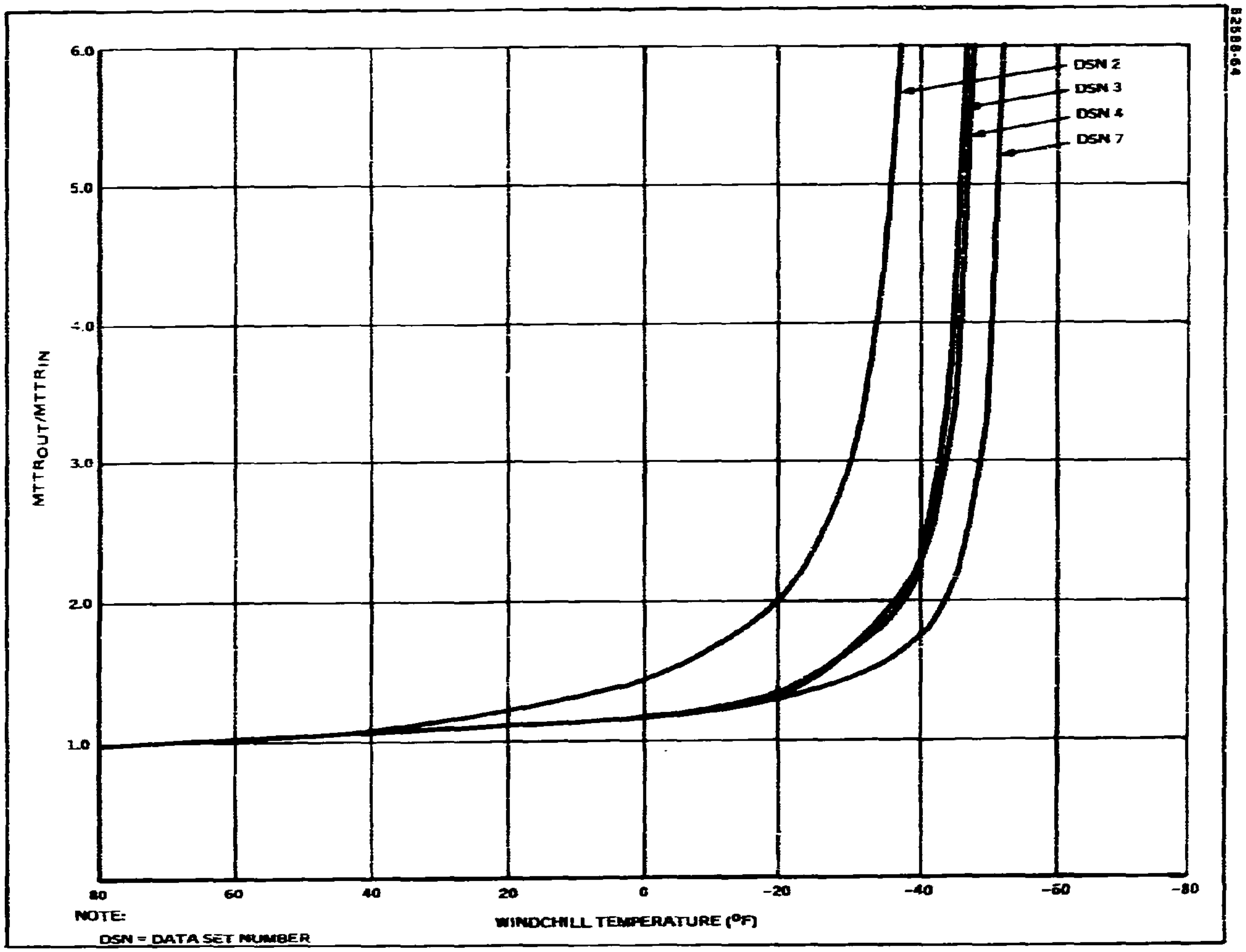

Figure E-1. Fitted Curves for the Data that had High Correlation

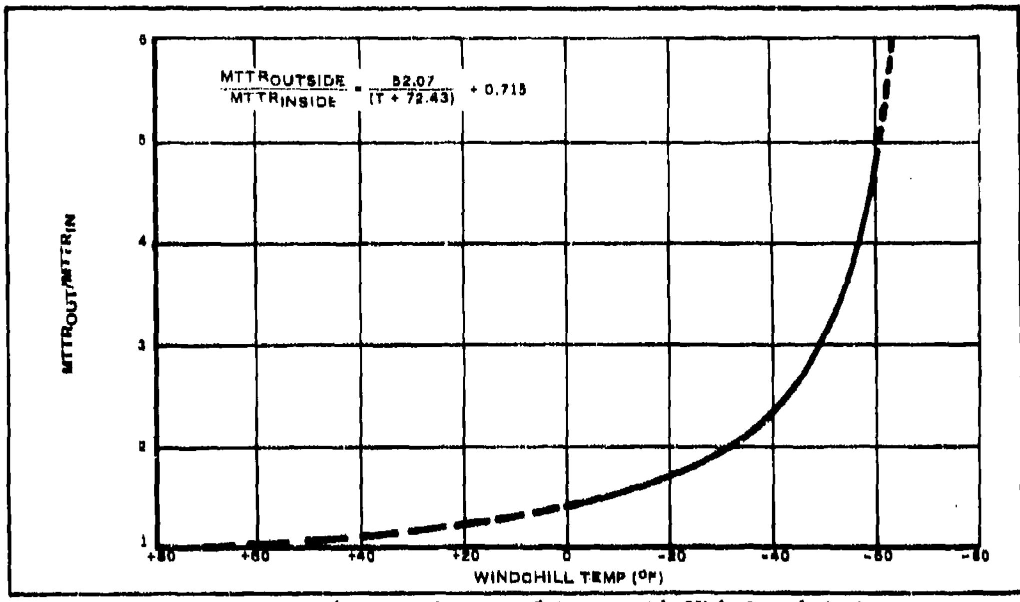

Figure E-2. Final Curve (Average of Curves with High Correlation)

APPENDIX F – SAMPLE DETAILED PREDICTION

A detailed prediction was performed on an existing airborne Radar in order to demonstrate the use of the detailed prediction methodology. The evaluated radar was selected since it had a relatively small quantity of RIs at the organizational level (i.e. flight line) and had a detailed BIT and maintainability analysis previously performed. Therefore, the prediction procedure could be easily illustrated and compared with the previous prediction. The following sections present the step by step procedure involved in implementing the detailed prediction methodology.

Define the Prediction Requirements and the Maintenance Concept

The prediction ground rules for this example were:

- the maintainability parameter to be predicted is MTTR
- the prediction is for flight-line (organizational) level corrective maintenance.
- the elemental maintenance activities included in the MTTR are:
  - fault isolation
  - disassembly
  - interchange
  - reassembly
  - check out
- faults will be isolated to a single RI or RI group via BIT/Diagnostics and/or operator observations
- When faults are isolated to a group of RIs, iterative replacement will be performed until the fault is corrected.
- The following units are defined as RIs:
  - 001 RF Oscillator
  - 011 Transmitter
  - 022 Receiver
  - 031 Antenna
  - 039 Analog Processor
  - 041 Digital Processor
  - 081 Data Processor
  - 541 Radar Set Control
  - 610 Power Supply

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Identify the Fault Isolation Outputs

The fault isolation outputs are those BIT/Diagnostic/System symptoms which inform the technician what repair action to perform. The faulty RI(s) will be isolated either by a latched BIT indicator or by observation and interpretation of the data presented in the bit matrix displayed on the pilot's console. The subject radar, by virtue of its dictated maintenance concept, imposes a condition of primary and secondary FD & I outputs. For each fault which is detected by BIT, there is a corresponding output on the BIT Matrix. Depending on the specific fault, there may also be a unit BIT indicator latched or a system BIT indicator latched. The maintenance concept requires that if a unit BIT indicator is latched, that unit is assumed faulty and replaced without regard to the BIT Matrix output. Then, if the fault is not cleared, the BIT Matrix is reviewed and further repair actions are taken. Table F-1 identifies all the unique fault isolation outputs that are associated with the subject radar. The designation BMR-x denotes a unique display on the BIT Matrix as defined in the radar maintenance manuals.

FD & I Output and RI Correlation

The FD & I Outputs and RI correlation analysis are presented in two ways. The first presentation, shown in figure F-1, is a FD & I Output Tree which shows 1) for each output which test, status monitor, or other FD & I feature(s) can generate that output, and 2) what RI(s) or portion(s) thereof are fault isolated with that particular feature. The tree was derived using information from a previously performed BIT analysis.

The second method of presenting the correlation is by the Maintenance Correlation Matrix shown in figure F-2. The unique fault isolation outputs (j) are listed down the side of the matrix and the RIs (n) are listed across the top. The intersection of each row and column provides 3 pieces of data: (1) The failure (λnj) rate of the n^{th} RI isolated by the j^{th} fault isolation output, (2) the order (K_{nj}) in which the n^{th} RI is replaced given that the j^{th} fault isolation output occurs, and (3) the corrective maintenance time (R_{nj}) given that the n^{th} RI is failed and the failure is isolated by the j^{th} fault isolation output. The corrective maintenance time is derived from the Maintenance Flow Diagram described below.

Table F-1. FD&I Outputs

J	FD & I Outputs	J	FD & I Outputs
1	Latched 001 BIT Indicator	25	SBI and BMR-15
2	Latched 011 BIT Indicator	26	SBI and BMR-16
3	Latched 022 BIT Indicator	27	SBI and BMR-17
4	Latched 031 BIT Indicator	28	SBI and BMR-18
5	Latched 039 BIT Indicator	29	SBI and BMR-19
6	Latched 041 BIT Indicator	30	SBI and BMR-20
7	Latched 081 BIT Indicator	31	SBI and BMR-21
8	Latched 541 BIT Indicator	32	SBI and BMR-22
9	Latched 610 BIT Indicator	33	MR-1, missiles do not tune after radar time out
10	Operator Observes Power Dump	34	MR-2, erratic antenna operation
11	001 BIT Indicator, and BIT Matrix Result #1 (BMR-1)	35	MR-3, missing targets in LRS on HPRF
		36	MR-4, no targets
12	011 BIT Indicator and BMR-2	37	MR-5, multiple return on single target
13	022 BIT Indicator and BMR-3	38	MR-6, weak or poor radar detection
14	022 BIT Indicator and BMR-4	39	MR-7, radar and IFF targets do not correlate
15	041 BIT Indicator and BMR-5	40	MR-8, antenna stops scanning
16	541 BIT Indicator and BMR-6	41	MR-9, search coverage incorrect or frozen
17	System BIT Indicator (SBI), and BMR-7	42	MR-10, will not lock on or hold lock on target
18	SBI and BMR-8	43	MR-11, will not hold or maintain lock on air to ground modes
19	SBI and BMR-9		
20	SBI and BMR-10	44	MR-12, track range in HPRF incorrect
21	SBI and BMR-11	45	MR-13, radar does not track transfer
22	SBI and BMR-12	46	MR-14, multiple beacon returns incorrect azimuth or range
23	SBI and BMR-13		
24	SBI and BMR-14	47	MR-15, beacon returns are missing
		48	MR-16, radar mode lights do not come on

SBI - *System Bit Indicator*
MR - Manual Result, Operator/Technician Observation

Prepare Maintenance Flow Diagram

The R_{nj} values contained in the FD & I output matrix are extracted from the maintenance flow diagram (MFD) shown in figure F-3. The MFD shows the maintenance repair procedure for every unique "j" FD&I output. The times for each elemental maintenance activity are based on time line analyses extracted from the previously prepared maintainability prediction. Normally these times would be synthesized using the timeline analysis approach of section 5.1.7.

The time for each elemental maintenance action is entered in the appropriate activity box along each repair path and the total time (R_{nj}) is found by adding all the elemental times from the starting point (i.e. failure occurs and is detected) to the appropri 'e end point for each "nj" set. These times are then entered in the maintenance correlation matrix (figure F-2).

Compute the Maintainability Parameters

Once the maintenance flow diagram (MFD) has been completed and the R_{nj} values entered in the maintenance correlation matrix, the RI average repair times (R_n) and MTTR can easily be computed by:

$$R_n = \frac{\sum_{j=1}^{J} \lambda_{nj} R_{nj}}{\sum_{j=1}^{J} \lambda_{nj}}$$

and

$$MTTR = \frac{\sum_{n=1}^{N} \lambda_n \ R_n}{\sum_{n=1}^{N} \lambda_n}$$

The predicted MTTR for the subject radar is 20.78 minutes. Table F-2 lists the associated times (R_n) for each RI that make up the MTTR. As shown above, the average time for each RI is computed by determining the failure rate weighted average of the repair times associated with each FD & I output (result) for that RI.

Table F-2. Predicted RI Repair Times and System MTTR

n	λ_n	R_n	$\lambda_n R_n$
1	79.720	12.88	1026.95
2	226.957	41.10	9327.53
3	40.779	18.45	752.21
4	233.571	43.78	10226.87
5	126.982	13.61	1727.71
6	663.186	11.28	7479.36
7	181.636	11.60	2106.55
8	9.961	11.36	113.11
9	27.476	10.46	287.51
Σ	1590.268		33047.8

$$\text{MTTR} = \frac{\sum_{n=1}^{N} \lambda_n R_n}{\sum_{n=1}^{N} \lambda_n} = \frac{33047.8}{1590.268} = 20.78 \text{ minutes}$$

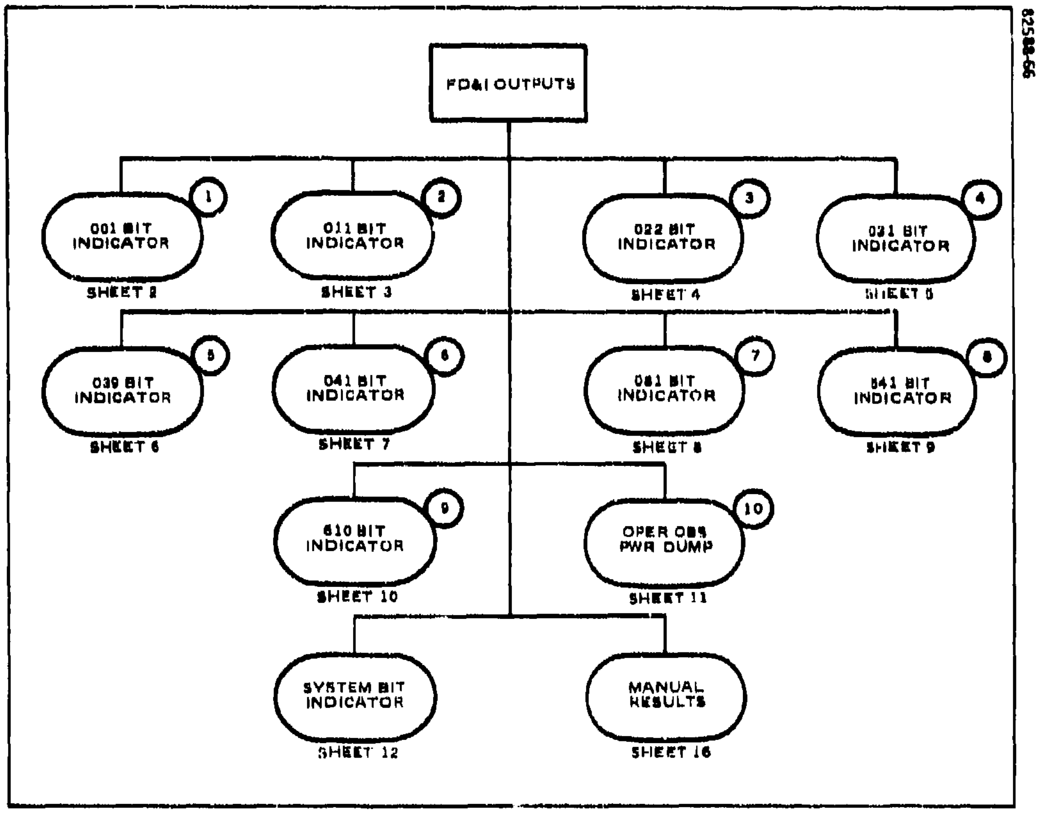

Figure F-1. Fault Isolation Output and RI Correlation Tree (Sheet 1 of 17)

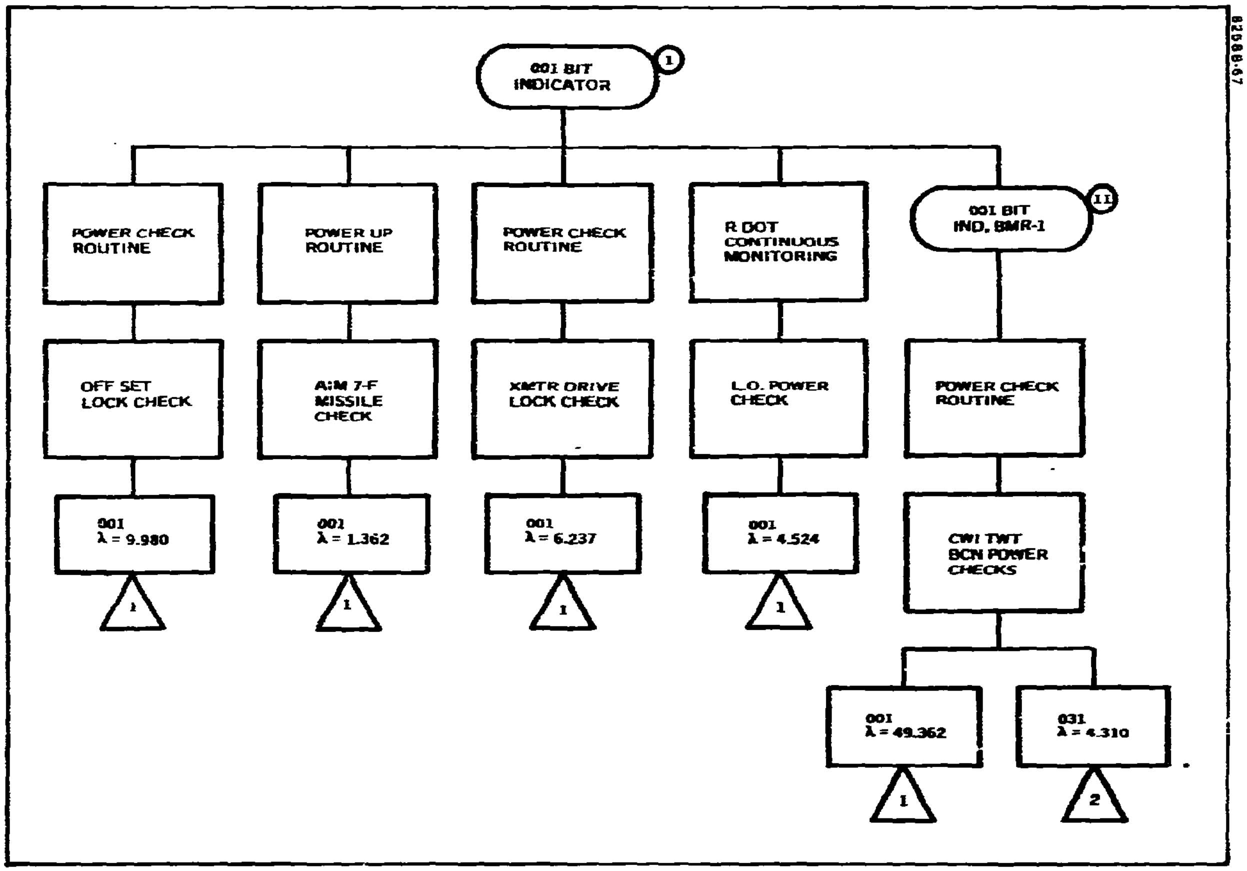

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 2 of 17)

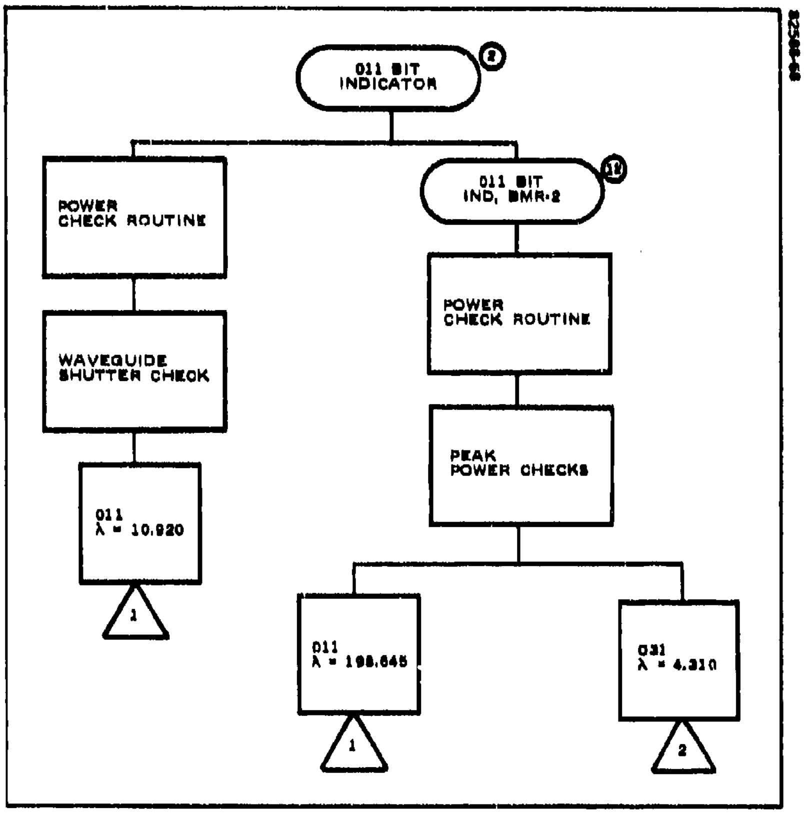

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 3 of 17)

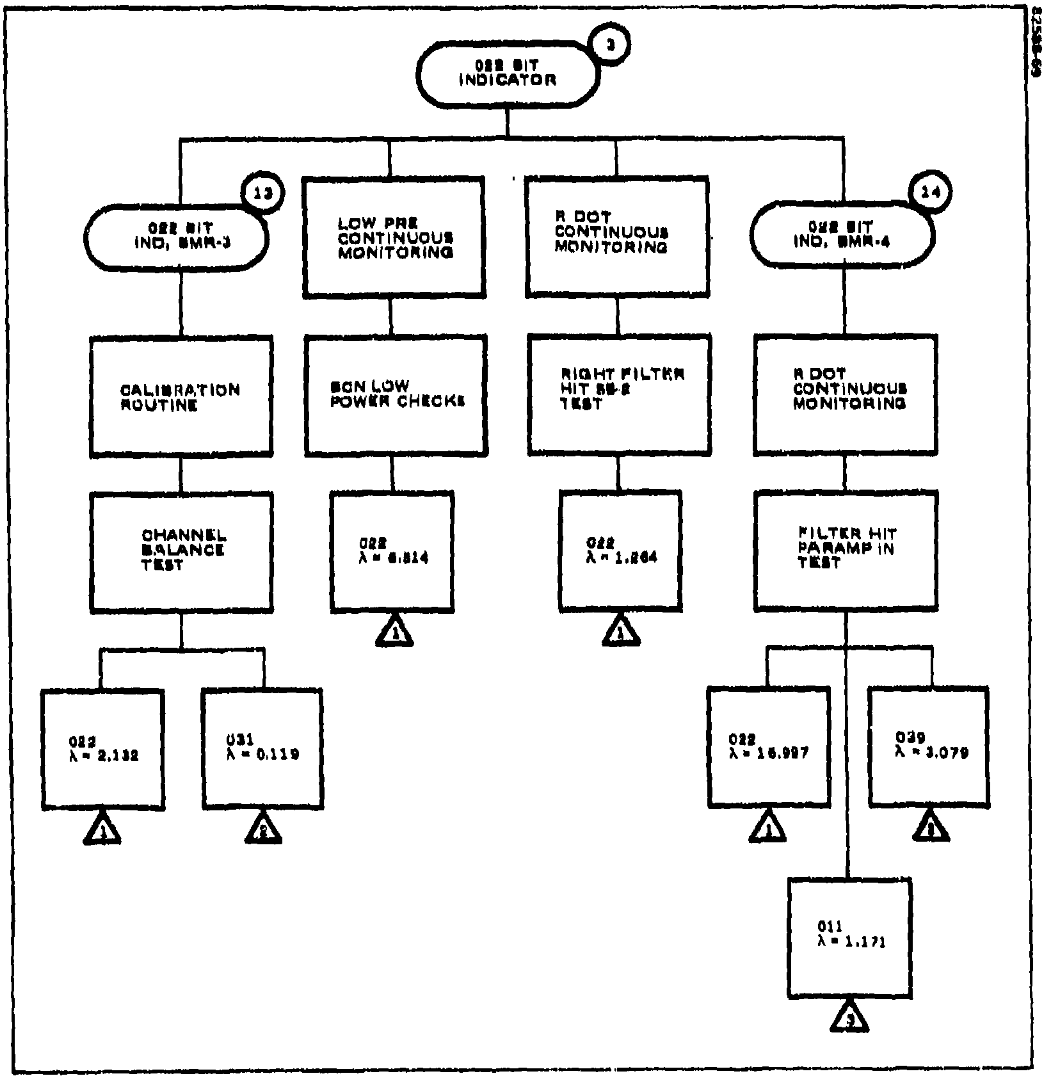

Figure F-1 (Cont). Fault Isolation Output and RI Correlation (Sheet 4 of 17)

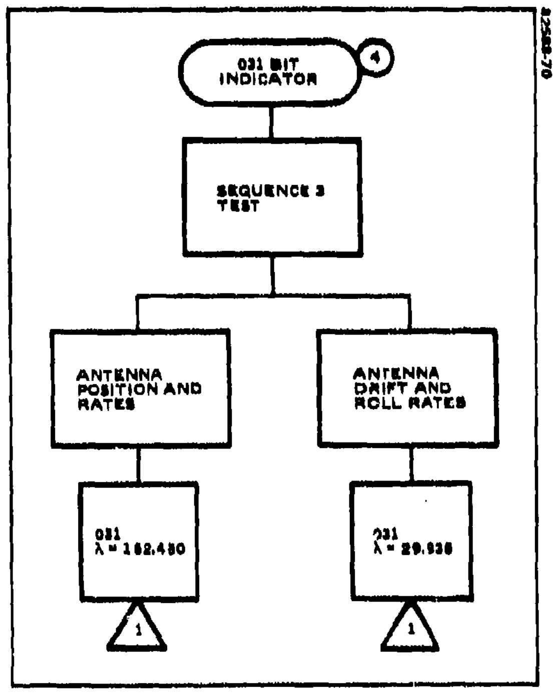

Figure F-1. Fault Isolation Output and RI Correlation Tree (Sheet 5 of 17)

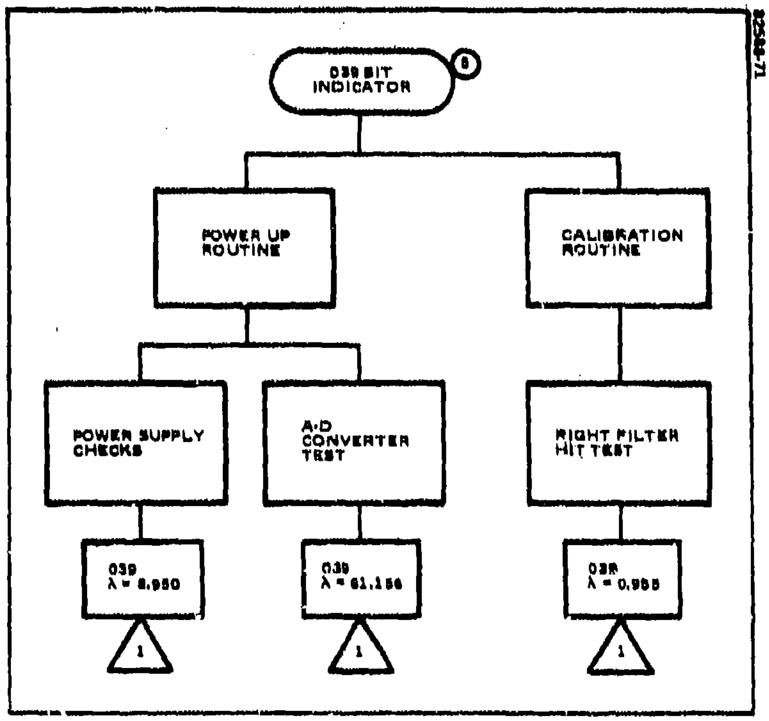

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 6 of 17)

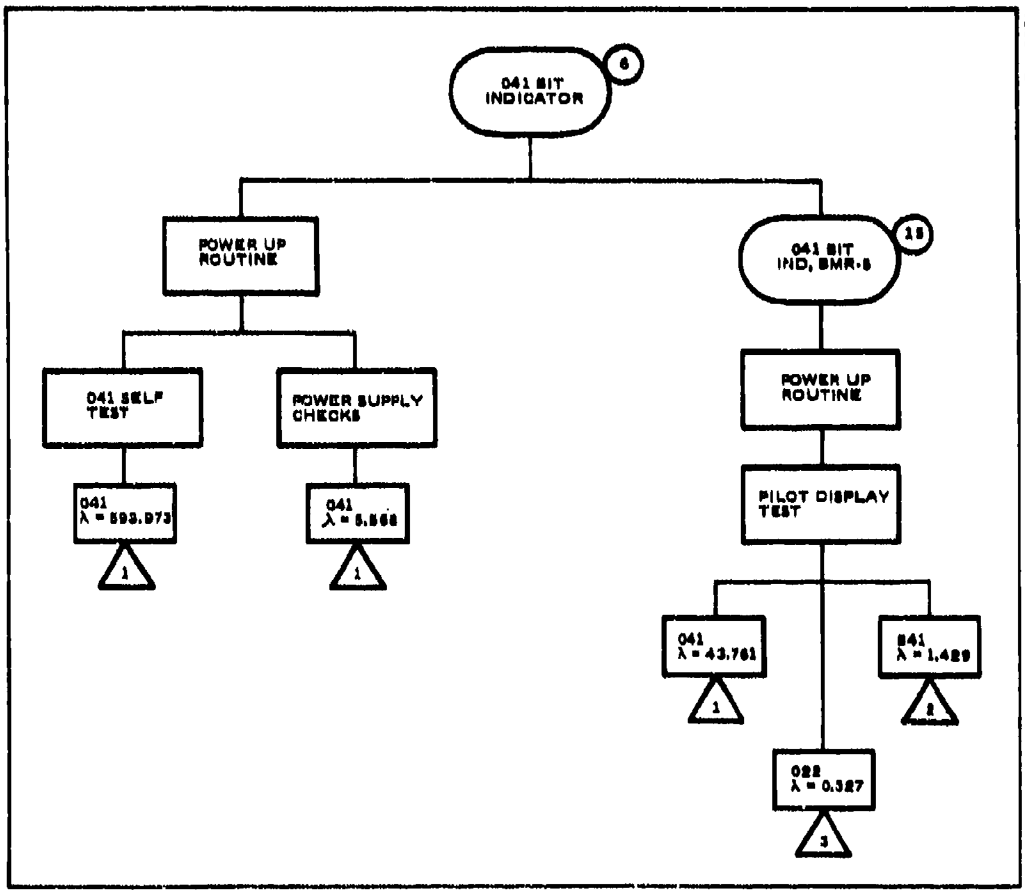

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 7 of 17)

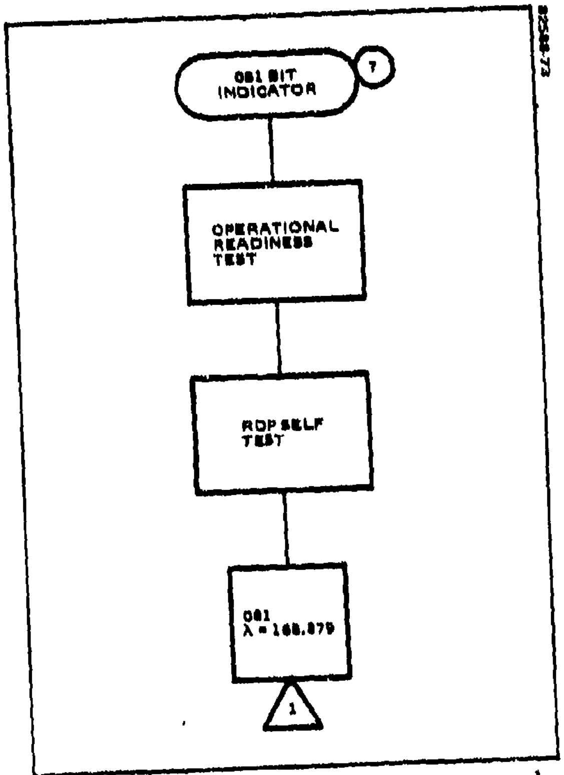

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 8 of 17)

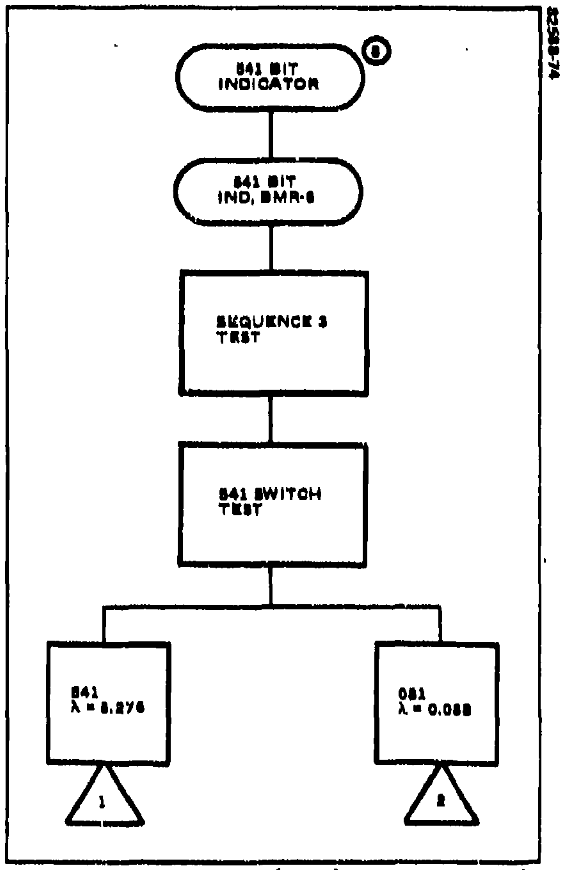

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 9 of 17)

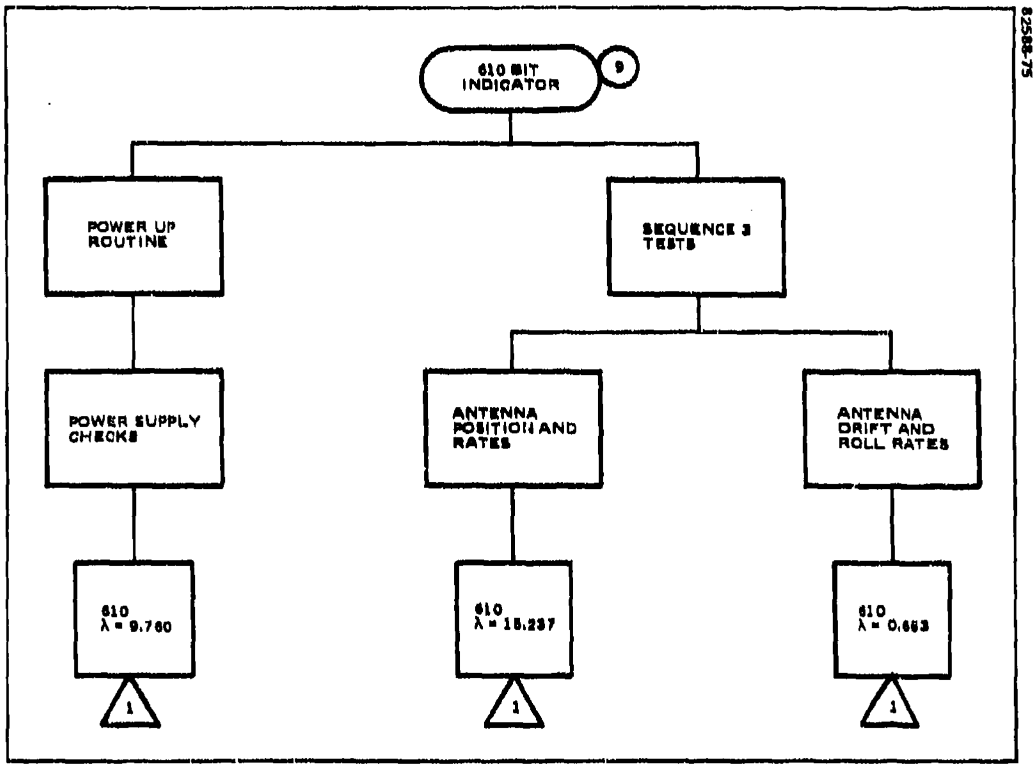

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 10 of 17)

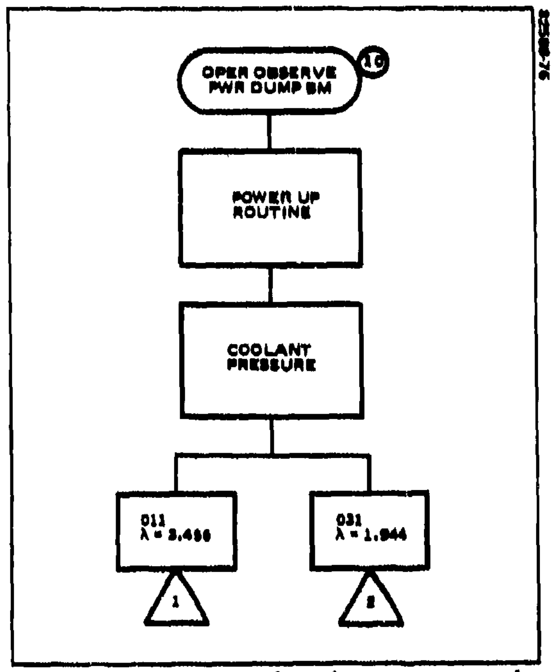

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 11 of 17)

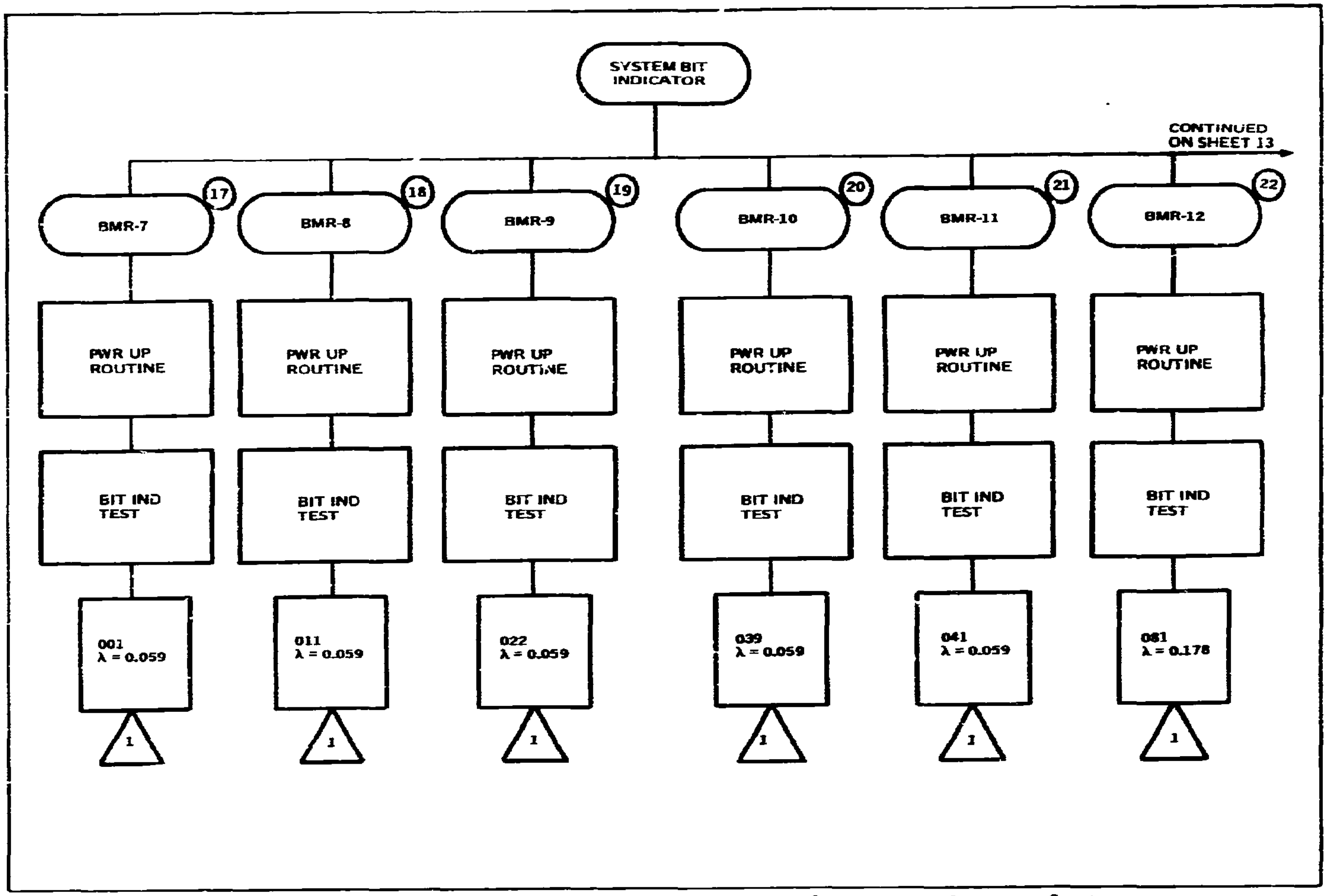

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 12 of 17)

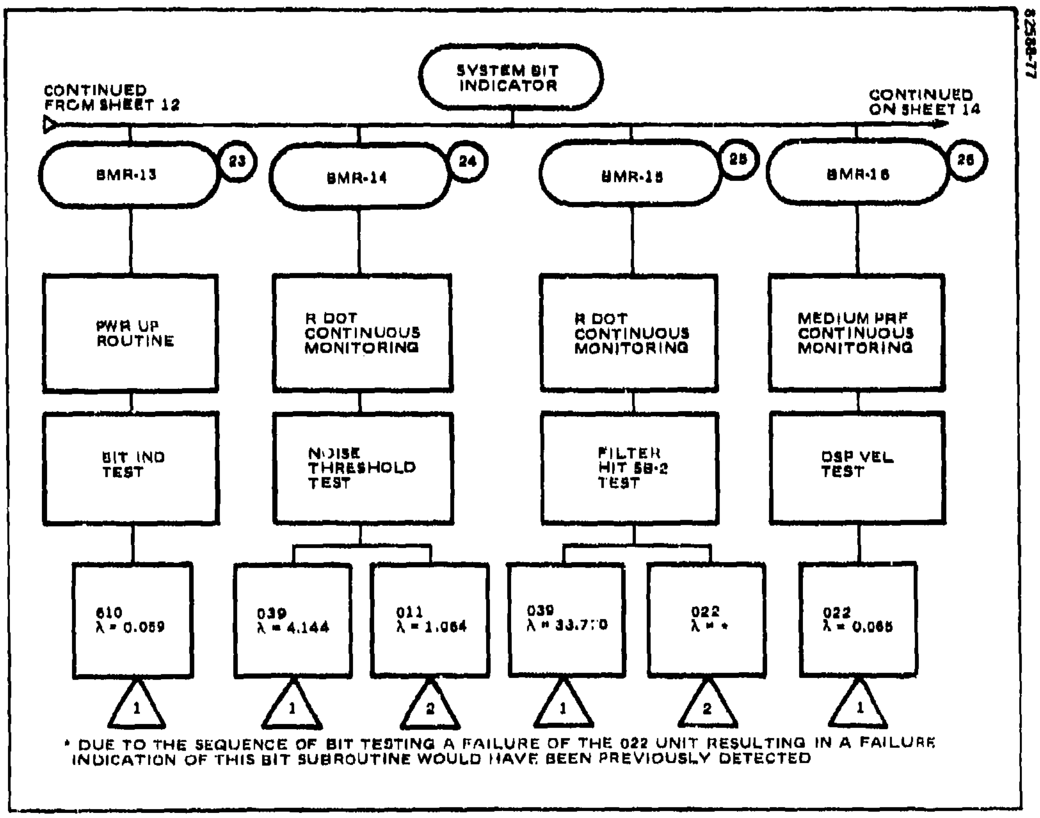

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 13 of 17)

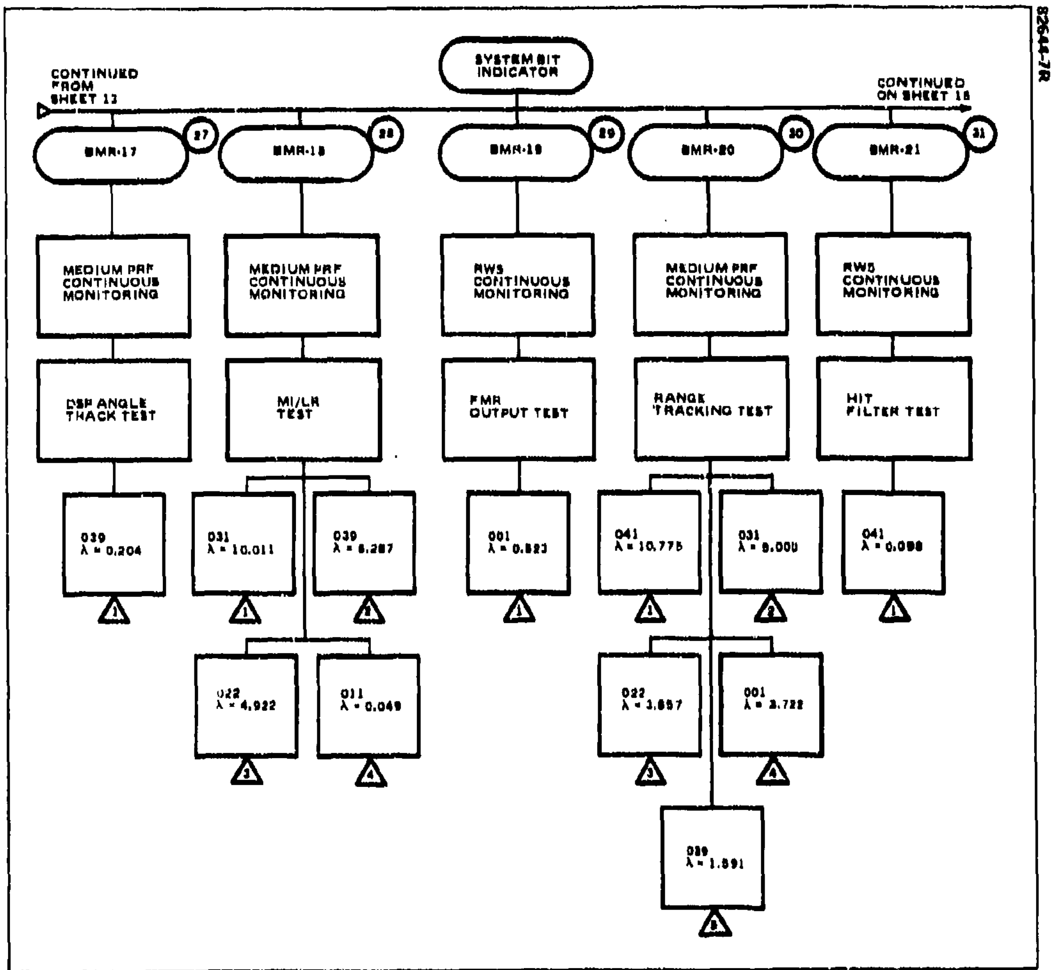

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 14 of 17)

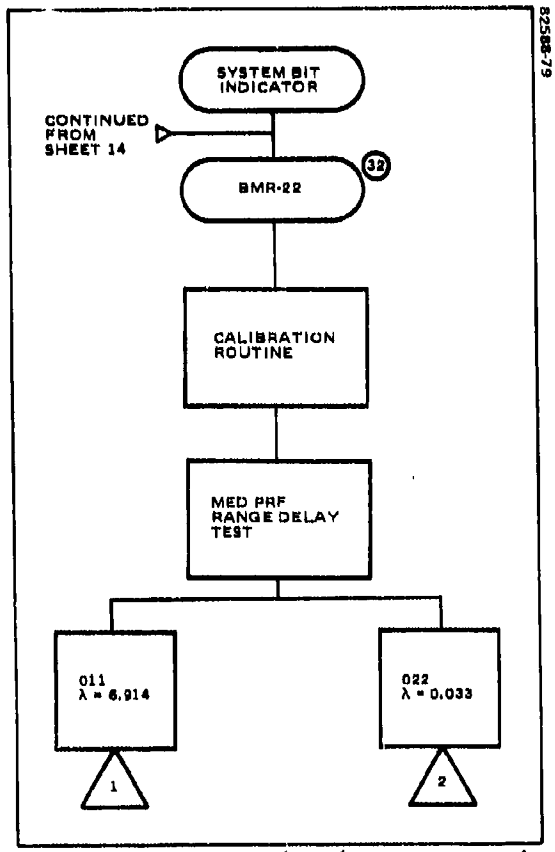

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 15 of 17)

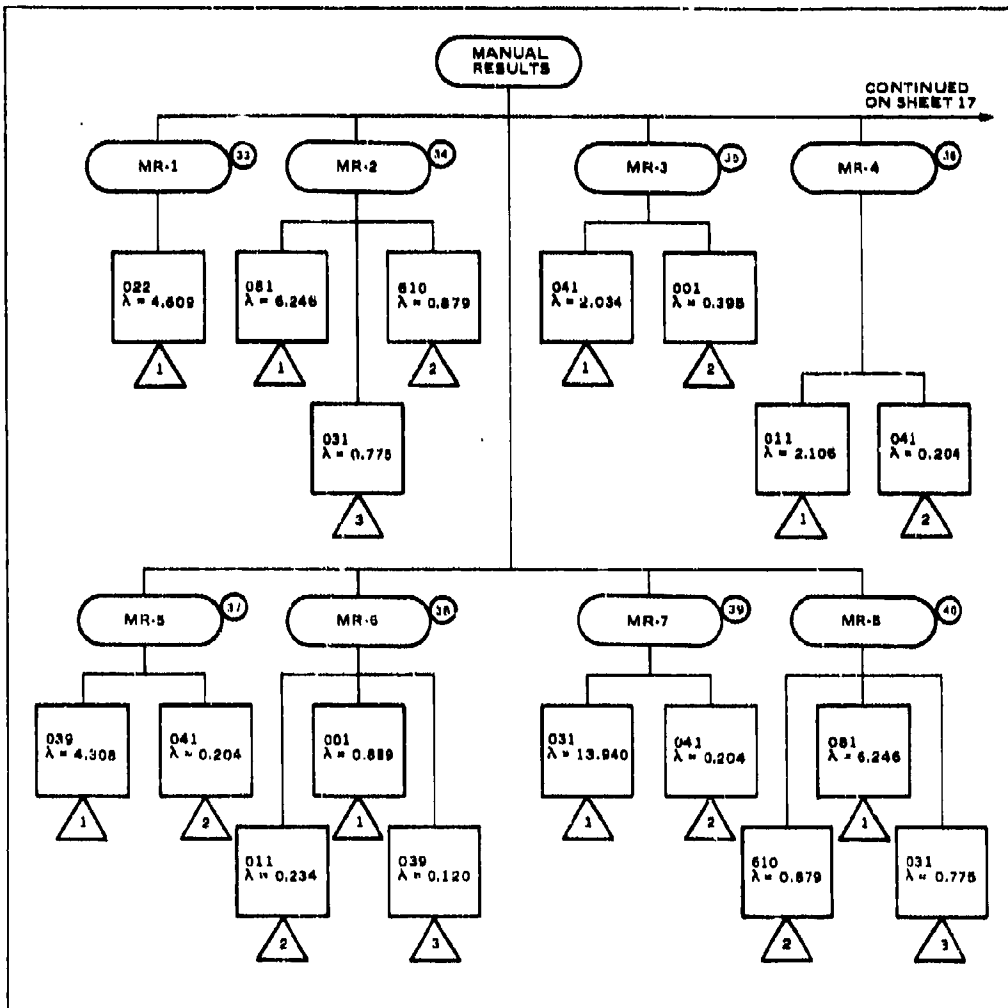

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 16 of 17)

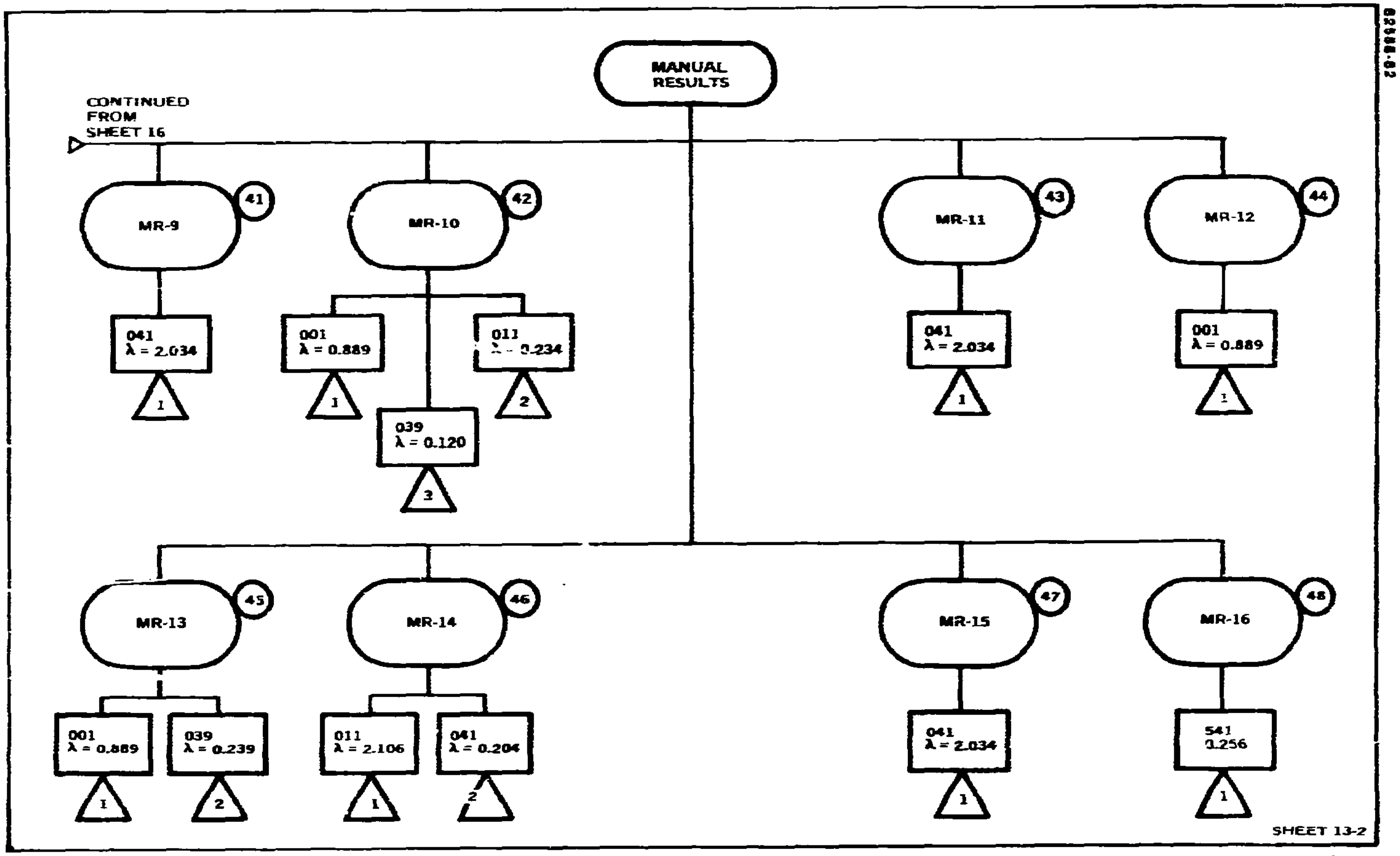

Figure F-1 (Cont). Fault Isolation Output and RI Correlation Tree (Sheet 17 of 17)

EQUIPMENT	001			011			022			031			039			641			081			541			610		
λ	79.720			226.957			40.779			233.571			126.982			663.186			181.636			5.961			27.476		
i	K_{1i}	λ_{1i}	R_{1i}	K_{2i}	λ_{2i}	R_{2i}	K_{3i}	λ_{3i}	R_{3i}	K_{4i}	λ_{4i}	R_{4i}	K_{5i}	λ_{5i}	R_{5i}	K_{6i}	λ_{6i}	R_{6i}	K_{7i}	λ_{7i}	R_{7i}	K_{8i}	λ_{8i}	R_{8i}	K_{9i}	λ_{9i}	R_{9i}
1	1	22.103	9.2																								
2				1	10.920	40.4																					
3							1	7.778	8.6																		
4										1	192.388	40.4															
5													1	71.061	9.2												
6																1	599.541	11.0									
7																			1	168.879	11.0						
8																			2	0.088	22.7	1	8.276	9.2			
9																									1	25.660	9.2
10				1	3.456	45.4				2	1.944	85.8															
11	1	49.362	9.2							2	4.310	52.1															
12				1	198.645	40.4				2	4.310	83.3															
13							1	2.132	8.6	2	0.119	51.5															
14				3	1.171	60.7	1	16.997	8.6				2	3.079	20.3												
15							3	0.327	31.3							1	43.761	11.0				2	1.429	22.7			
16 *																											
17	1	0.059	16.7																								
18				1	0.059	47.9																					
19							1	0.059	16.1																		
20													1	0.059	16.7												

*THIS REPAIR HAS BEEN ABSORBED INTO THE j = 8 RESULT

Figure F-2. Maintenance Correlation Matrix (Sheet 1 of 3)

EQUIPMENT	001			011			022			031			039			041			081			541			610		
λ	79.720			226.957			40.779			233.571			126.982			663.186			181.636			9.961			27.476		
i	K_{1i}	λ_{1i}	R_{1i}	K_{2i}	λ_{2i}	R_{2i}	K_{3i}	λ_{3i}	R_{3i}	K_{4i}	λ_{4i}	R_{4i}	K_{5i}	λ_{5i}	R_{5i}	K_{6i}	λ_{6i}	R_{6i}	K_{7i}	λ_{7i}	R_{7i}	K_{8i}	λ_{8i}	R_{8i}	K_{9i}	λ_{9i}	R_{9i}
21																1	0.059	18.5									
22																			1	0.178	18.5						
23																									1	0.059	16.7
24				2	1.064	57.1							1	4.144	16.7												
25													1	33.770	16.7												
26							1	0.065	16.1																		
27													1	0.204	16.7												
28				4	0.043	106.1	3	4.922	65.7	2	10.011	57.1	1	8.287	16.7												
29	1	0.523	16.7																								
30	4	3.722	76.7				2	3.457	27.1	3	5.000	67.5	5	1.591	85.9	1	10.775	18.5									
31																1	0.098	18.5									
32				1	6.974	47.9	2	0.033	56.5																		
33							1	4.609	17.1																		
34										3	0.775	69.1							1	6.246	19.5				2	0.879	28.7
35	2	0.395	28.7													1	2.034	19.5									
36				1	2.106	48.9										2	0.204	59.9									
37													1	4.208	17.7	2	0.204	28.7									
38	1	0.889	177	2	0.234	58.1							3	0.120	67.3												
39										1	13.940	48.9				2	0.204	59.9									
40										3	0.775	69.1							1	6.246	19.5				2	0.879	28.7

Figure F-2 (Cont). Maintenance Correlation Matrix (Sheet 2 of 3)

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EQUIPMENT	001			011			022			031			039			041			081			541			610		
λ	79.720			226.957			40.779			233.571			126.982			663.186			181.636			9.961			27.476		
j	K_{1j}	λ_{1j}	R_{1j}	K_{2j}	λ_{2j}	R_{2j}	K_{3j}	λ_{3j}	R_{3j}	K_{4j}	λ_{4j}	R_{4j}	K_{5j}	λ_{5j}	R_{5j}	K_{6j}	λ_{6j}	R_{6j}	K_{7j}	λ_{7j}	R_{7j}	K_{8j}	λ_{8j}	R_{8j}	K_{9j}	λ_{9j}	R_{9j}
41																1	2.034	19.5									
42	1	0.889	17.7	2	0.234	58.1							3	0.120	67.3												
43																1	2.034	19.5									
44	1	0.889	17.7																								
45	1	0.889	17.7										2	0.239	26.3												
46				1	2.106	43.9										2	0.204	58.1									
47																1	2.034	19.5									
48																						1	0.256	17.7			

Figure F-2 (Cont). Maintenance Correlation Matrix (Sheet 3 of 3)

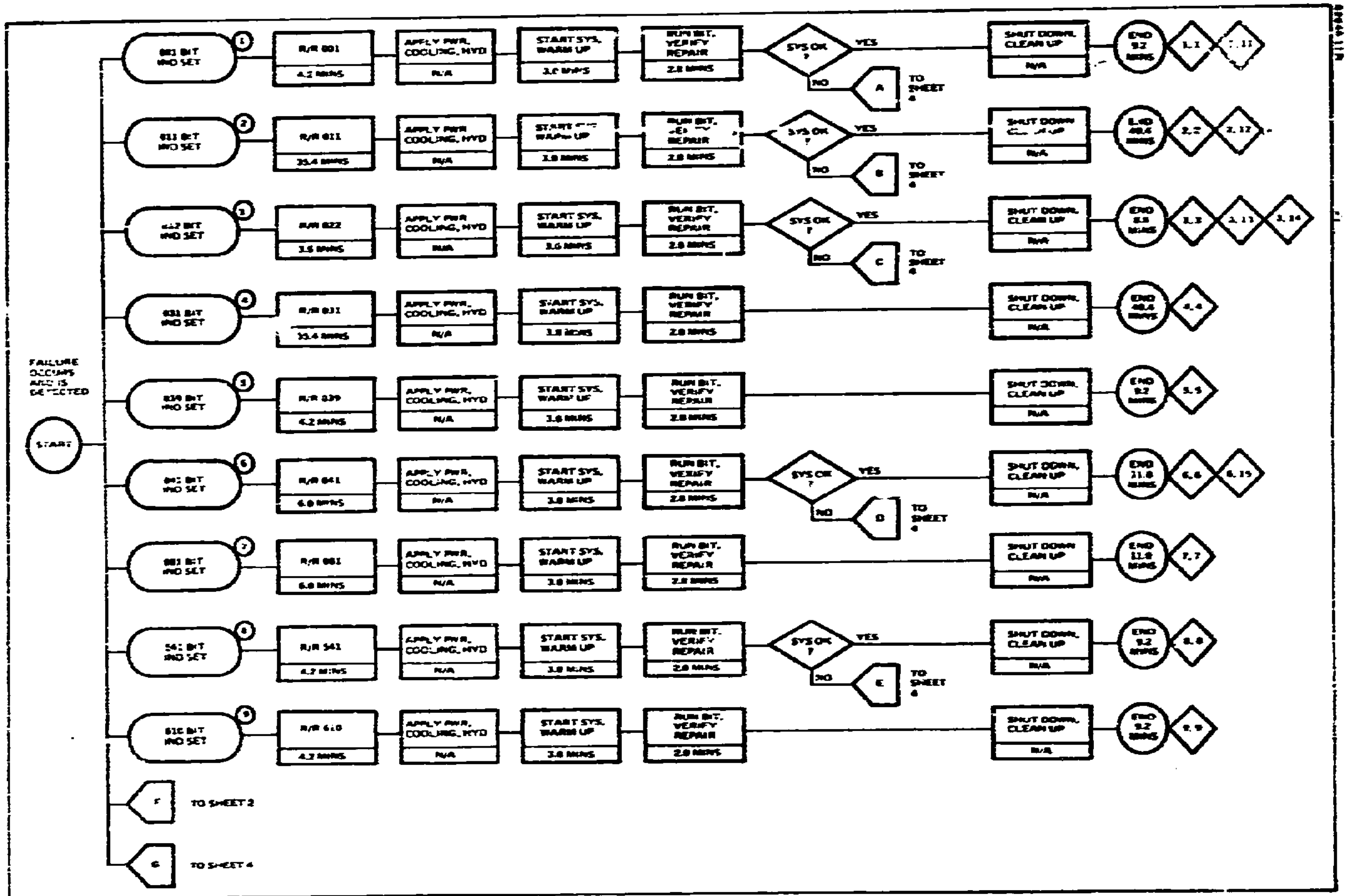

Figure F-3. Maintenance Flow Diagram (Sheet 1 of 9)

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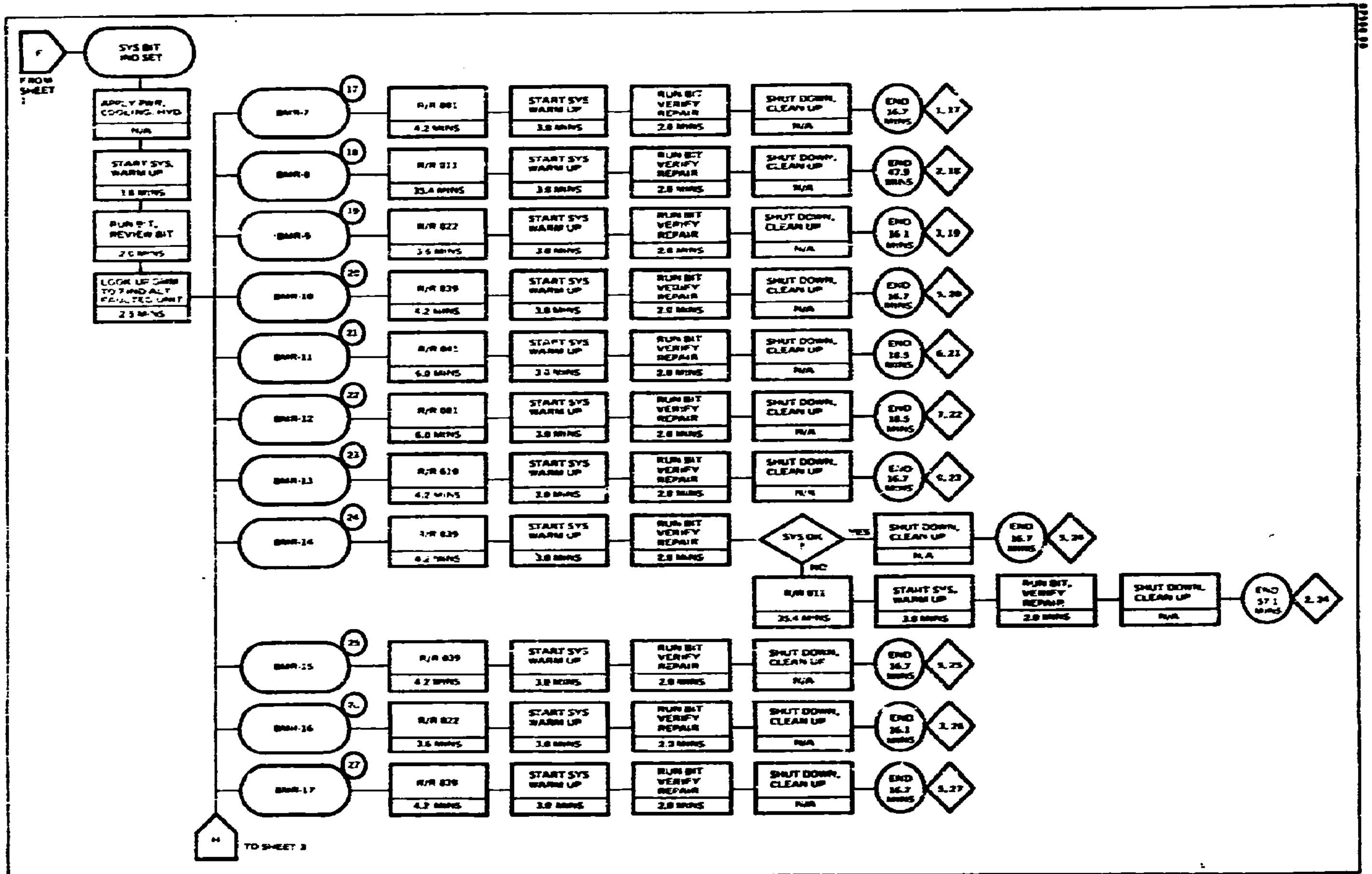

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet 2 of 9)

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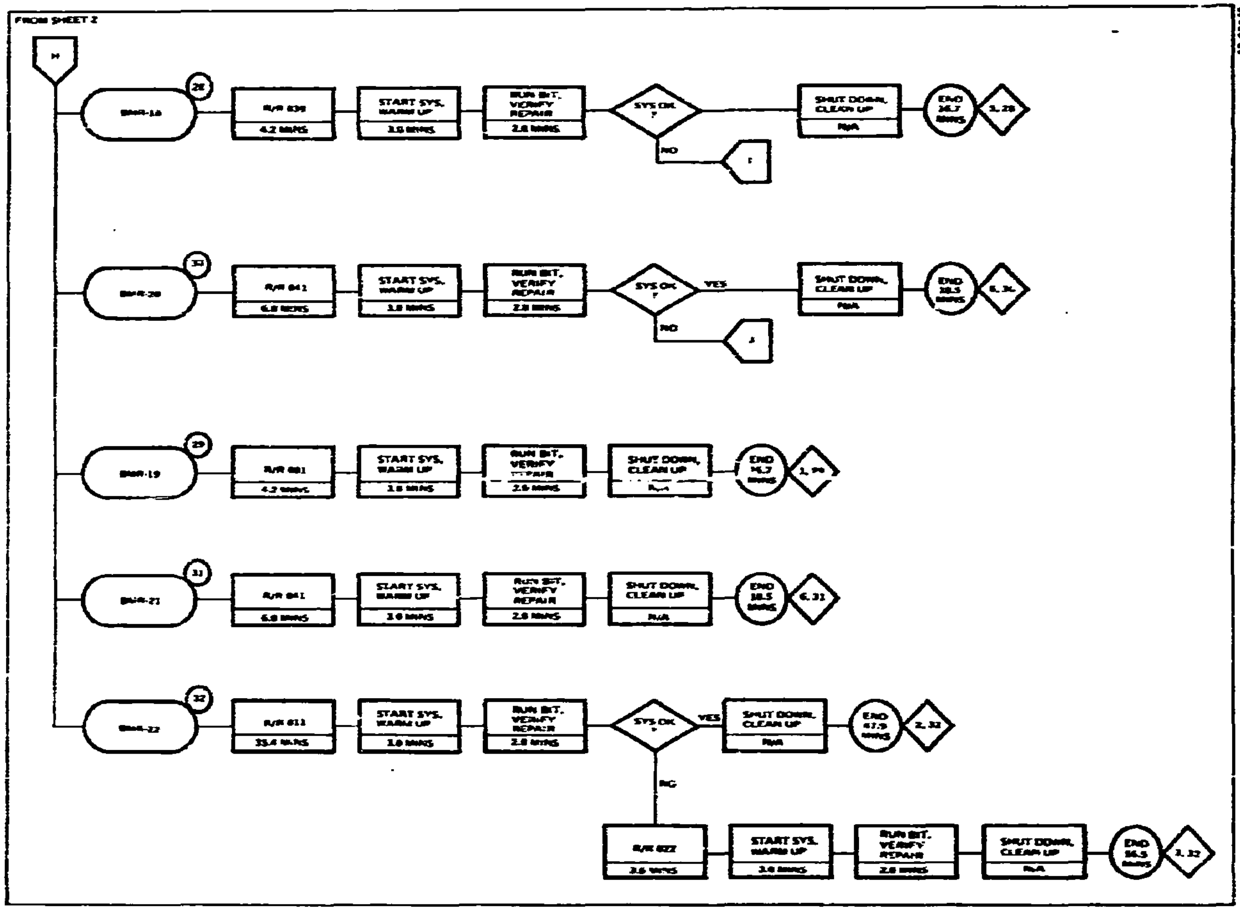

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet 3 of 9)

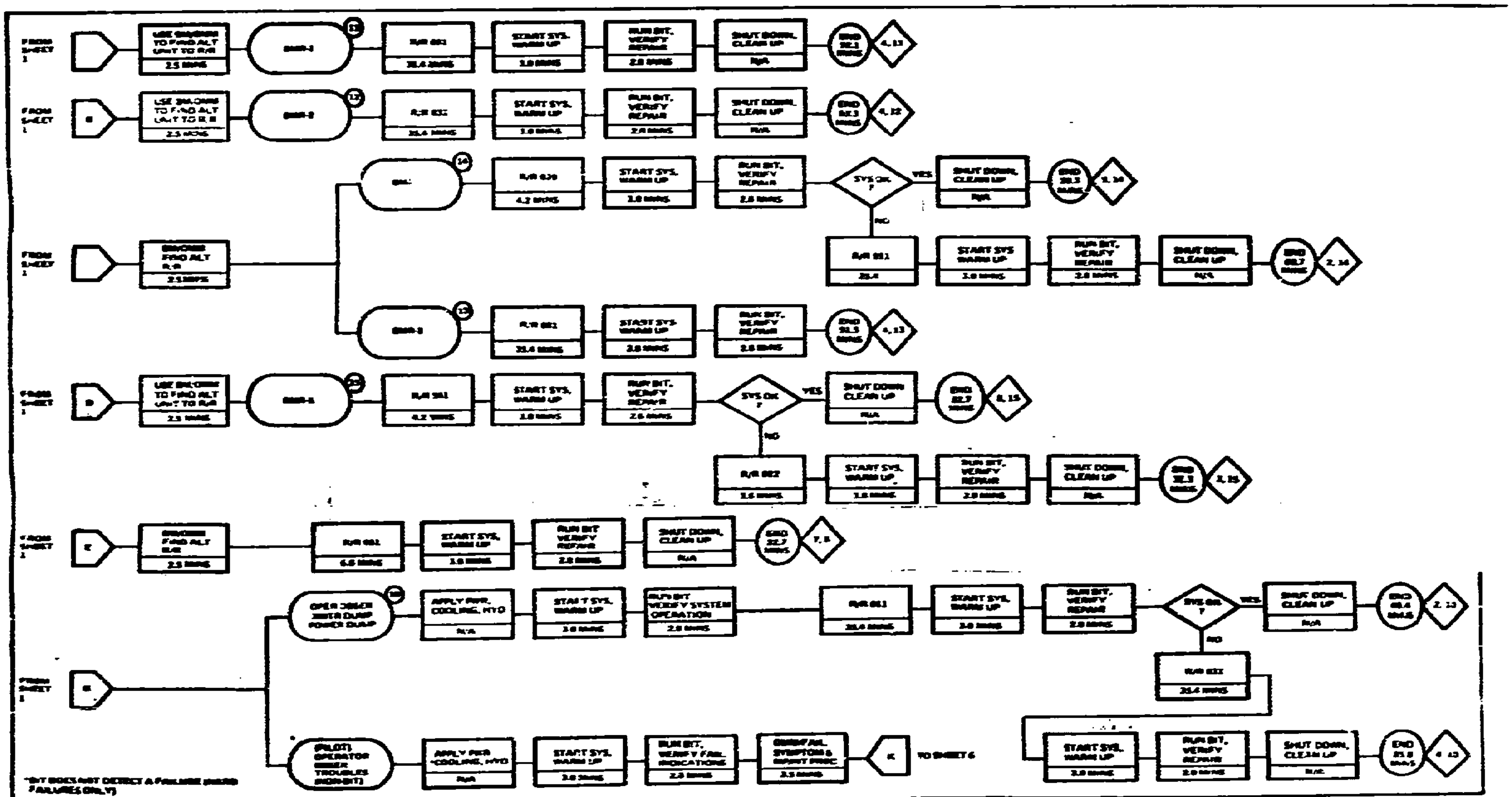

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet 4 of 9)

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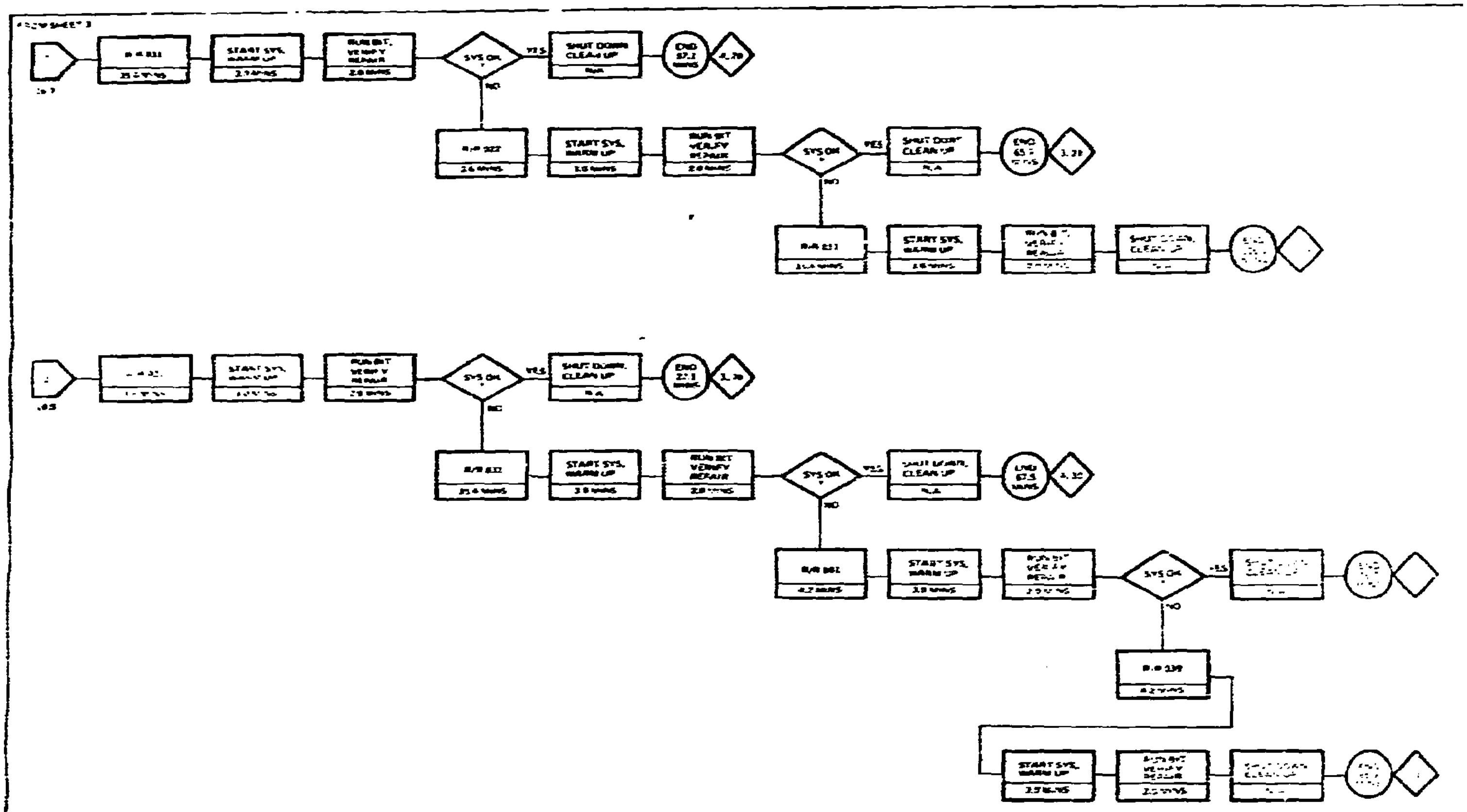

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet ...)

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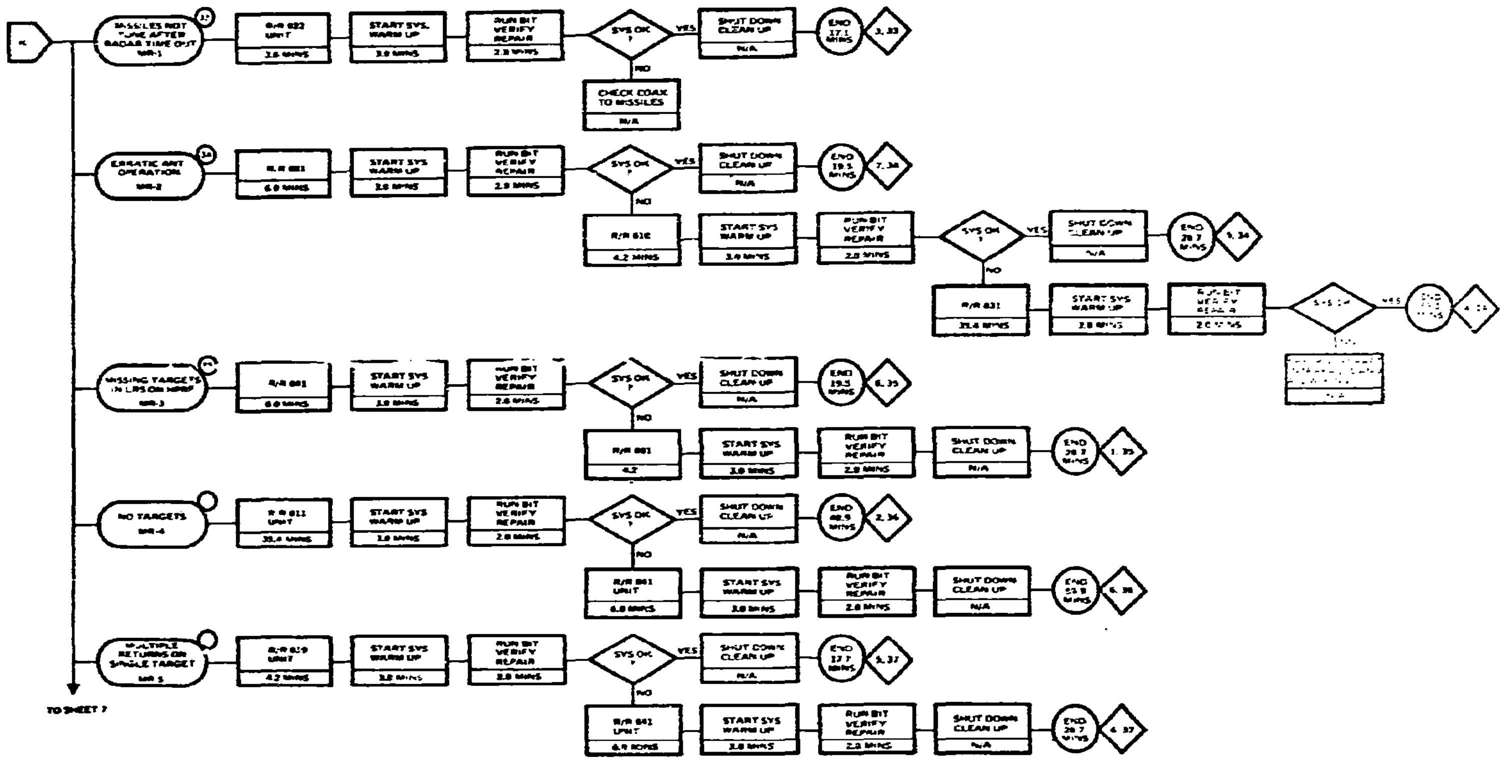

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet 6 of 9)

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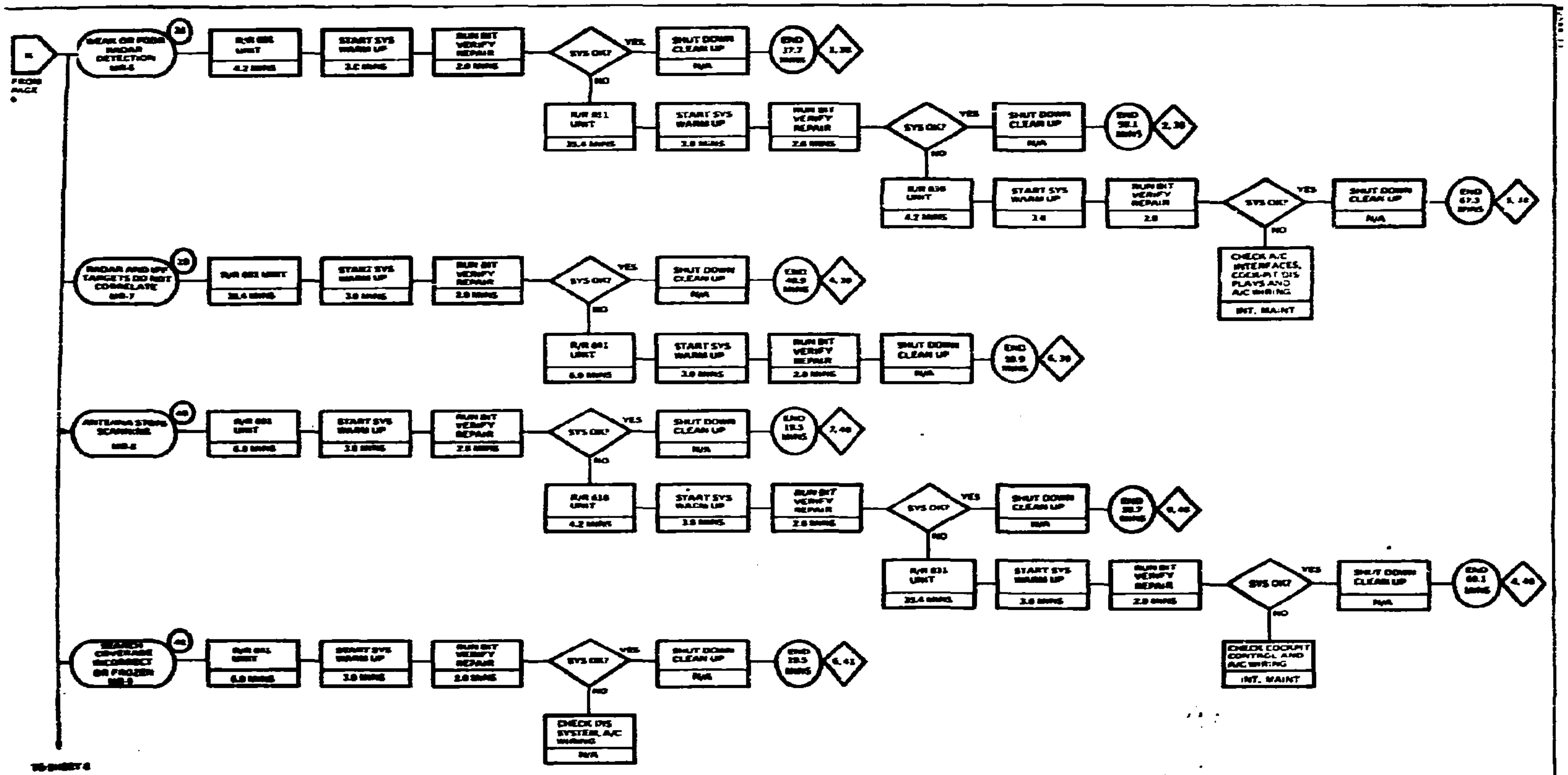

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet 7 of 9)

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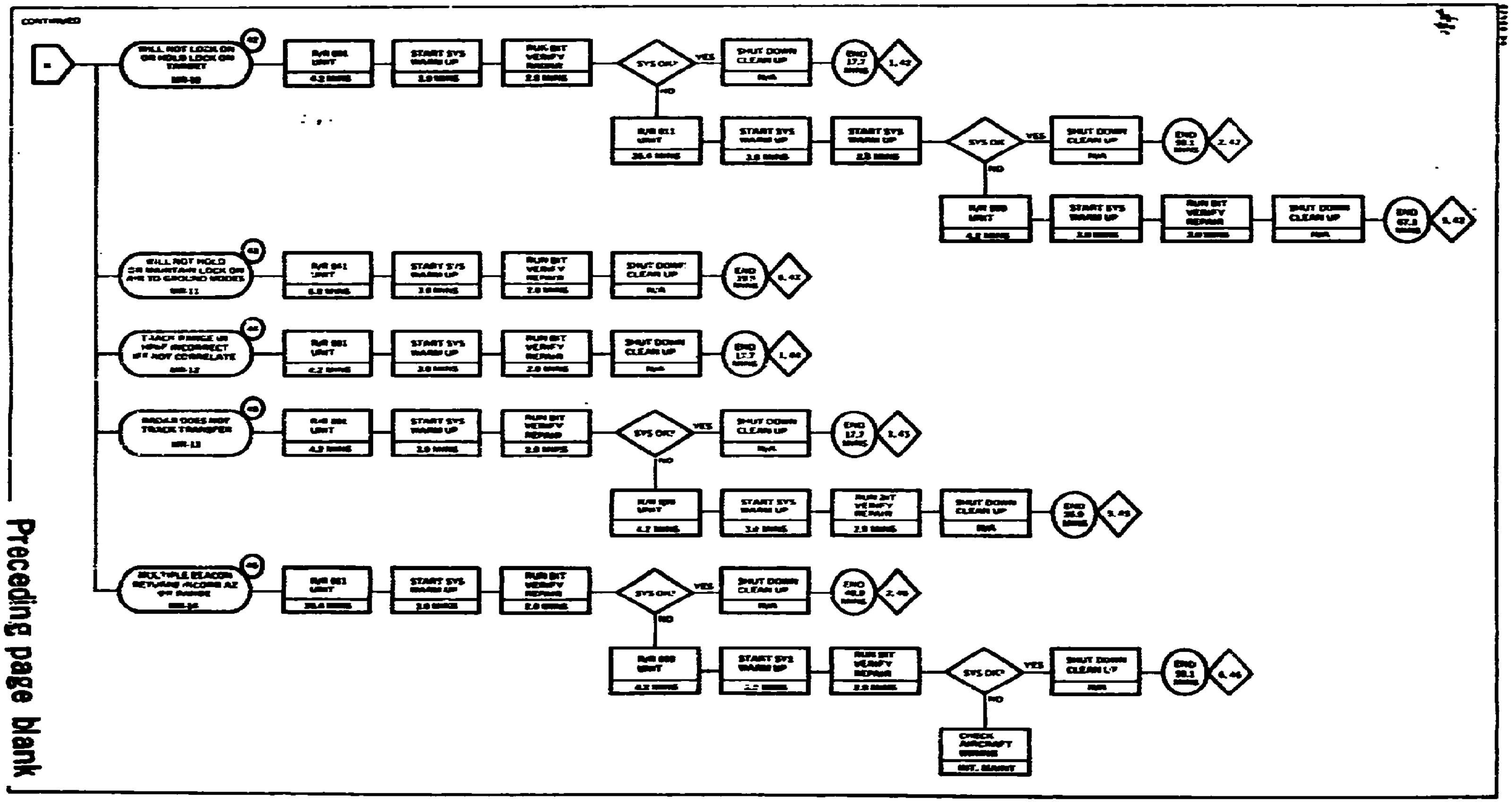

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet 5 of 9)

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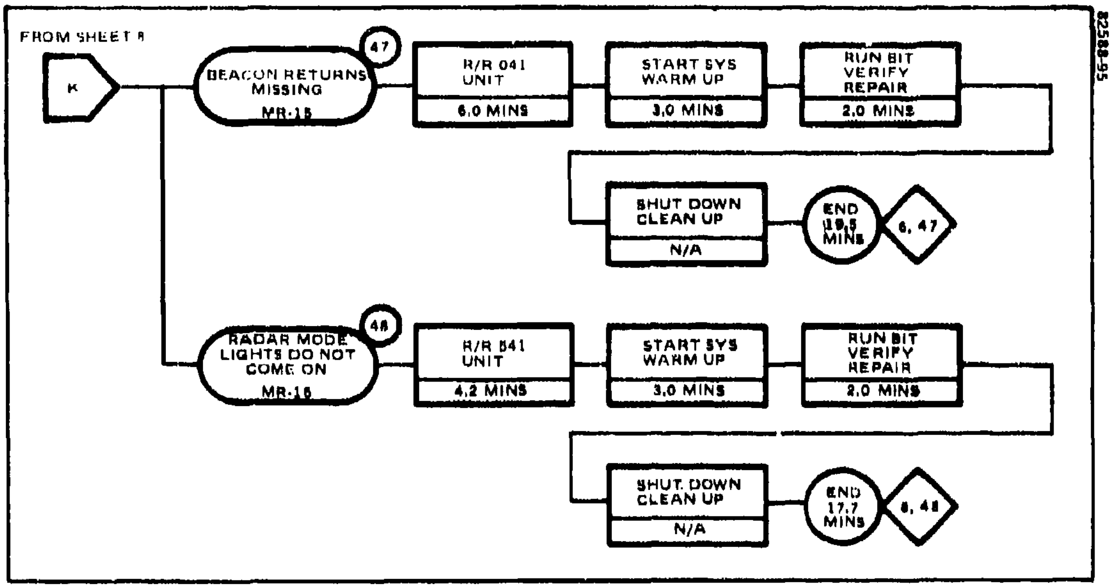

Figure F-3 (Cont). Maintenance Flow Diagram (Sheet 9 of 9)

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Appendix G – SAMPLE EARLY PREDICTIONS

This appendix contains two sample predictions performed using the early prediction methodology presented in section 5.2. Two samples are given to show the two different methods that can be used when applying the early prediction technique. The first sample is a maintainability prediction on a communications terminal using the prediction equations at the system level. This sample prediction is based on the fault isolation requirements that were specified by the buyer, therefore analysis of the fault isolation capabilities was not necessary.

The second sample was a maintainability prediction on a data processing and display subsystem using the prediction equations at a lower level. This sample demonstrates how estimates of the fault isolation resolution can be determined and used in the prediction equations.

Both prediction methods provide an MTTR estimate. The MTTR obtained in the first sample is the mean repair time expected if the specified fault isolation requirements are met. The MTTR obtained in the second sample prediction is the predicted repair time of the system based on the capabilities of the fault isolation procedures. The method used for the second sample prediction is preferred since it predicts the mean repair time based on the actual system characteristics. The first method should be used when design data is not sufficiently developed to assess the actual fault isolation characteristics or for assessing if the specified requirements are consistent and feasible.

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SAMPLE G-1 – EARLY MTTR PREDICTION ON A COMMUNICATIONS TERMINAL UTILIZING THE SPECIFIED FAULT ISOLATION REQUIREMENTS

In order to demonstrate the early prediction technique the procedure was implemented for an existing communications terminal. The following sections contain the step by step procedure involved in performing the preliminary prediction.

Definition of the Prediction Requirements

The communications terminal MTTR was predicted for flight-line (organizational) level maintenance. The elemental maintenance tasks included in the MTTR requirement were:

- fault isolation
- disassembly
- interchange
- reassembly
- alignment
- checkout

Therefore, the preparation, spare retrieval, and start-up time are not a part of this prediction.

Definition of the Maintenance Concept

The definition of the maintenance concept determines which models will be used. For the communications terminal the following concepts hold true at the organizational level:

1. The following units are removed and replaced as RIs on the flight-line:
   - Transmitter/Receiver/Processor (TPU)
   - High Power Amplifier Power Supply (HPAPS)
   - Low Power Amplifier and Power Supply (LPA/PS)
   - Unformatted Message Element (UME)
   - Antenna Interface Unit (AIU)
   - Secure Data Unit (SDU)
2. The following units have RIs within them removed and replaced on the flight-line:
   - Control Display Panel (CDP)
   - High Power Amplifier (HPA)
3. For failures of the CDP and HPA enclosure parts, the entire unit is replaced.
4. For ambiguous fault isolation (i.e. fault isolation to a group of RIs), iterative replacement is performed until the fault is corrected.
5. Reassembly is required after each replacement prior to check-out.

Determination of the Prediction Parameters

In order to perform an early prediction on the communications terminal the following data was necessary:

- preliminary definition of the primary replaceable items (RIs)
- the estimated failure rate of each RI
- the packaging (i.e., access and interchange) of each RI
- the basic fault isolation approach for each RI

The data necessary to perform the prediction was collected on forms similar to the ones shown in figures 66 and 67 of section 5.2.3.

First, all the unique tasks associated with each elemental maintenance activity were listed on form B (Table G-1). Then times were synthesized for each unique task. An example of how times were synthesized is shown in figure G-1.

Next, all the primary RIs were listed in the left most column of form A (Table G-2). Within each elemental activity type (e.g., fault isolation, disassembly) the type(s) of that activity associated with each RI was identified. The RI failure rate associated with each elemental activity type was then entered in Form A. For example, the TPU faults were isolated entirely by off-line diagnostics, so the entire failure rate of the TPU is entered under fault isolation type 1. Note, the total failure rate of each RI must be accounted for within each elemental maintenance activity (e.g., fault isolation, disassembly, etc.).

The columns corresponding to each unique task were then summed up to determine the total failure rate associated with each task. Table G-2 shows the completed form A for the communications terminal.

Next, the failure rates associated with each task (λ_{m_v}) were entered in form B. The completed form B for the communications terminal is shown in Table G-1.

Selection of the Prediction Models

From the definition of the prediction requirements (step 1) the general form of the model for the MTTR is:

$$MTTR = \bar{\bar{T}}_{FI} + \underbrace{\bar{\bar{T}}_{D} + \bar{\bar{T}}_{I} + \bar{\bar{T}}_{R}}_{\bar{\bar{T}}_{FC}} + \bar{\bar{T}}_{A} + \bar{\bar{T}}_{C}$$

TABLE G-1. RI DATA ANALYSIS SHEET B

MTTR Element (m)	Type (v)	Description	T_{m_v}	λ_{m_v}
Preparation	1	Not Applicable	-	-
Fault Isolation	1	Off-line Diagnostics Direct Readout	2	1750
	2	LED Indicators	2	278
	3	Operator Interpretation	10	193
	4	Off-line Diagnostics & Operator Interpretation	4	405
	5	Off-line Diagnostics & LED examination	3	34
	6	CDP Self Test	5	280
Spare Retrieval	1	Not Applicable	-	-
Disassembly/ Reassembly	1	Open CDP front panel, remove retaining bar, reverse process	6	82
	2	Remove & Replace HPA top cover	5	278
	3	No disassy/reassy required	-	2584
Interchange	1	R/R TPU	8.9	1606
	2	R/R LPA/PS	5.2	106
	3	R/R UME	5.2	258
	4	R/R SDU	6.0	91
	5	R/R AIU	10.8	21
	6	R/R HPAPS	3.1	43
	7	R/R HPA Modules	13.0	278
	8	R/R HPA enclosure	8.5	117
	9	R/R CDP cards	0.9	68
	10	R/R LED Assy	3.3	259
	11	R/R CDP PS	4.9	9
	12	R/R Sw. Panel	33.0	3
	13	R/R Ind. Sw.	8.1	16
	14	R/R Rotary Sw.	10.5	2
	15	R/R CDP Enclosure	60.0	67
Alignment	1	None Required	-	-
Checkout	1	Run Diagnostic	3	1338
	2	Load Program Run Diagnostic	7	1606

DISASSEMBLY	REMOVE CAPTIVE FASTENERS	18 @ 0.15	2.70
	OPEN CDP PANEL	1 @ 0.10	0.10
			2.80
INTERCHANGE	REMOVE P/S WIRING FROM SCREW TERMINALS	4 @ 0.23	0.92
	REMOVE P/S BOLTS	6 @ 0.21	1.26
	REMOVE/REPLACE P/S MODULE	1 @ 0.26	0.26
	REPLACE P/S BOLTS	6 @ 0.44	2.64
	REPLACE P/S WIRING	4 @ 0.45	1.80
			6.88
REASSEMBLY	CLOSE CDP PANEL	1 @ 0.10	0.10
	REPLACE CAPTIVE FASTENERS	18 @ 0.20	3.60
			3.70

$\bar{T}_{FC}$ FOR A FAILED CDP P/S IS 13.38 MIN.

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Figure G-1. Example of How a Time is Synthesized

TABLE G-2. DATA ANALYSIS SHEET A – COMMUNICATIONS TERMINAL

				Fault Isolation						Disassembly/Reassembly			Interchange															Checkout	
RI Description	λ	Qty	λ x Qty	$\lambda_{FI_{1n}}$	$\lambda_{FI_{2n}}$	$\lambda_{FI_{3n}}$	$\lambda_{FI_{4n}}$	$\lambda_{FI_{5n}}$	$\lambda_{FI_{6n}}$	$\lambda_{D/R_{1n}}$	$\lambda_{D/R_{2n}}$	$\lambda_{D/R_{3n}}$	$\lambda_{I_{1n}}$	$\lambda_{I_{2n}}$	$\lambda_{I_{3n}}$	$\lambda_{I_{4n}}$	$\lambda_{I_{5n}}$	$\lambda_{I_{6n}}$	$\lambda_{I_{7n}}$	$\lambda_{I_{8n}}$	$\lambda_{I_{9n}}$	$\lambda_{I_{10n}}$	$\lambda_{I_{11n}}$	$\lambda_{I_{12n}}$	$\lambda_{I_{13n}}$	$\lambda_{I_{14n}}$	$\lambda_{I_{15n}}$	$\lambda_{C_{1n}}$	$\lambda_{C_{2n}}$
TPU	1606	1	1606	1606								1606	1606																1606
LPAPS	106	1	106	53			53					106		106														106	
CME	86	3	258				258					258			259													259	
SDC	91	1	91	91								91				91												91	
AIE	21	1	21				21					21					21											21	
HPA/PS	43	1	43				43					43						43										43	
HPA																													
input modules	24	2	46		48						48								48									48	
output modules	23	4	92		92						92								92									92	
input modules	23	2	46		46						46								46									46	
output modules	23	4	92		92						92								92									92	
enclosure parts	117	(1)	117			117						117								117								117	
CDP																													
P/S +5V	9	1	9			9				9													9					9	
keyboard decode	5	1	8				4	4		8											8							8	
I/O interface	11	1	11				5	6		11											11							11	
I/O control	13	1	13				7	6		13											13							13	
display control	5	1	5				2	3		5											5							5	
timing control	12	1	12				6	6		12											12							12	
indicator logic	5	1	5				3	2		5											5							5	
switching logic	6	1	6				3	3		6											6							6	
I/O distribution	8	1	8				4	4		8											8							8	
LED display	259	1	259						259			259										259						259	
enclosure parts	67	(1)	67			67						67															67		
indicator switch	1	16	16						16			16													16			16	
rotary switch	1	2	2						2	2																2		2	
panel switches	3	1	3						3	3														3				3	
Totals		51	2944	1750	279	193	409	34	280	32	279	2584	1606	106	258	91	21	43	278	117	58	259	9	3	16	2	67	1336	1606

For the communications terminal, alignment times were allowed ($\overline{T}_A$) but no alignments were necessary, therefore the model reduces to:

$$MTTR = \overline{T}_{FI} + \overline{T}_{FC} + \overline{T}_C$$

The models selected for the above elemental tasks were extracted from the fifth row in Table 52 pertaining to isolation to a group of RIs, iterative replacement, multiple access, and reassembly required for checkout. The models are:

Fault isolation time:

$$\overline{T}_{FI} = \frac{\sum_{v=1}^{FI} \lambda_v T_{FI}}{\lambda_T}$$

Check-out time:

$$\overline{T}_C = \overline{S}_I \left(\frac{\sum_{v=1}^{V_C} \lambda_v T_{C_v}}{\lambda_T} \right)$$

(reassembly is required for check-out)

Fault Correction time:

$$\overline{T}_{FC} = \overline{S}_I (\overline{T}_D + \overline{T}_I + \overline{T}_R)$$

The maintenance concept calls for iterative replacement, and reassembly is required for checkout.

$$\overline{T}_m = \frac{\sum_{v=1}^{V_M} \lambda_v T_{m_v}}{\lambda_T}$$

$$m = D, I, R$$

$\overline{S}_I$ was determined by computing the average number of iterations required to correct a fault from the specified requirements:

90% to 1 RI

95% to $\leq$ 3 RIs

100% to $\leq$ 4 RIs

Therefore:

$$\overline{S}_I = \frac{90 + (95 - 90)\left(\frac{3 + 2}{2}\right) + (100 - 95)\,(4)}{100}$$

$\overline{S}_I$ = 1.225 iterations required per repair action

Computation of the MTTR

Once the models were selected, the MTTR was computed using the models and the data tabulated in form B. The resulting times for each elemental task are:

$\overline{T}_{FI}$ = 3.10 minutes

$\overline{T}_{FC}$ = $\overline{S}_I$ 9.79 = 11.99 minutes

$\overline{T}_{CO}$ = $\overline{S}_I$ 4.73 = 5.79 minutes

*MTTR = 3.10 + 11.99 + 5.79 = 20.88 minutes

*The predicted MTTR is based on the assumption that the specified fault isolation requirements have been met.

SAMPLE G-2 – EARLY PREDICTION OF A DATA PROCESSING AND DISPLAY SUBSYSTEM WHEN THE FAULT ISOLATION RESOLUTION IS ESTIMATED

A second sample prediction using the early prediction methodology was performed to illustrate its application when fault isolation resolution is estimated at a level below the system. The sample shows the prediction procedure when the following data is available.

- Description of equipment(s) to be predicted including a preliminary definition of the replaceable items
- Estimated failure rate of each RI
- Packaging (i.e. access and interchange) concept for each RI
- Alignment requirements for each RI
- Basic fault isolation approach for each RI or by RI groups

Definition of the Requirement

This sample provides a prediction of MTTR for the organizational level corrective maintenance of the Data Processing and Display (DP&P) Subsystem shown in figure G-2. The prediction covers all failures of the subject subsystem which are designated as repairable by organizational maintenance level personnel.

Definition of Maintenance Concept

The DP&D is maintained by a combination of resident (i.e., organizational level) maintenance personnel and contact team (i.e., intermediate level) personnel. Repairs are accomplished by fault isolation to one or more RIs and replacement of the suspect RIs iteratively (with checkout after each iteration) until the faulty RI is located. A definition of RIs, their respective failure rate estimates, and designation of the authorized RI maintenance level is shown in Table G-3.

Determine the Prediction Parameters

The next step in predicting the MTTR for DP&D subsystem is collating the data necessary to perform the prediction. First each unique method (v^{th}) for performing each (m^{th}) elemental maintenance activity is tabulated. For example the alignment activity can be broken down to RIs that do not require alignment and the RIs in the display console that require some alignment or calibration.

All the unique tasks involved in maintaining the DP&D subsystem are tabulated in Table G-4.

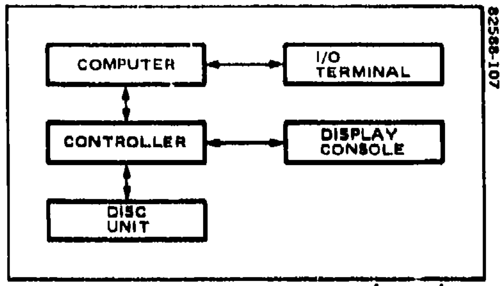

Figure G-2. Data Processing and Display (DP&D) Subsystem Block Diagram

TABLE G-3. DEFINITION OF RIs

RI Description	Qty of RIs	Total Failure Rate	Level of Repair*
Computer			
AU/PCU CCAs	21	285	O
Memory CCAs	16	90	O
Buffered I/O CCAs	9	45	O
Console I/O CCAs	3	16	O
P/S	4	257	O
FIU	4	20	I
Panel/Cabinet Piece parts	-	5	I
I/O Terminal	1	1400	O
Controller			
P/S	2	50	O
Processor CCAs	12	428	O
Disc Interface CCAs	2	25	O
Display Buffer CCAs	5	16	O
Display Driver CCAs	1	6	O
CCIU CCAs	8	5	O
Panel/Cabinet Piece parts	-	5	I
Disc Unit	1	600	O
Display Console			
I/O CCAs	2	53	O
Display Electronics CCAs	9	1524	O
P/S	6	124	O
Panel/Cabinet Piece parts	-	10	I

* O - Organizational level maintenance
I - Intermediate level maintenance

TABLE G-4. RI DATA ANALYSIS SHEET B

MTTR Element (m)	v	Description of the v^{th} Method	T_{m_v}	λ_{m_v}
Preparation	1	No preparation time, fault isolation capabilities self contained. Technicians and necessary support equipment (e.g., tools, manuals) in immediate vicinity. No equipment warmup or stabilization time required.	-	-
Fault Isolation	1	System Diagnostic	2.0	2116
	2	Computer FI Unit	5.0	375
	3	Computer Maintenance Panel	1.0	257
	4	System Diagnostic & Controller Diagnostic	2.0	523
	5	Controller P/S Indicators	1.0	50
	6	Display Patterns	10.0	1524
	7	Display P/S Indicators	1.0	124
Spare Retrieval	1	No spare retrieval time, spares are co-located with equipment	-	-
Disassembly/ Reassembly	1	No Disassembly/Reassembly	0.0	2000
	2	Computer Card Rack	0.28	436
	3	Computer P/S Drawer	0.33	257
	4	Controller Card Rack	0.28	525
	5	Controller P/S Drawer	0.33	50
	6	Display Card Drawer	0.75	1577
	7	Display LV P/S	0.75	24
	8	Display HV P/S	3.64	100
Interchange	1	Computer CCAS	0.11	436
	2	Computer P/S	6.10	257
	3	I/O Terminal	10.0	1400
	4	Controller CCAS	0.11	525
	5	Controller P/S	6.10	50
	6	Disc Unit	10.0	600
	7	Display CCAS	6.20	1577
	8	Display LV P/S	6.10	24
	9	Display HV P/S	5.50	100
Alignment	1	No Alignment	0.0	4919
	2	Display Symbols	10.0	50
Checkout	1	System Diagnostic	2.0	3445
	2	Display Patterns	5.0	1524
Start-up	1	No start-up time	-	-

Times associated with each unique maintenance activity are synthesized using the maintenance time standards of section 3.0, or engineering judgement. These times are also tabulated in Table G-4.

The next task is to correlate each activity type with the associated RIs. For every RI that is associated with a unique activity an appropriate failure rate is denoted in Table G-5.

Selection of the Prediction Models

Once the data was collected the appropriate prediction submodels were selected, according to the maintenance philosophy. Using Table 52 and identifying the appropriate maintenance philosophies, the following submodels were selected:

Fault Isolation

$$\bar{T}_{FI} = \frac{\sum_{v=1}^{V_{FI}} \lambda_{FI_v} T_{FI_v}}{\sum_{v=1}^{V_{FI}} \lambda_{FI_v}}$$

Disassembly/
Reassembly

$$\bar{T}_D + \bar{T}_R = \bar{T}_{D/R} = \bar{S}_I \left[\frac{\sum_{v=1}^{V_{D/R}} \lambda_{D/R_v} \left(T_{D_v} + T_{R_v} \right)}{\sum_{v=1}^{V_{D/R}} \lambda_{D/R_v}} \right]$$

TABLE G-5. RI DATA ANALYSIS SHEET A

RI Description	g	Qty	λ	Fault Isolation λ_{FI_1}	λ_{FI_2}	λ_{FI_3}	λ_{FI_4}	λ_{FI_5}	λ_{FI_6}	λ_{FI_7}
Computer										
AU/PCU CCAs	1	21	285		285					
Memory CCAs	1	16	90		90					
Buffered I/O CCAs	4	9	45				45			
Console I/O CCAs	3	3	16	16						
P/S	2	4	257			257				
I/O Terminal	3	1	1400	1400						
Controller										
P/S	5	2	50					50		
Processor CCAs	7	12	428				428			
Disc Interface CCAs	6	2	25	25						
Display Buffer CCAs	8	5	16	16						
Display Driver CCAs	9	1	6	6						
CCIU CCAs	4	8	50				50			
Disc Unit	6	1	600	600						
Display Console										
I/O CCAs	9	2	53	53						
Display Electronics CCAs	10	9	1524						1524	
P/S	11	6	124							124
Totals			4969	2116	375	257	523	50	1524	124

TABLE G-5. RI DATA ANALYSIS SHEET A (Continued)

RI Description	g	Qty	λ	Disassembly/Reassembly						
				λ_{D/R_1}	λ_{D/R_2}	λ_{D/R_3}	λ_{D/R_4}	λ_{D/R_5}	λ_{D/R_6}	λ_{D/R_7}
Computer										
AU/PCU CCAs	1	21	285		285					
Memory CCAs	1	16	90		90					
Buffered I/O CCAs	4	9	45		45					
Console I/O CCAs	3	3	16		16					
P/S	2	4	257			257				
I/O Terminal	3	1	1400	1400						
Controller										
P/S	5	2	50					50		
Processor CCAs	7	12	428				428			
Disc Interface CCAs	6	2	25				25			
Display Buffer CCAs	8	5	16				16			
Display Driver CCAs	9	1	6				6			
CCIU CCAs	4	8	50				50			
Disc Unit	6	1	600	600						
Display Console										
I/O CCAs	9	2	53						53	
Display Electronics CCAs	10	9	1524						1524	
P/S	11	6	124							24
Totals			4969	2000	436	257	525	50	1577	24

TABLE G-5. RI DATA ANALYSIS SHEET A (Continued)

				D/R	Interchange				
RI Description	g	Qty	λ	λ_{D/R_8}	λ_{I_1}	λ_{I_2}	λ_{I_3}	λ_{I_4}	λ_{I_5}
Computer									
AU/PCU CCAs	1	21	285		285				
Memory CCAs	1	16	90		90				
Buffered I/O CCAs	4	9	45		45				
Console I/O CCAs	3	3	16		16				
P/S	2	4	257			257			
I/O Terminal	3	1	1400				1400		
Controller									
P/S	5	2	50						50
Processor CCAs	7	12	428					428	
Disc Interface CCAs	6	2	25					25	
Display Buffer CCAs	8	5	16					16	
Display Driver CCAs	9	1	6					6	
CCIU CCAs	4	8	50					50	
Disc Unit	6	1	600						
Display Console									
I/O CCAs	9	2	53						
Display Electronics CCAs	10	9	1524						
P/S	11	6	124	100					
Totals			4969	100	436	257	1400	525	50

TABLE G-5. RI DATA ANALYSIS SHEET A (Continued)

RI Description	g	Qty	λ	Interchange λ_{I_6}	Interchange λ_{I_7}	Interchange λ_{I_8}	Interchange λ_{I_9}	Alignment λ_{A_1}	Alignment λ_{A_2}
Computer									
AU/PCU CCAs	1	21	285					285	
Memory CCAs	1	16	90					90	
Buffered I/O CCAs	4	9	45					45	
Console I/O CCAs	3	3	16					16	
P/S	2	4	257					257	
I/O Terminal	3	1	1400					1400	
Controller									
P/S	5	2	50					50	
Processor CCAs	7	12	428					428	
Disc Interface CCAs	6	2	25					25	
Display Buffer CCAs	8	5	16					16	
Display Driver CCAs	9	1	6					6	
CCIU CCAs	4	8	50					50	
Disc Unit	6	1	600	600				600	
Display Console									
I/O CCAs	9	2	53		53			53	
Display Electronics CCAs	10	9	1524		1524			1474	50
P/S	11	6	124			24	100	124	
Totals			4969	600	1577	24	100	4919	50

TABLE G-5. RI DATA ANALYSIS SHEET A (Continued)

RI Description	g	Qty	λ	Checkout C_1	Checkout C_2
Computer					
AU/PCU CCAs	1	21	285	285	
Memory CCAs	1	16	90	90	
Buffered I/O CCAs	4	9	45	45	
Console I/O CCAs	3	3	16	16	
P/S	2	4	257	257	
I/C Terminal	3	1	1400	1400	
Controller					
P/S	5	2	50	50	
Processor CCAs	7	12	428	428	
Disc Interface CCAs	6	2	25	25	
Display Buffer CCAs	8	5	16	16	
Display Driver CCAs	9	1	6	6	
CCIU CCAs	4	8	50	50	
Disc Unit	6	1	600	600	
Display Console					
I/O CCAs	9	2	53	53	
Display Electronics CCAs	10	9	1524		1524
P/S	11	6	124	124	
Totals			4969	3445	1524

Interchange $$\overline{T}_I = \overline{S}_I \left[\frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_{DIR}} \lambda_{I_v}} \right]$$

Alignment $$T_A = \frac{\sum_{v=1}^{V_A} \lambda_{A_v} T_{A_v}}{\sum_{v=1}^{V_A} \lambda_{A_v}}$$

Checkout $$T_C = \frac{\sum_{v=1}^{V_C} \lambda_{C_v} T_{C_v}}{\sum_{v=1}^{V_C} \lambda_{C_v}}$$

Computation of $\overline{S}$

The specified maintenance concept requires that a value for $\overline{S}_I$ (the average number of iterations of RI replacement required to correct a fault) be computed before the values of $\overline{T}_I$, $\overline{T}_D$ and $\overline{T}_R$ can be determined. $\overline{S}_I$ is established by dividing the subsystem into "G" grouping of RIs for which values of $\overline{S}_{(I)_g}$ can be established. The RI groupings as shown in figure G-3 were established according to the following criteria:

- The RI sets are determined at the lowest level at which a fault isolation resolution can be estimated.
- The RI sets are independent of each other.
- The RI sets include only those RIs specified for inclusion in the prediction.

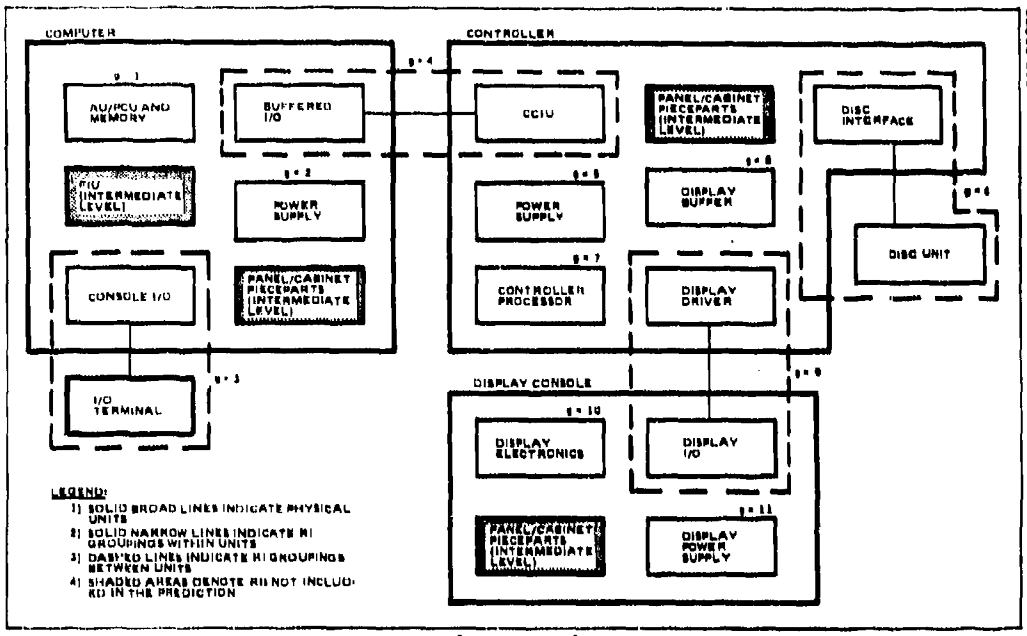

Figure G-3. Mapping of DP&D Subsystem into G RI Sets

The RI sets which were established are listed in Table G-6 along with the fault isolation resolution for each set. $\overline{S}_{(I)_g}$ for each set is computed from:

$$\overline{S}_{(I)_g} = \frac{X_1\left(\frac{N_1+1}{2}\right) + (X_2 - X_1)\left(\frac{N_1+N_2+1}{2}\right) + (100 - X_2)\left(\frac{N_2+N_3+1}{2}\right)}{100}$$

where the fault isolation resolution is expressed in terms of the number of interchanges necessary to accomplish repair, as:

TABLE G-6. ESTIMATED VALUES FOR S_{Ig}

Group Name	g	λ_g	Resolution	Qty of RIs	$\overline{S}_{(I)_g}$	$\lambda_g \overline{S}_{(I)_g}$
AU/PCU and Memory	1	375	90% to 1, 95% ≤ 3, 100% ≤ 8	35	1.32	495.0
Computer Power Supply	2	257	100% to 1	4	1.0	257.00
Console I/O and I/O Terminal	3	1416	99% to 1, 100% ≤ 4	4	1.02	1444.32
CCIU	4	95	50% to 1, 80% ≤ 4, 90% to 10, 100% ≤ 17	17	3.55	337.25
Controller Power Supply	5	50	100% to 1	2	1.0	50.00
Disc Interface and Disc Unit	6	625	99% to 1, 100% ≤ 3	3	1.02	637.5
Controller Processor	7	428	50% to 1, 95% ≤ 4, 100% ≤ 8	12	2.18	933.04
Display Buffer	8	16	20% to 1, 100% ≤ 5	5	3.0	48.0
Display Driver and Display I/O	9	59	90% ≤ 2, 100% ≤ 3	3	2.1	123.9
Display Electronics	10	1524	50% to 1, 95% ≤ 5, 100% ≤ 8	9	2.2	3352.80
Display Power Supply	11	124	100% to 1	6	1.0	124.00
		4969				7802.81

$$\overline{S}_I = \frac{7802.81}{4969} = 1.57$$

$X_1\%$ to N_1 RIs

$X_2\%$ to N_2 RIs or less

100% to N_3 RIs or less

The overall resolution ($\bar{S}_I$) is computed as:

$$\bar{S}_I = \frac{\sum_{g=1}^{G} \lambda_g \bar{S}_{(I)_g}}{\sum_{g=1}^{G} \lambda_g} = \frac{7802.81}{4969} = 1.57$$

Table G-6 presents the computed values for $\bar{S}_I$ and $\bar{S}_{(I)_g}$ (for each set).

Computation of MTTR

There are two approaches in computing MTTR for this example. A prediction of $MTTR_g$ for each of the RI groups can be accomplished first, with a secondary prediction of the subsystem MTTR, or the subsystem MTTR can be computed directly. For this example both approaches are shown:

Approach Number 1

This approach first computes the average repair time for each RI set (g), then computes the overall repair time by taking a failure rate weighted average of the RI sets.

An additional column (g) was inserted into Table C-5 to denote which RIs belonged to each RI set. Normally each RI set would be tabulated on separate Form A's, but due to the simplicity of the data available all the RIs were tabulated on one form.

Using the submodels that were selected, the average times for each elemental activity were computed for each RI set (g) and tabulated in Table G-7.

The $MTTR_g$ for each RI set was computed from

$$MTTR_g = \bar{T}_{FI_g} + \bar{S}_{(I)_g}\left\{\bar{T}_{D/R_g} + \bar{T}_{I_g}\right\} + \bar{T}_{A_g} + \bar{T}_{C_g}$$

TABLE G-7. COMPUTED AVERAGES FOR EACH ELEMENTAL ACTIVITY AND EACH RI SET

				Average Time for Each Elemental Activity						
RI Set	g	λ_g	$\overline{S}_{(I)_g}$	$\overline{T}_{FI_g}$	$\overline{T}_{D/R_g}$	$\overline{T}_{I_g}$	$\overline{T}_{A_g}$	$\overline{T}_{C_g}$	$MTTR_g$ *	$\lambda_g MTTR_g$
AU/PCU & Memory	1	375	1.32	5.0	0.28	0.11	0.0	2.0	7.51	2,816.25
Computer P/S	2	257	1.00	1.0	0.33	6.10	0.0	2.0	9.43	2,423.51
Console I/O & I/O Terminal	3	1416	1.02	2.0	0.003	9.89	0.0	2.0	14.09	19,951.44
Buffer I/O & Controller (CCIU)	4	95	3.55	2.0	0.28	0.11	0.0	2.0	5.38	511.1
Controller P/S	5	50	1.00	1.0	0.33	6.10	0.0	2.0	9.43	471.50
Disc Unit & Disc Interface	6	625	1.02	2.0	0.01	9.60	0.0	2.0	13.80	8,625.0
Controller Processor	7	428	2.18	2.0	0.28	0.11	0.0	2.0	4.85	2,075.8
Display Buffer	8	16	3.00	2.0	0.28	0.11	0.0	2.0	5.17	82.72
Display Driver & Display I/O	9	59	2.10	2.0	0.70	5.58	0.0	2.0	17.19	1,014.21
Display Electronics	10	1524	2.20	10.0	0.75	6.20	0.33	5.0	30.62	46,664.88
Display P/S	11	124	1.00	1.0	3.08	1.62	0.0	2.0	7.70	954.8
Subsystem Total		4969								85,591.21

$$*MTTR_g = \overline{T}_{FI_g} + \overline{S}_{(I)_g}\left(\overline{T}_{D/R_g} + \overline{T}_{I_g}\right) + \overline{T}_{A_g} + \overline{T}_{C_g}$$

The overall subsystem MTTR is then computed by taking a failure rate weighted average of the average repair times of each RI set.

$$\text{MTTR} = \frac{\sum_{g=1}^{G} \lambda_g \, \text{MTTR}_g}{\sum_{g=1}^{G} \lambda_g} = 17.23 \text{ minutes}$$

The repair times of each equipment can be computed by taking a failure rate weighted average of the RI sets associated with each equipment.

$$\text{MTTR}_E = \frac{\sum_{g=1}^{G} \lambda_{E_g} \, \text{MTTR}_g}{\sum_{g=1}^{G} \lambda_{E_g}}$$

λ_{E_g} = failure of the gth RI set associated with the E equipment

Approach Number 2

The second approach computes the average repair time at the system level instead of the RI set (g) level as was done by approach one. This approach requires fewer steps and can save time if lower level predictions are not required. First, the failure rate associated with each vth type of each mth elemental maintenance activity is summed to determine λ_{m_v}. This summation is shown at the bottom of Table G-5 for each v. The average repair time for each elemental activity is then computed using the submodels selected.

$\bar{S}_I$ (for the entire subsystem) is required for this approach. The computation of $\bar{S}_I$ is the same as for approach one. The computed value of $\bar{S}_I$ is 1.57.

Fault Isolation

$$\overline{T}_{FI} = \frac{\sum_{v=1}^{V_{FI}} \lambda_{FI_v} T_{FI_v}}{\sum_{v=1}^{V_{FI}} \lambda_{FI_v}}$$

$$\overline{T}_{FI} = \frac{22824}{4969} = 4.59 \text{ minutes}$$

Disassembly/
Reassembly

$$\overline{T}_{D/R} = \frac{\sum_{v=1}^{V_{D/R}} \lambda_{D/R_v} T_{D/R_v}}{\sum_{v=1}^{V_{D/R}} \lambda_{D/R_v}}$$

$$\overline{T}'_{D/R} = \overline{S}_I \overline{T}_{D/R}$$

$$\overline{T}'_{D/R} = 1.57 \left(\frac{1934.61}{4969}\right)$$

$$\overline{T}'_{D/R} = 0.61 \text{ minutes}$$

Interchange

$$\overline{T}_I = \frac{\sum_{v=1}^{V_I} \lambda_{I_v} T_{I_v}}{\sum_{v=1}^{V_I} \lambda_{I_v}}$$

$$\overline{T}'_I = \overline{S}_I \overline{T}_I$$

$$\overline{T}'_I = 1.57 \left(\frac{31902.21}{4969}\right)$$

$$\overline{T}'_I = 10.08 \text{ minutes}$$

Alignment

$$\bar{T}_A = \frac{\sum_{v=1}^{V_A} \lambda_{A_v} T_{A_v}}{\sum_{v=1}^{V_A} \lambda_{A_v}}$$

$$\bar{T}_A = \frac{500}{4969} = 0.10 \text{ minutes}$$

Checkout

$$\bar{T}_C = \frac{\sum_{v=1}^{V_C} \lambda_{C_v} T_{C_v}}{\sum_{v=1}^{V_C} \lambda_{C_v}}$$

$$\bar{T}_C = \frac{14510}{4969} = 2.92 \text{ minutes}$$

The subsystem MTTR is determined by taking the sum of the average elemental times.

$$\text{MTTR} = \sum_{m=1}^{M} \bar{T}_m$$

$$= \bar{T}_{FI} + \bar{T}'_{D/R} + \bar{T}'_I + \bar{T}_A + \bar{T}_C$$

$$= 4.59 + 0.63 + 10.08 + 0.10 + 2.92$$

$$= 18.3 \text{ minutes}$$

Comparison of the Two Approaches

Although the predicted repair times using the two approaches were very close, approach one is more accurate. Approach one also has the advantage that repair times of lower levels are also available. This can be very useful in performing allocations and identifying maintainability problem areas.

The second approach is good when computing a quick estimate of the MTTR. For example, if $\bar{S}_I$ were a specified value, then a quick prediction can be made using the second approach to see if the specified values are practical.

LIST OF ACRONYMS AND SYMBOLS

$\bar{A}$	-	average number of unique accesses required per fault isolation
A_g	-	quantity of unique accesses in the g^{th} RI set
BIT	-	Built in Test
BITE	-	Built In Test Equipment
CCA	-	Circuit Card Assembly
DV	-	dependent variable
FDIT	-	fault detection/isolation/test
FD&I	-	fault detection and isolation
FI	-	fault isolation
G	-	quantity of RI sets
IV	-	independent variable
J	-	quantity of FI results
K_{nj}	-	the replacement order of the n^{th} RI given the j^{th} FI result
LRU	-	Line Replaceable Unit
M	-	quantity of elemental tasks required that make up MTTR
MFD	-	maintenance flow diagram
$M_{max}(\phi)$	-	maximum corrective maintenance time for the ϕ^{th} percentile
M_{nj}	-	quantity of elemental tasks required to perform corrective maintenance for the n^{th} RI given the j^{th} FI result
MTTR	-	mean time to repair
N	-	quantity of RIs
N_g	-	quantity of RIs in the g^{th} RI set
N_{ga}	-	quantity of RIs in the g^{th} RI set with the a^{th} access
N_j	-	quantity of RIs whose failures produce the j^{th} FI result
PCB	-	printed circuit board
P_{ga}	-	probability that an RI from assembly "a" of the g^{th} RI set will be contained in a FI result
p^x_{ga}	-	the probability that any RI with the a^{th} type access will be contained in the FI group of the g^{th} RI set given that it is not in the first x-1 call-outs of the FI group
Q_{ga}	-	the probability that none of the RIs called out in a FI group of the g^{th} RI set have an a^{th} type access (equal to $1 - P_{ga}$)

LIST OF ACRONYMS AND SYMBOLS (Continued)

q^x_{ga}	-	$1 - p^x_{ga}$
R	-	correlation coefficient
RI	-	replaceable item
R_n	-	average repair time of the n^{th} RI
R_{nj}	-	repair time of the n^{th} RI given the j^{th} FI result
R/R	-	remove and replace
$\bar{S}_G$	-	average quantity of RIs in a FI callout
$\bar{S}_g$	-	average quantity of RIs in the FI callouts over all the FI groups of the g^{th} RI set
$\bar{S}_I$	-	average quantity of RIs replaced to correct a fault
$\bar{T}_m$	-	average time to perform the m^{th} elemental maintenance task
T_{m_n}	-	time to perform the m^{th} elemental task for the n^{th} RI
$T_{m_{nj}}$	-	time to perform the m^{th} elemental task for the n^{th} RI given the j^{th} FI result
T_{m_v}	-	time required to perform the m^{th} elemental task using the v^{th} method
V_m	-	the quantity of unique types of ways to perform each m^{th} elemental maintenance activity
λ_g	-	failure rate of the g^{th} RI set
λ_{m_v}	-	failure rate of the RIs associated with the v^{th} method of performing the m^{th} elemental maintenance task
λ_n	-	failure rate of the n^{th} RI
λ_{nj}	-	failure rate of the n^{th} RI fault isolated with the j^{th} FD&I output

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