AD-A009 044

MAINTAINABILITY AND ENGINEERING DESIGN NOTEBOOK, REVISION II, AND COST OF MAINTAINABILITY

MARTIN MARIETTA AEROSPACE

PREPARED FOR
ROME AIR DEVELOPMENT CENTER

JANUARY 1975

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The RADC Maintainability Engineering Design Notebook brings together currently available knowledge of maintainability engineering and treats such knowledge from a practical rather than theoretical viewpoint. The notebook provides both quantitative and qualitative information and techniques which can serve as guidelines for those personnel who are directly responsible for establishing maintainability requirements and maintainability design, and for the acceptance of the maintainability of Air Force ground electronic systems

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and equipments.

Although the notebook is directed at ground electronic systems, the majority of the material is applicable to a much broader class of hardware.

Specifically, the notebook includes a description of the time phasing of the maintainability program tasks, a breakdown of maintainability into its roots, and detailed description, guidelines and methodology, procedures, and an example of each maintainability task, as applicable.

Since maintainability covers a wide range of disciplines ranging through electronic and mechanical design, instrumentation requirements, logistic support, personnel requirements, and statistics, it is not anticipated that any single group will find all of its responsibilities completely described in this notebook. It should, however, contribute significantly to improved maintainability programs and subsequent improved system/equipment maintainability.

It is intended that the notebook will be updated and revisions issued as necessary to enhance its applicability and maintain its currency with advances in the maintainability discipline.

MAINTAINABILITY ENGINEERING DESIGN NOTEBOOK, REVISION II, AND COST OF MAINTAINABILITY

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FOREWORD

This three volume final technical report was prepared by Martin Marietta Aerospace Corporation, Orlando, Florida under Contract F30602-73-C-0201, Job Order Number 55190123 for Rome Air Development Center, Griffiss Air Force Base, New York. It was prepared in accordance with the format requirements set forth in AFSC Design Handbook DH 1-1, General Index and Reference. The format permits updating of the notebook as new methods and information become available.

RADC Project Engineer was James Saporito, Jr. (RBRS).

This notebook is dedicated to Mr. Frank Mazzola whose untimely death resulted in a great loss to the maintainability world.

This report has been reviewed by the Office of Information (OI), RADC, and approved for release to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This report has been reviewed and is approved for publication.

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ABSTRACT

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CONTENTS

CHAPTER 9

MAINTAINABILITY MODEL

This chapter contains a discussion of the use of models and their application to the maintainability discipline. In addition, detailed task descriptions, guidelines, methodology, procedures, and a detailed example are presented for a revision of the Discard-at-Failure Maintenance (DAFM) mathematical model as contained in RADC-TR-68-187 (AD 842 399). This model is one example of the general and specific models which exist in industry today.

CHAPTER 9 MAINTAINABILITY MODEL

SECTION 9A

DETAILED TASK DESCRIPTION

This section contains a detailed task description of modeling, outlining the different types of models and modeling considerations.

SECTION 9A DETAILED TASK DESCRIPTION

DESIGN NOTE 9A1 - MODEL USAGE

1. INTRODUCTION
2. TYPES OF MODELS
3. MODEL CONSIDERATIONS
4. MODEL DESCRIPTION

DESIGN NOTE 9A1 MODEL USAGE

1. INTRODUCTION

The systems engineering process is defined as the process by which input requirements from the user or procuring agency are converted into output information which describes an optimum combination of system elements to satisfy requirements. The optimum decision is derived based on an iterative process which includes functional analysis, synthesis of alternative candidates, and evaluation. Selection of an optimum configuration for design or support in most cases is based on life cycle cost (acquisition and support costs) and performance characteristics relative to total cost effectiveness.

Models are used in the deterministic process for the cost and performance parameters. A model is defined as a systematic, analytical process used to predict system parameters. The model may consist of a simple functional flow or block diagram of few elements to a complex flow diagram depicting a total system operational flow. Models may be implemented either manually or through computer programming, and may specifically be used as a maintainability tool to perform allocations, predictions, design, or support concept alternative trade-offs.

2. TYPES OF MODELS

Basically, models are divided into two major categories: computation and simulation.

a. The computational model is developed to identify the extensive computations involved in the procedures for prediction, performance, evaluation, and total life cycle costing and to assure that exactly the same computational procedure is used for each candidate.

b. The simulation model is developed to perform a simulation of system operation over its entire life cycle. From the simulation, statistics are developed which isolate critical support, reliability, and maintainability elements and identify problem areas and probable areas of improvement. It also provides quantitative output information suitable for direct input to systems and cost effectiveness models.

3. MODEL CONSIDERATIONS

The emphasis by DoD on an integrated logistics support program, which involves consideration of total life cycle cost for a system, has required industry to concentrate on sophisticated methods for determination of these factors. Industry has developed computerized models that are used for determining system cost, system requirements, performance characteristics, support requirements, etc. The need for computerization of models depends on the following:

- Time frame of program
- Magnitude and complexity of equipment
- Identification of trade study requirements
- Detail of data to be available
- Program budget.

The computerization of a model provides the following advantages:

- Facilitates the competitive response to a system RFP
- Insures rapid response in terms of life cycle costs, availability, and optimum system effectiveness on all programs and proposals
- Presents a more salable approach to the formulation and development of engineering and logistic decisions
- Permits handling of vast amounts of data, variables, and iterations.
- Eliminates or reduces the risk of human error in calculations

The development of computer programs should be considered by both the contractor and procuring agency to aid in the conduct of trade-offs. The data used in trade-offs during equipment concept, definition, or development may be constantly changing parameters. The effect a change in one variable has on total system cost or the performance characteristics may be negligible, or it may be quite significant. In the case of a reliability (failure rate) change, the impact has a mushrooming effect. The performance parameters such as availability and mean corrective time, and the life cycle cost parameters (due to impact on support features such as spares quantities, personnel requirements, or maintenance labor) are all affected by a reliability change.

4. MODEL DESCRIPTION

The model addressed in this notebook is a computational model. The model provides the identification of all cost factors and the formulas required to calculate the total cost (acquisition, operation, and support) of a system. The model addressed is the Discard-at-Failure Maintenance (DAFM) mathematical model (reference RADC-TR-68-187 (AD 842 399)).

The Discard-at-Failure Maintenance (DAFM) Mathematical Model is sufficiently comprehensive and applicable for treatment of design alternatives incorporating microelectronic devices. Salient parameters and relationships relevant to consideration of microelectronic devices are adequately defined and developed. The model is flexible enough to accommodate most conceivable maintenance and logistics concepts which may accompany the introduction and widespread application of microelectronic technology; e.g., discard-at-failure maintenance and lifetime logistics self-sufficiency.

Microelectronic devices, while capable of supplanting thousands of generally recognized piece parts (resistors, transistors, etc.), are themselves piece parts. The piece part quality of microelectronic devices is inherent due to the nature of their composition and construction which relegates them to the category of nonrepairables. Therefore, in applications of the model, microelectronic devices may generally be treated as discardable lowest replaceable elements (i.e., piece parts), and the module or higher modular assembly that contains more than one of these devices may be categorized as either repairable or discardable. The DAFM model presents a straightforward computation of the cost factors.

Section 9B presents guidelines and methodology of the model as a lead into the actual applications procedures. Section 9D presents an example of model application.

SECTION 9B

GUIDELINES AND METHODOLOGY

This section contains guidelines and methodology for use of a model for determining maintenance alternatives and cost factors.

SECTION 9B GUIDELINES AND METHODOLOGY

DESIGN NOTE 9B1 MAINTENANCE ALTERNATIVE IDENTIFICATION

1. GENERAL

In the design of modern systems and major equipment programs, adequate attention must be given to optimize the level of repair. The level of repair identifies not only the repair location, but the extent of maintenance permitted and the resources necessary to support the repair process. Repair in this sense includes the identification of items to be supported under a discard-at-failure maintenance policy. Optimum maintenance is achieved over a system's total life cycle if the repair-level alternatives selected minimize total support cost for a specified level of system effectiveness, as compared with other possible maintenance concepts, procedures, or design alternatives. In this context, system effectiveness includes availability, dependability, maintainability, and capability.

In the past, design considerations relating to maintenance and repair-level policy have frequently been resolved by assuming that the best design permits and facilitates a maximum degree of organizational- and intermediate-level maintenance. Recent experience has demonstrated that planning for cost-effective support, with full consideration of operational alternatives of the equipment merits a greater degree of attention in making repair-level decisions. For example, failure to properly consider the impact of support equipment requirements as a constraint on equipment mobility can result in reduced effectiveness during rapid deployment of tactical units. It is also evident, however, that such decisions must be made as an integral part of system design. The investments made during the development and production phases preclude or seriously inhibit subsequent reversal of repair-level decisions during the operational phase. Design features incorporated to achieve optimum logistics support can be made at minimal cost to preliminary drawings and specifications rather than more costly charges to prototype and production hardware. The potential for greatly improved reliability, particularly in electronic systems, provides the opportunity for both industry and the procuring agencies to adopt an enlightened viewpoint toward designing certain components for discard at failure (throwaway).

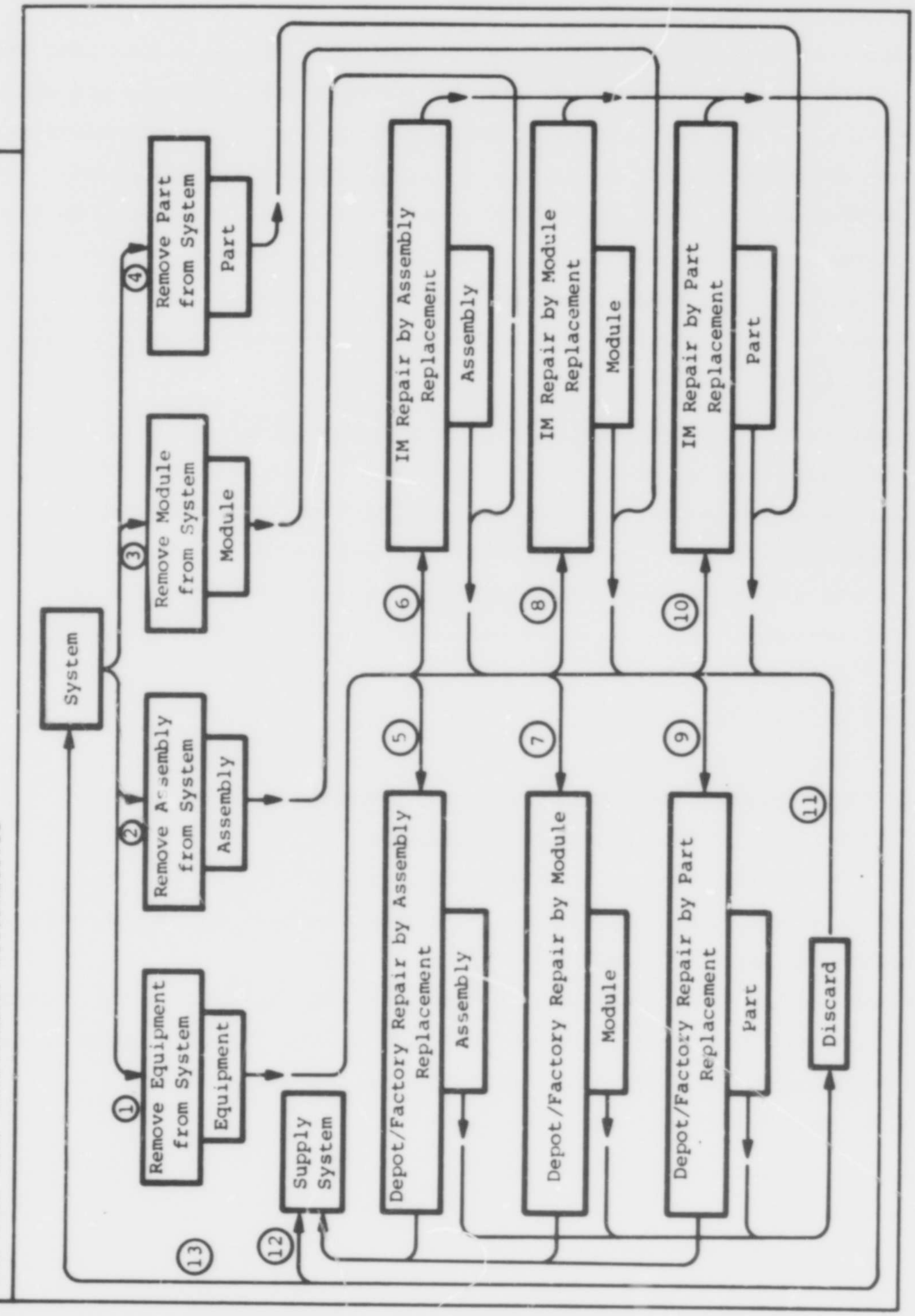
2. PROGRAM PHASE APPLICATION

During the conceptual phase and validation phase of procurement, various design and support alternatives must be postulated and evaluated. The selected alternative establishes the baseline for eventual hardware fabrication and for operation and support policies. The DAFM model is one technique that may be used in the process of selection of the proper maintenance alternative in terms of optimum system life-time costs. The model may be applied as a repair level analysis to perform trade-off studies during the conceptual, validation, and full-scale development phases as part of the system engineering process. Additionally, the technique may be applied for the analysis and evaluation of existing equipment in operation for the purpose of potential support performance improvement and/or cost reduction.

3. MAINTENANCE ALTERNATIVES

Formulating the maintenance concept and making the discard or repair decision are highly dependent activities that should be accomplished in parallel as the system evolves. The maintainability engineer must examine each feasible maintenance alternative, and combination of alternatives, from the aspect of both cost and operational requirements. SN 3(1) presents all of the maintenance alternatives that the maintainability engineer must consider. The circled numbers on SN 3(1) facilitate the identification of any particular alternative. For example, ② - ⑩ - ⑪ - ⑫ represent removing and replacing an assembly, sending the assembly to intermediate level maintenance (IM), repairing it by part replacement, and then returning the assembly to the supply system. The replaced part is discarded.

SUB-NOTE 1(1) Maintenance Alternatives



It is apparent that many alternatives are available for consideration. Fortunately, most of them can be eliminated by system characteristics and operational requirements. For example, a maintenance concept beginning with alternative (1) would not be practical for a physically large, complex system, because the equipments in that system may be too large to be removed and replaced. On the other hand, it may be quite feasible to use a maintenance concept such as described in (1) - (11) for simple low-cost systems. The maintenance concept for the Multiplexer Set is defined by the maintenance concepts (2) - (9) - (12) and (3) - (9) - (12).

The proper procedure for selecting the maintenance alternative is as follows:

a. Select feasible maintenance alternatives. Eliminate all alternatives that are not practical. (In eliminating impractical alternatives, the maintainability engineer must be careful not to exclude, on the basis of intuition alone, those alternatives which might be practical.) Constraints that may render alternatives impractical include, but are not limited to the following:

- Deployment concept
- Utilization
- Type of equipment
- Maintenance time or resource constraints
- Project or procuring agency dictates
- Operational and performance requirements

b. Determine the cost of the remaining alternatives in accordance with the instructions in this section.

c. Determine the sensitivity of the total costs to changes in the cost factors.

d. Evaluate how total cost will be affected by significant changes in cost factors that have the predominant influence on the total cost.

e. Select the lowest cost alternative.

DESIGN NOTE 9B2 — REPAIR POLICY COST FACTORS

1. GENERAL

After selecting the candidate maintenance alternatives (those which both satisfy the operational requirements and are reasonable), the maintainability engineer must determine cost differences among all the alternatives. SN 1(1) is a diagram of the cost factors that are to be considered. The total cost (T) of a system, equipment, etc., at all locations can be expressed by T = A + S, where A = the cost of acquisition and S = the total system, equipment (etc.) lifetime operation and support cost.

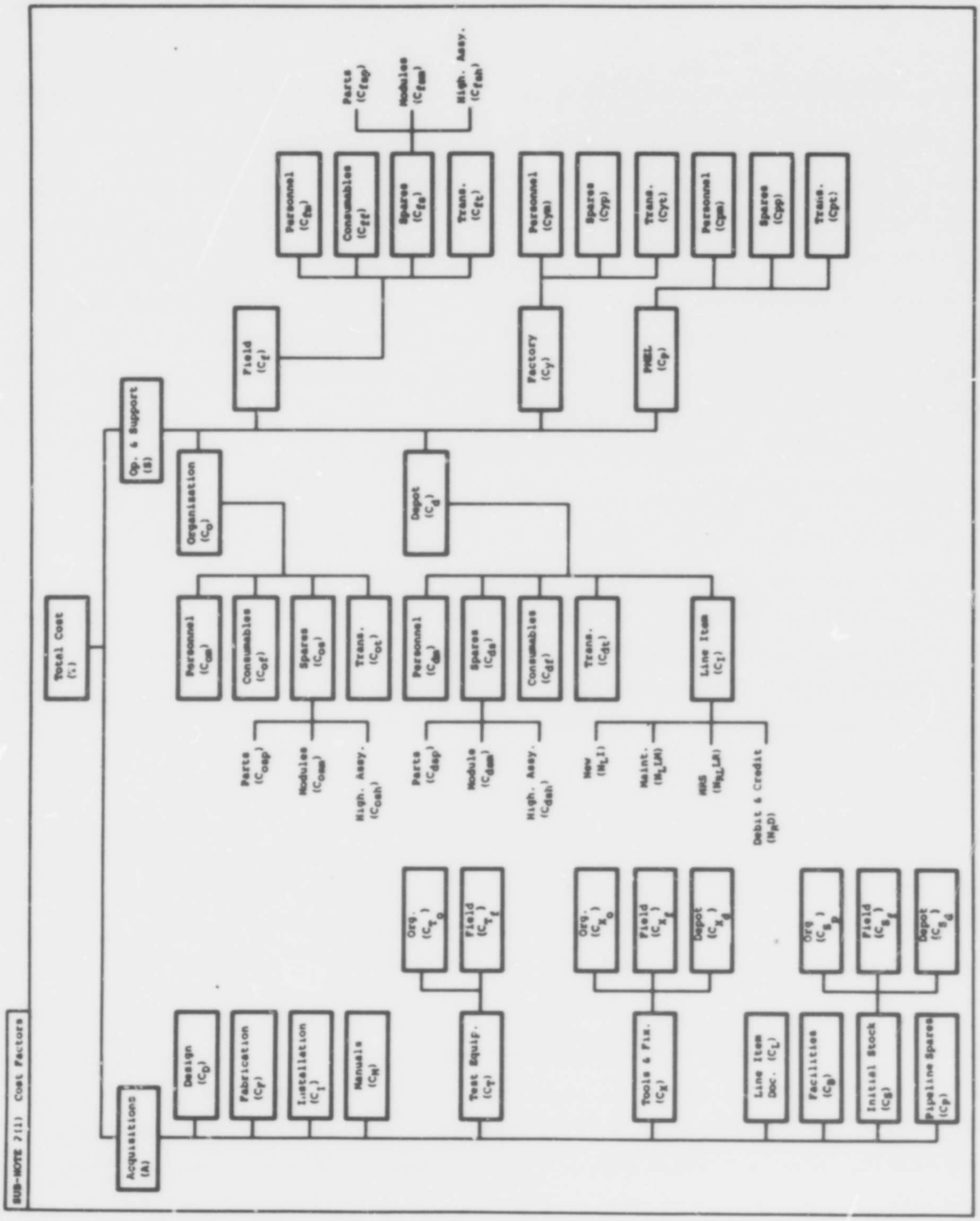
2. COST FACTOR ELEMENTS

The elements considered in making acquisition cost (A) should include all charges to the government that may result from the research, design, development, fabrication, and installation and checkout of the equipment. Particular attention should be paid to charges that result in significant cost differences between otherwise similar alternatives. These may include the following:

- Built-in isolation features
- Special test equipment
- Special tools
- Maintenance manuals.

The elements considered in making operation and support cost (S) should include all charges to the government expended to maintain the equipment in operational and readiness status upon installation for the service life of the equipment.

SN 1(1) shows the basic model and model elements to be evaluated. Ordinarily each element would be evaluated, separated, and then accumulated to obtain the total cost. The DAFM model approach, however, somewhat alleviates this laborious task by using a "difference in cost" concept. Under this concept, only


SUB-NOTE 2(1) Cost Factors
Total Cost
Op. & Support (S)
Acquisitions (A)
Field (C_f)
Factory (C_y)
PMEL (C_p)
Organization (C_o)
Depot (C_d)
Personnel (C_{fm})
Consumables (C_{ff})
Spares (C_{fs})
Trans. (C_{ft})
Parts (C_{fsp})
Modules (C_{fsm})
High. Assy. (C_{fsh})
Personnel (C_{ym})
Spares (C_{yp})
Trans. (C_{yt})
Personnel (C_{pm})
Spares (C_{pp})
Trans. (C_{pt})
Personnel (C_{om})
Consumables (C_{of})
Spares (C_{os})
Trans. (C_{ot})
Parts (C_{osp})
Modules (C_{osm})
High. Assy. (C_{osh})
Personnel (C_{dm})
Spares (C_{ds})
Consumables (C_{df})
Trans. (C_{dt})
Line Item (C_I)
Parts (C_{dsp})
Module (C_{dsm})
High. Assy. (C_{dsh})
New (N_LI)
Maint. (N_LLM)
MRS ($N_{RL}LR$)
Debit & Credit (N_RD)
Design (C_D)
Fabrication (C_F)
Installation (C_I)
Manuals (C_M)
Test Equip. (C_T)
Org. (C_{T_o})
Field (C_{T_f})
Tools & Fix. (C_X)
Org. (C_{X_o})
Field (C_{X_f})
Depot (C_{X_d})
Line Item Doc. (C_L)
Facilities (C_B)
Initial Stock (C_S)
Org (C_{S_o})
Field (C_{S_f})
Depot (C_{S_d})
Pipeline Spares (C_P)

those elements which would give cost differences between alternatives would be evaluated. Element costs which would not significantly vary between alternatives need not be evaluated. Thus, the model deals only with total cost differences between alternatives and not the total cost of each alternative. Of course, in exercising the model, only cost alternatives that do not compromise performance, physical, and policy constraints should be considered.

Let the difference in total cost ($\Delta T_{2,1}$) be represented by:

$$\Delta T_{2,1} = T_2 - T_1$$

where

T_1 = total cost (acquisition, operation, and support) of the first alternative, excluding the elements of cost common to the second alternative and equal in magnitude.

T_2 = total cost (acquisition, operation, and support) of the second alternative, excluding elements of cost common to the first alternative and equal in magnitude.

If the quantity $\Delta T_{2,1}$ is negative, it means that the second alternative is less costly. If positive, then the first alternative is less costly. Once two alternatives have been compared, the one yielding the highest cost is dropped from further consideration. Successive alternatives are devised and matched against the current least cost alternative. The process continues until a satisfactory level of refinement is reached.

DESIGN NOTE 9B3 GENERAL CONSIDERATIONS OF THE MODEL

1. GENERAL

The DAFM model considers maintenance support alternatives, discard at failure or repair for various levels of maintenance organization, and identifiable hardware levels of an end item.

The levels of maintenance organization are organization, field, depot, factory, and precision measurement equipment laboratory (PMEL). The hardware levels of end item breakdown are system, subsystem, equipment, assembly, module, and part.

2. MAINTENANCE SUPPORT ALTERNATIVES

SN 2(1) delineates possible maintenance support alternatives for the different assembly levels at each maintenance level.

The DAFM model considers the cost for acquisition (A) and operation and support (S) for an end item based on selected maintenance support alternatives. The acquisition cost consists of cost factors attributed to:

- Research, design, and development
- Fabrication
- Installation
- Manuals
- Test equipment
- Tools and fixtures
- Line item documentation
- Facilities
- Initial spares, including pipeline

SUB-NOTE 2(1) Possible Maintenance Support Alternatives

No.	Units Involved	Organization	Field	Depot	Factory	PMEL***
1 2 3	Organizational	Part repair HMA* Discard Module Discard HMA				
4 5 6 7 8	Organizational Field	R and R** Module R and R Module R and R HMA R and R HMA R and R HMA	Discard Module Module repair Discard HMA Discard Module Part repair HMA			
9 10 11 12 13	Organizational Depot	R and R Module R and R Module R and R HMA R and R HMA R and R HMA		Discard Module Module repair Discard HMA Discard Module Part repair HMA		
14 15 16 17 18	Organizational Factory	R and R Module R and R Module R and R HMA R and R HMA R and R HMA			Discard Module Module repair Discard HMA Discard Module Part repair HMA	
19 20 21 22 23	Organizational PMEL	R and R Module R and R Module R and R HMA R and R HMA R and R HMA				Discard Module Module repair Discard HMA Discard Module Part repair HMA
24 25	Organizational Field-Depot	R and R HMA R and R HMA	R and R Module R and R Module	Discard Module Module repair		
26 27	Organizational Field-Factory	R and R HMA R and R HMA	R and R Module R and R Module		Discard Module Module repair	
28 29	Organizational Field-PMEL	R and R HMA R and R HMA	R and R Module R and R Module			Discard Module Module repair
30 31	Organizational Depot-Factory	R and R HMA R and R HMA		R and R Module R and R Module	Discard Module Module repair	
32 33	Organizational Depot-PMEL	R and R HMA R and R HMA		R and R Module R and R Module		Discard Module Module repair

* HMA = higher modular assembly
** R and R = remove and replace
***PMEL = Precision Measurement Equipment Laboratory

Underlined Items Indicate the Most Generally Practical Alternatives

The operation and support cost consists of cost factors at the various levels of maintenance organization attributed to:

- Personnel
- Consumables
- Spares
- Transportation
- Line item

3. GUIDELINES FOR MODEL APPLICATION

Several general guidelines are applicable to the use of the model. These guidelines are as follows:

a. Data Source

Accurate prediction of the lifetime costs associated with a military system requires data from its future user, its designer, and its future manufacturer. The costs of design, development, and manufacture will be estimated, normally almost entirely from data which the manufacturer has concerning his own operation, using procedures that he uses in estimating bids. The costs of operations and maintenance require data from two sources: the manufacturer, providing estimates of failure and repair rates, skills, and test equipment required, cost of spares, and such; and the customer providing costs of human resources, facilities handling, etc. SN 3(1) contains a list of model parameters, values for which should be furnished by the customer. Items not on this list are the responsibility of the contractor.

b. Tools and Fixtures

The cost of general test equipment, tools, and fixtures at factory and PMEL may normally be neglected as they will generally be shared with other systems and their cost usually included in the service facilities charge rate. Depot tools and fixtures are, in most cases, unique for the item to be supported.

SUB-NOTE 3(1) (Sheet 1 of 3 sheets) Customer Parameter Responsibilities

Operation Parameters:

L = Expected life of equipment ________

E = Number of equipments scheduled for operation ________

r = Fraction of time equipment will operate per hour ________

F_s = Number of field shops ________

Operation readiness goal ________

Reliability goal (to equipment level, if applicable) ________

Mean-time-to-restore goal ________

Downtime permissible per unit time (to equipment, if applicable, preventive, corrective) ________

Self-Sufficiency Restrictions:

Autonomous Operation Period

Maximum personnel assignable, per location (if applicable) and permissible skills ________

Minimum personnel assignable, per location, and permissible skills ________

Mobility Requirements:

Weight ________

Power ________

Volume ________

Facilities, space restriction ________

Cost Constants:

I = Line item entrance, DOD cost ________

M = Line item maintenance, cost per year ________

D = Documentation per repair (debit and credit) ________

R = Cost of maintaining stock items (MRS) per year ________

SUB-NOTE 3(1) (Sheet 2 of 3 sheets) Customer Parameter Responsibilities

Facilities and Utilities:

Floor space per square foot __________

Air conditioning __________

White room __________

B = constant representing the average number of parts replaced per failure __________

c_d = depot level direct and indirect costs as incurred

Personnel costs by classification per year

CMSgt - E-9 __________

MSgt - E-7 __________

SSgt - E-5 __________

A2C - E-3 __________

Airman Basic - E-1 __________

+________ per month of training (special and basic)

Transportation cost per shipment:

Commercial - as incurred __________

Military - as incurred __________

Manning Utilization (if applicable):

For analysis of maintenance manning requirements, the following information pertaining to existing systems which are to be collocated with the new system, must be provided by the Air Force user organization:

a. By skill, manhours of maintenance per clock hour required by other equipments or systems to be used at the same sites as the equipments under study.

b. Test equipment required for maintenance of other equipment at the same site.

SUB-NOTE 3(1) (Sheet 3 of 3 sheets) Customer Parameter Responsibilities

c. Tasks and utilization of equipment operators (and other personnel on-site).

Personnel by skill level

Airman Basic - E-1 ________

A2C - E-3 ________

SSgt - E-5 ________

MSgt - E-7 ________

CMSgt - E-9 ________

d. Preventive maintenance scheduled by location:

Periodicity ________

Duration ________

Team personnel requirements ________

The cost of facilities includes such items as land, buildings, power generators, vehicles, etc., when chargeable. Ordinarily, these costs will cancel between alternatives. When facilities are obtained on a lease or rental basis, the total rental costs for the considered life should be determined and treated as acquisition costs. Facility costs may be handled similar to test equipment; i.e., organization, field, and depot.

c. Cost of Personnel

Cost of personnel (c_m) should represent the total burdened cost of the person to the government. This value should be the aggregate of such expenses as base pay, cost of rations, quarters allowance, clothing allowance, special and incentive pay, training costs, and miscellaneous expenses. Costs such as training costs should be prorated over the period of time a person would be expected to be associated with the system or the period of time which will pass before he requires retraining.

d. Training Cost

Training costs vary significantly between skill fields which are dependent on hardware design. The training costs incurred, which include basic and specialized, are charged based on the number of replacement personnel required by the system under consideration. Training of personnel already trained represent funds already spent and should not be charged against a potential system. Training costs should be based on standard military basic pay and allowance rate by skill level. Training cost estimates may be obtained from AFM 173-10.

e. Manpower Requirements

The number of men required (G_{ij}) is estimated from consideration of the operations and maintenance tasks. Detailed manpower analyses are not generally required unless it is anticipated that significant manning cost differences will exist between alternatives. Similarly, administrative cost (F) differences between alternatives will generally be negligible unless extreme differences in manning levels are expected.

f. Consumables

Normally, the cost of consumables (C_{of}) is negligible, or will cancel when differential costs are considered.

Generally, the depot consumable costs will be insignificant or cancel when cost differences are taken. In fact, in most cases, the cost of consumables attributable to the considered system will be indistinguishable if the depot provides services to many other systems. These costs may be reflected in the indirect man-hour charges for repair and logistics costs.

g. Spares

The cost of base stock level or initial spares (C_s) and the cost of pipeline spares (C_p) must be considered an element of acquisition (A) cost.

h. Transportation

Transportation costs from organization to field are usually negligible. The cost of transportation to depot, factory, and PMEL is considered in those sections which deal with the particular receiving maintenance echelons.

i. Factory Cost

Repair at factory is not predominant; however, special conditions may make it appropriate in some instances. Most instances are accounted for by one of the following:

(1) Rare skills and/or expensive special test equipment is required to perform maintenance; e.g., gyroscopes and some other sealed assemblies

(2) Demands for maintenance exceed capacity at depot (as limited, for example, by employment budget) and factory charges are not far in excess of depot costs.

(3) Interim factory repair may be planned during early deployment prior to activation of depot, especially if phased deployment and factory assembly line are still operating.

Requirements for self-sufficiency of the military generally preclude consideration of factory as a life cycle repair echelon for operational equipment. Furthermore, where factory repair may be considered, such considerations will generally be inherent in all alternatives and will therefore cancel. When this is not the case, estimates from the probable contractor should provide adequate cost figures for comparison.

j. PMEL Cost

Precision Measurement Equipment Laboratory (PMEL) costs (C_p) are incurred as a result of repairs, alignment, calibration, or adjustments made to operating and test equipment calling for secondary measurement standards. Ordinarily, these costs will be insignificant or be common to all alternatives.

DESIGN NOTE 9B4 **DETAILED COST FORMULAS**

1. COST FORMULAS

Following is a list of the formulas used in the DAFM model:

$$T = A + S \tag{1}$$

$$A = C_D + C_F + C_I + C_M + C_T + C_X + C_L + C_B + C_S + C_P \tag{2}$$

$$C_T = C_{T_o} + C_{T_f}$$

$$C_X = C_{X_o} + C_{X_f} + C_{X_d}$$

$$C_S = C_{S_o} + C_{S_f} + C_{S_d}$$

$$C_P = \sum_i c_i \left(\mu_i + K\sqrt{\mu_i} \right)$$

$$\mu_i = \lambda_i \, T_{T_i} \, N_i \, V$$

$$S = C_o + C_f + C_d + C_y + C_p \tag{3}$$

$$C_o = C_{om} + C_{of} + C_{os} \tag{3.1}$$

$$C_{om} = \left\{ \left[\sum_k V_K \left(\sum_j \sum_i G_{ij} X_{ij} + F \right) \right] + \left[V \cdot c_m \left(\sum_E N_E \lambda_E / \mu_E \right) \right] \right\} L$$

$$X_{i_j} = P_{si} + P_{ti}$$

$$C_{of} = \left(C_{ofu} + C_{ofm} + C_{oft} \right) V \cdot L/8766$$

$$C_{os} = C_{osp} + C_{osm} + C_{osh}$$

$$C_{osp} = V \cdot L \sum_i N_i \lambda_i c_i$$

$$C_{osm} = V \cdot L \left\{ \left(\sum_i N_i \lambda_i c_i Z_i \right) + \left[\sum_i N_i \lambda_i c_i \left(1 - Z_i \right) W_i \right] \right\}$$

$$C_{osh} = V \cdot L \sum_i N_i \lambda_i c_i Z_i$$

$$C_f = C_{fm} + C_{ff} + C_{fs} \tag{3.2}$$

$$C_{fm} = L \cdot V \cdot c_m \left(\sum_E N_E \lambda_E / \mu_E \right)$$

$$C_{ff} = \left(C_{ffu} + C_{ffm} + C_{fft}\right) V \cdot L/8766$$

$$C_{fs} = C_{fsp} + C_{fsm} + C_{fsh}$$

$$C_{fsp} = V \cdot L \sum_i N_i \lambda_i c_i$$

$$C_{fsm} = V \cdot L \left\{ \left(\sum_i N_i \lambda_i c_i Z_i \right) + \left[\sum_i N_i \lambda_i c_i \left(1 - Z_i\right) W_i \right] \right\}$$

$$C_{fsh} = V \cdot L \sum_i N_i \lambda_i c_i Z_i$$

$$C_d = C_{dm} + C_{df} + C_{ds} + C_{dt} \tag{3.3}$$

$$C_{dm} = L \cdot V \left(\sum_n N_n \lambda_n / \mu_n + \sum_h N_h \lambda_h / \mu_h \right) c_d$$

$$C_{df} = (C_{dfm} + C_{dft} + C_{dfu} + C_{dfb}) L$$

$$C_{ds} = C_{dsp} + C_{dsm} + C_{dsh}$$

$$C_{dsp} = V \cdot L \sum_i N_i \lambda_i c_i$$

$$C_{dsm} = V \cdot L \left\{ \left(\sum_i N_i \lambda_i c_i Z_i \right) + \left[\sum_i N_i \lambda_i c_i \left(1 - Z_i\right) W_i \right] \right\}$$

$$C_{dsh} = V \cdot L \sum_i N_i \lambda_i c_i Z_i$$

$$C_{dt} = L \cdot V \left(\sum_n N_n \lambda_n + \sum_h N_h \lambda_h \right) \bar{c}_{dt}$$

$$C_{dl} = \left(N_{RL} \; L \cdot R/8766 \right) + N_R D$$

$$N_R = L \cdot V \left(\sum_n N_n \lambda_n + \sum_h N_h \lambda_h \right)$$

$$C_y = C_{ym} + C_{yp} + C_{yt} \tag{3.4}$$

$$C_{ym} = L \cdot V \left(\sum_n N_n \lambda_n / \mu_n + \sum_h N_h \lambda_h / \mu_h \right) c_y$$

$$C_{yp} = L \cdot V \sum_z N_z \lambda_z \bar{c}_z \bar{N}_z$$

$$C_{yt} = L \cdot V \left(\sum_n N_n \lambda_n + \sum_h N_h \lambda_h \right) \bar{c}_{yt}$$

$$C_p = C_{pm} + C_{pp} + C_{pt} \qquad (3.5)$$

$$C_{pm} = L \cdot V \left(\sum_n N_n \lambda_n / \mu_n + \sum_h N_h \lambda_h / \mu_h \right) c_p$$

$$C_{pp} = L \cdot V \sum_z N_z \lambda_z \bar{c}_z \bar{N}_z$$

$$C_{pt} = L \cdot V \left(\sum_n N_n \lambda_n + \sum_h N_h \lambda_h \right) \bar{c}_{pt}$$

2. COST FORMULA TERM DEFINITIONS

The definitions of the terms used in the formulas delineated in this design note and presented in their order of appearance in the cost formulas are as follows:

NOTE: The following symbols are common to numerous formulas and are defined below one time only:

V	Number of sites
L	Anticipated life of the subject equipment (hr)
λ_i	Failure or usage rate of applicable part, module, or higher assembly i (failures/hr)
N_i	Total number of part, module, or higher assembly i in the subject equipment per site (items)
c_i	Cost of part, module, or higher assembly i
z_i	1 if module or higher assembly i is discarded at failure; 0 if module or higher assembly i is repaired at failure

All costs are expressed in dollars. Unit time measurements are specified in definitions.

T	Total cost of system, equipment, etc., across all sites	Equation (1,2)
A	Cost of acquisition	
C_D	Cost of research, design, and development	
C_F	Cost of fabrication	
C_I	Cost of installation	
C_M	Cost of manuals	
C_T	Cost of test equipment	

C_{T_o}	Cost of test equipment at organization
C_{T_f}	Cost of test equipment at field
C_X	Cost of tools and fixtures
C_{X_o}	Cost of tools and fixtures at organization
C_{X_f}	Cost of tools and fixtures at field
C_{X_d}	Cost of tools and fixtures at depot
C_L	Cost of line item documentation
C_B	Cost of facilities
C_S	Cost of base stock level or initial spares
C_{S_o}	Cost of base stock level or initial spares at organization
C_{S_f}	Cost of base stock level or initial spares at field
C_{S_d}	Cost of base stock level or initial spares at depot
C_P	Cost of pipeline spares
μ_i	Average number of failures of module or higher assembly i during turnaround time
K	Constant value determines probability item i will be available when needed

Value of K	Probability (%)
0.67	75
1.65	95
2.33	99

These values are obtained from the table of cumulative normal distribution in Appendix C of this notebook.

T_{T_i} Turnaround time of module or higher assembly i (hrs)

Equation (1,3)

S Total system, equipment, etc., life-time operation and support cost (3.1)

C_o Cost at organization

C_{om} Cost of personnel at organization

V_K Number of sites with operation and maintenance group of size $\sum_j \sum_i G_{ij}$

G_{ij} Number of personnel with skill i in an operation and maintenance unit j

X_{ij} Average manpower expense, per unit time, incurred by the government as a result of manning with skill i in an operation and maintenance unit j (\$/hr)

P_{si} Composite pay rate for skill i per unit time (\$/man hr)

P_{ti} Training cost per unit time (\$/man hr)

F The administrative and service costs, per unit time, normal to operation and maintenance group of size $\sum_j \sum_i G_{ij}$ (\$/hr)

c_m	Cost of labor, per unit time, of maintenance personnel - direct and indirect ($/man-hr)
N_E	Number of items of equipment E per site requiring support (items)
λ_E	Failure rate of equipment E (failures/hr)
μ_E	Mean repair service rate for equipment E (number of equipment/man-hr)
C_{of}	Cost of consumables at organization
C_{ofu}	Cost of utilities per unit time ($/yr)
C_{ofm}	Cost of materials for maintenance of facilities per unit time ($/yr)
C_{oft}	Cost of materials for maintenance of test equipment per unit time ($/yr)
8766	Number of hours per year
C_{os}	Cost of spares at organization
C_{osp}	Cost of spare parts at organization
C_{osm}	Cost of spare modules at organization
W_i	Condemnation rate of module i (percent)
C_{osh}	Cost of spare higher assemblies at organization

C_f Cost at field — Equation (3.2)

- C_{fm} Cost of personnel at field
  - c_m, N_E, λ_E — See equation (3.1)
- C_{ff} Cost of field consumables
  - C_{ffu} Cost of utilities per unit time (\$/hr)
  - C_{ffm} Cost of materials per unit time, for facilities maintenance (\$/hr)
  - C_{fft} Cost of materials, per unit time, for test equipment maintenance at field (\$/hr)
  - 8766 See equation (3.1)
- C_{fs} Cost of spares at field
  - C_{fsp} Cost of spare parts at field
  - C_{fsm} Cost of spare modules at field
    - W_i See equation (3.1)
  - C_{fsh} Cost of spare higher assemblies

C_d Cost at depot — Equation (3.3)

- C_{dm} Cost of personnel at depot
  - N_n Number of type n modules contained in the subject equipment per site, to be repaired at depot (types)

λ_n	Failure rate of type n module (failures/hr)
μ_n	Mean repair service rate for type n modules at depot (units/hr)
N_h	Number of type h higher assemblies contained in the subject equipment per site, to be repaired at depot (types)
λ_h	Failure rate of type h higher assembly (failures/hr)
μ_h	Mean repair service rate for type h higher assemblies at depot (units/hr)
c_d	Cost of depot labor - direct and indirect
C_{df}	Cost of consumables at depot
C_{dfm}	Appropriate share of the cost of materials for maintenance of facilities at depot per unit time ($/yr)
C_{dft}	Appropriate share of the cost of materials, per unit time, for maintenance of test equipment at depot ($/yr)
C_{dfu}	Appropriate share of the cost of utilities, per unit time, at depot ($/yr)
C_{dfb}	Appropriate share of cost of buildings, per unit time, at depot ($/yr)

C_{ds}	Cost of spares at depot
C_{dsp}	Cost of spare parts at depot
C_{dsm}	Cost of spare modules at depot
W_i	See equation (3.1)
C_{dsh}	Cost of spare higher assemblies at depot
C_{dt}	Cost of transportation from organization/field to the depot
N_n, λ_n, N_h, λ_h	See C_{dm} in equation (3.3)
$\bar{c}_{dt}$	Mean transportation cost between organization/field and depot (\$/item)
C_{dl}	Line item cost at depot (\$)
N_{RL}	Number of different types of modules and higher assemblies repaired by depot (types)
R	Cost, per unit time, of maintaining a stock item in the Master Repair System (MRS) (\$/yr)
8766	Number of hours per year

N_R Number of maintenance actions at depot during equipment (actions)

N_n, λ_n, N_h, λ_h — See C_{dm} in equation (3.3)

D Debit and credit costs associated with inventory, accountability, and storage for items repaired at the depot ($/item)

C_y Cost of factory — Equation (3.4)

C_{ym} Cost of personnel at factory

N_n Number of type n modules contained in the subject equipment per site, to be repaired at factory (modules)

λ_n Failure rate of type n module (failures/hr)

μ_n Mean repair service rate for type n modules at factory (modules/hr)

N_h Number of type h higher assemblies contained in the subject equipment per site, to be repaired at factory (assemblies)

λ_h	Failure rate of type h higher assembly (failures/hr)
μ_h	Mean repair service rate for type h higher assembly at factory (assemblies/hr)
c_y	Labor cost at factory - direct and indirect ($/hr)
C_{yp}	Cost of items replaced at factory
N_z	Number of type z items contained in the subject equipment per site, to be replaced at factory (items)
λ_z	Failure rate of type z item (failures/hr)
$\bar{c}_z$	Average cost of replacement parts for type z item failure ($/item)
$\bar{N}_z$	Average number of parts replaced for oe z item failure
C_{yt}	Cost of transportation at factory
N_n, λ_n, μ_n, N_h, λ_h, μ_h	See C_{ym} in equation (3.4)
$\bar{c}_{yt}$	Mean transportation cost between organization/field and factory ($/item)

C_p Cost at Precision Measurement Equipment Laboratory (PMEL) Equation (3.5)

C_{pm} Cost of personnel at PMEL

N_n Number of type n modules contained in the subject equipment per site, to be repaired at PMEL (modules)

λ_n Failure rate of type n modules (failures/hr)

μ_n Mean repair service rate for type n module (modules/hr)

N_h Number of type h higher assemblies contained in the subject equipment per site, to be repaired to PMEL (assemblies)

λ_h Failure rate of type h higher assemblies (failures/hr)

μ_h Mean repair service rate for type h higher assembly (assemblies/hr)

c_p PMEL labor cost - direct and indirect ($/hr)

C_{pp} Cost of replacement items at PMEL

N_z Number of type z items contained in the subject equipment per site, to be replaced at PMEL (items)

λ_z	Failure rate of type z item (failures/hr)
$\bar{c}_z$	Average cost of replacement parts for type z item failure ($/item)
N_z	Average number of parts replaced for type z item failure
C_{pt}	Cost of transportation at PMEL
N_n, λ_n, N_h, λ_h	See C_{pm} in equation (3.5)
$\bar{c}_{ft}$	Mean transportation cost from organization/field to PMEL ($/item)

SECTION 9C

PROCEDURE

This section contains procedures for applying a DAFM model and selection of alternative equipment design.

SECTION 9C

PROCEDURE

DESIGN NOTE 9C1 — OVERALL APPLICATION

1. GENERAL

The DAFM model is applicable for design of new equipment, modification of existing equipment, and determining optimum maintenance and logistics posture ("where to" and "how to" perform maintenance) for existing electronic equipment. The model can be used during any phase of a system from contract definition phase through operational phase. The model may be used by equipment designers, maintenance and logistic personnel, etc., and is applicable to most Air Force systems utilizing electronic equipment.

Due to the comprehensiveness of the model, the evaluation process may become time consuming and unwieldy. However, the evaluation process can be simplified in the following manner:

- Reduce the number of types of items to be considered. Proper grouping of items will frequently allow simultaneous treatment of a number of items by averaging similar characteristics. This procedure can result in significant savings in the number of computations. Items should be grouped in terms of similar costs and failure rates within each gross level grouping of assembly levels - higher assembly, module, etc. Some cost elements can be eliminated by examining the alternative design configuration and the system in which the equipment design is to be utilized.
- Eliminate cost elements which are insensitive to the alternatives under consideration. The design alternatives may not significantly alter the costs of consumables, manuals cost, etc.; therefore, such cost elements can be eliminated.

- Eliminate unfeasible support alternatives. Examination of the system and its performance requirements may identify unfeasible alternatives. For instance, the on-line part repair of a higher assembly may be unfeasible because of mean restore time requirements. The system under consideration may prohibit the utilization of factory level maintenance because of base self-sufficiency requirements; therefore, factory support alternatives can be eliminated.

2. SEQUENCE FOR EVALUATION OF ALTERNATIVE EQUIPMENT DESIGN

SN 2(1) delineates the general sequence for evaluation of alternative equipment decisions. With reference to SN 2(1), the general steps associated with this sequence are outlined in blocks 1 through 7 and are as follows:

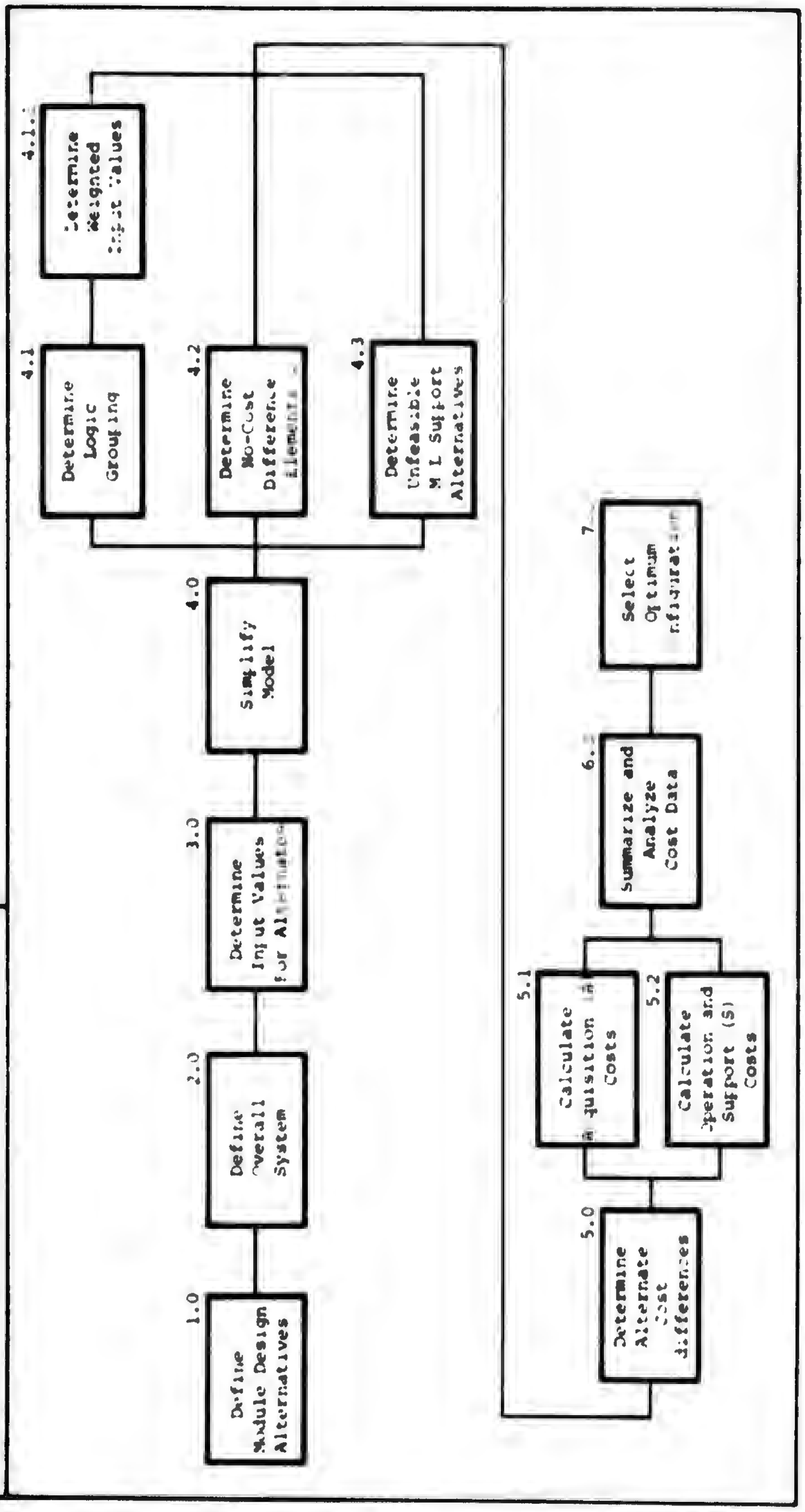
Block 1.0 - Define Module Design Alternatives

The basic procedure is initiated with the development of several alternative design alternatives. Data elements used in this process include performance requirements, design constraints, and system parameters.

Block 2.0 - Define Overall System

The data elements used in this process include:

- Equipment life
- Number of sites
- Number of equipments/site
- Operational constraints: operational life, operational unreadiness, mean time to repair, mean time between failure, and distance between facilities.



SUB-NOTE 2(1) General Sequence for Evaluation of Alternative Equipment Designs

Block 3.0 - Determine Input Values for Alternates

Specific input data for each alternate is required and relates to

- Number of each type of item
- Failure rate of each type
- Cost of each item type
- Predicted repair rate

Block 4.0 - Simplify Model

The simplification of the model to reduce the overall effort related to calculations, data requirements, and time is performed by the following substeps:

Block 4.1 - Determine Logic Grouping

In order to simplify the DAFM mathematical model for manual computation, system components (i.e., piece parts, modules, higher assembles), are broken down into subgroups which reflect certain identifiable characteristics, the differences of which are insignificant with respect to the DAFM model decision process. In the case of equipments which are made up of subassemblies of similar components (e.g., blocks of power circuitry, logic, or analog circuitry), the natural grouping is readily apparent. Where higher assemblies are made up of nonhomogeneous elements, the breakdown must be by characteristics related to the highest identifiable module: the components of which are homogeneous in character and significant with respect to the DAFM model.

Gross level groupings should be by the following order:

- Assembly level - module, higher assembly, etc.
- Significant differences in repairability due to complexity and package design; i.e., planar, volumetric, sealed, etc.
- Grouping by special maintenance skill and test equipment requirements; i.e., RF, analog, digital logic, fluids, etc.

Block 4.1.1 - Determine Weighted Input Values

Subgroupings should then be developed in terms of item acquisition cost, failure rate, cost failure rate, or other appropriate criteria; in other words, a tree-type breakdown should be applied. For example, one breakdown might be by function (digital, analog, etc.), failure rate, repair time, and cost, in that order.

For each new grouping, the input values specified in block 3.0 must be modified to reflect the changes made.

Block 4.2 - Determine No-Cost Difference Elements

The elimination of insensitive cost elements is a function of the DAFM model application. Since it is difficult to prescribe step-by-step procedures to perform this process, examples are given to illustrate how this step may be achieved.

Consider an application in which the design configuration (higher modular assemblies, modules, etc.) is already specified, and the contractor would like to determine the optimum maintenance and logistics support posture. Since the design is fixed, there will be no cost differences in the following cost elements:

- All design costs except test equipment costs
- PMEL costs - PMEL requirements will not change
- Cost of consumables will remain constant

Block 4.3 - Determine Unfeasible Maintenance/Logistics (M/L) Support Alternatives

Step-by-step procedures are difficult to prescribe to perform this process. An example of application is as follows: Consider an extremely short requirement for mean time to restore and a requirement for base self-sufficiency. The short mean time to restore will probably make the maintenance action of on-line part repair of higher module assemblies unfeasible. The base self-sufficiency requirement will probably eliminate factory and depot level maintenance.

Block 5.0 - Determine Alternate Cost Differences

The model is based on net differences in total cost between alternatives. The total cost includes acquisition and the lifetime operation and support costs. The "difference in cost" concept permits evaluation of those elements that result in cost delta between alternatives.

The procedure must be iterated for each alternative design configuration identified in block 1.0 and each of the feasible M/L postures identified in block 4.3. The determination of cost differences is performed in the following substeps:

Block 5.1 - Calculate Acquisition (A) Costs

The elements to be considered in making acquisition cost (A) estimates should include all charges to the government which may arise from the research, design, development, fabrication, and installation and checkout of the equipment. Particular attention should be paid to items which result in significant cost differences between otherwise similar alternatives.

Among these may be:

- Built-in fault isolation features
- Special test equipment
- Special tools
- Maintenance manuals

Cost of acquisition (A) may be expressed by:

$$A = C_D + C_F + C_I + C_M + C_T + C_X + C_L + C_B + C_S + C_P$$

where

C_D = cost of research, design and development

C_F = cost of fabrication

C_I = cost of installation

C_M = cost of manuals

C_T = cost of test equipment

C_X = cost of tools and fixtures

C_L = cost of line item documentation

C_B = cost of facilities

C_S = cost of base stock level or initial spares

C_P = cost of pipeline spares

Block 5.2 - Calculate Operation and Support (S) Costs

Operation and support costs (S) include all costs incurred by the government associated with operating and maintaining the system over its expected life. These costs may be represented by:

$$S = C_o + C_f + C_d + C_y + C_p$$

where

C_o = cost at organization

C_f = cost at field

C_d = cost at depot

C_y = cost at factory

C_p = cost at Precision Measurement Equipment Laboratory (PMEL)

Block 6.0 - Summarize and Analyze Cost Data

To determine the least cost support posture for a given configuration, four major cost factors must be considered: acquisition costs, cost of consumables, organization and field personnel costs, and the costs associated with the maintenance/logistics (M/L) alternatives. Each of these factors may be considered and treated as independent of one another.

The selection of an optimal M/L alternative requires simultaneous consideration of the influential cost elements: spares, repair facility personnel costs, and transportation costs. These cost elements must be evaluated and summed for each feasible M/L alternative for a given item group and the least cost M/L alternative selected.

For each type of item (a given power supply, a group of similar printed circuit cards, etc.) contained within the subject equipment, a number of decisions must be made governing the application of logistics and maintenance policies to that item. The logistics decisions include (1) if to spare and how many and (2) where to spare. The maintenance decisions are (1) to repair or discard at failure and (2) if repair, where to repair.

In determining the optimum logistics and maintenance policies, the strong interdependence of logistics and maintenance decision effects precludes consideration of their independent treatment.

SN 2(2) presents practical M/L alternatives and possible combinations thereof.

Following selection of the least cost M/L alternative for all item groups comprising the subject configuration candidate and computation of organization and field personnel and consumables costs, the total cost of the subject configuration may be determined by summing these factors plus the acquisition costs.

SN 2(3) shows the cost decision elements summary matrix that may be used to compile factor costs for each design alternative.

Block 7.0 - Select Optimum Configuration

The optimum configuration in relation to design and M/L alternative is selected based on the optimum cost configuration. In addition to cost difference delineated in SN 2(3), the overall cost effectiveness of the alternatives must be evaluated.

The evaluation considers cost and other system effectiveness parameters, such as, performance, availability, dependability, reliability, etc.

SUB-NOTE 2(2) Maintenance/Logistics Policy Alternatives

Logistics Policy	Maintenance Policy
Site spare item only	Discard
	Repair at site
	Repair at depot
	Repair at factory
	Repair at PMEL
Depot spare item only	Discard
	Repair at depot
	Repair at factory
	Repair at PMEL
Site and depot spare item	Discard
	Repair at depot
	Repair at factory
	Repair at PMEL

SUB-NOTE 2(3) Cost Decision Elements Summary Matrix

Cost Element (C)	Subscript	Configuration				
		A( )	A( )	A( )	A( )	A( )
Design	D					
Fabrication	F					
Installation	I					
Manuals	M					
Test equipment						
Organization	T_o					
Field	T_f					
Depot	T_d					
Tools and fixtures	X					
Organization	X_o					
Field	X_f					
Depot	X_d					
Line item documentation	L					
		S( )	S( )	S( )	S( )	S( )
Organization	o					
Personnel	om					
Consumables	of					
Field	f					
Personnel	fm					
Consumables	ff					
Maintenance/logistics	z_{min}					
Total cost		T( )	T( )	T( )	T( )	T( )

DESIGN NOTE 9C2 — DETAILED PROCEDURE

1. INTRODUCTION

The procedure presented herein consists of detailed step-by-step procedures, instructions for completing the computational forms, and the logical sequence for performing the computations to compare alternative design configurations. The model is constructed in such a manner that it can be either manually exercised with the aid of a desk calculator or may be computerized. In addition, the lowest level of formulas for which detailed data is available is the point at which the application of procedure begins. This is facilitated by the "building block" approach to model development.

The model may be used in the following manner:

- Step-by-step procedures based on solution of all cost decision elements for each individual level of maintenance organization (organization, field, depot, etc.) before proceeding to the next level of maintenance calculations.
- Step-by-step procedures based on solution of each individual cost decision element (personnel, spares, consumables, transportation, etc.) for all levels of maintenance organization before proceeding to next cost decision element calculation.

The procedure used is a matter of the user's preference. The step-by-step procedure presented herein is the level of maintenance approach.

2. DETAILED STEP PROCEDURES

2.1 Input Specification (Step 1)

The specification of input data is required to initiate the evaluation process and also in determining values of each cost element. Since all cost elements will probably not be required, for any particular application of the DAFM model procedures, input data is specified at the time required in the evaluation scheme. In this manner, the requirement for generating superfluous input data will be minimized.

SN 2.1(1) lists the basic input data required to initiate the evaluation procedure.

SUB-NOTE 2.1(1) (Sheet 1 of 2 sheets)
Systems Related Constants

1. Number of subject operating equipments per site $\left(\frac{E}{V}\right)$ ________
2. Anticipated equipment operational life (L) ________
3. Operational unreadiness (Q) ________
4. Mean time to repair (MTTR) ________
5. Mean time between failure (MTBF) ________
6. DISTANCES BETWEEN MAINTENANCE FACILITIES

	SITE (1)	SITE (2)	•	SITE (K)	DEPOT (1)	DEPOT (2)	•	DEPOT (L)	FACTORY (1)	FACTORY (2)	•	FACTORY (M)	PMEL (1)	PMEL (2)	•	PMEL (N)
SITE (1)																
SITE (2)																
•																
SITE (K)																
DEPOT (1)																
DEPOT (2)																
•																
DEPOT (L)																
FACTORY (1)																
FACTORY (2)																
•																
FACTORY (M)																

SUB-NOTE 2.1(1) (Sheet 2 of 2 sheets) Systems Related Constants

	SITE (1)	SITE (2)	•	SITE (K)	DEPOT (1)	DEPOT (2)	•	DEPOT (L)	FACTORY (1)	FACTORY (2)	•	FACTORY (M)	PMEL (1)	PMEL (2)	•	PMEL (N)
PMEL (1)																
PMEL (2)																
•																
PMEL (N)																

where:

1. Number of Operating Equipment $\left(\frac{E}{V}\right)$ - specify the number of subject operating equipment that is being evaluated at each site/location that corresponds to an organizational unit.

2. Equipment Life (L) - the expected length of time that the equipment will be operational.

3. Operational Unreadiness (Q) - the allowable fraction of time that the equipment is down due to waiting for a spare.

4. Mean time to repair (MTTR) - total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time. This time begins with localization of the failure and terminates with repair verification.

5. Mean time between failures (MTBF) - for a particular interval, the total functioning life of a population of an item, divided by the total number of failures within the population during the measurement interval.

6. Specify the general location of each maintenance echelon and the distances between the various maintenance echelons.

2.2 Input Data (Step 2)

The design configuration specific input data must be defined. SN 2.2(1) has been designed for this purpose:

SUB-NOTE 2.2(1) Model Constants by Configuration

1	2	3	4	5	6
Line Item Identification No./Name	Assembly Family No./Name	Failure rate λ_h	Number of item i in equipment N_h	Unit cost per item c_h	Item Repair Rate μ_h
Module No.		λ_m	N_m	c_m	μ_m
Part No.		λ_p	N_p	c_p	

1. Column 1: Line item identification number or name.
2. Column 2: Assembly family number or name - denotes the higher assembly of which the item is a constituent.
3. Column 3: Predicted failure or usage rate of item (λ).
4. Column 4: Aggregate number of the particular item in the equipments under consideration per site (N).
   a. Column 5: Unit cost per item - procurement cost (e).
   b. Column 6: Predicted repair rate of item (μ) - the reciprocal of the estimated time to repair.

2.3 Simplification of Parameters (Step 3)

a. Grouping

In order to simplify the DAFM mathematical model for manual computation, system components (i.e., piece parts, modules, higher assemblies) are broken down into subgroups which reflect certain identifiable characteristics, the differences of which are insignificant with respect to the DAFM model decision process. In the case of equipments which are made up of subassemblies of similar components (e.g., blocks of power circuitry, logic, or analog circuitry), the natural grouping is readily apparent. Where higher assemblies are made up of nonhomogeneous elements, the breakdown must be by characteristics related to the highest identifiable module, the components of which are homogeneous in character and significant with respect to the DAFM model.

Gross level groupings should be by the following order:

- Assembly level - module, higher assembly, etc.
- Significant differences in repairability due to complexity and package design; i.e., planar, volumetric, sealed, etc.
- Grouping by special maintenance skill and test equipment requirements; i.e., RF, analog, digital logic, fluids, etc.

Subgroupings should then be developed in terms of item acquisition cost, failure rate, cost failure rate, or other appropriate criteria; in other words, a tree-type breakdown should be applied. For example, one breakdown might be by function (digital, analog, etc.), failure rate, repair time, and cost, in that order.

For each new grouping, the input values specified in SN 2.2(1) must be modified to reflect the changes made. The average input values are obtained by the following simple equations:

$$(1)\quad N = \sum_{i}^{G} N_i$$

where

N = number of items in the new group

N_i = number of item type i in the equipment

G = number of types grouped together

$$(2)\quad \lambda = \frac{\sum_{i}^{G} N_i \lambda_i}{\sum_{i}^{G} N_i}$$

where

λ_i = failure rate of item type i.

λ = average failure rate of the new group.

$$(3)\quad c = \frac{\sum_{i}^{G} N_i c_i}{\sum_{i}^{G} N_i}$$

where

c_i = Unit cost of item type i

c = Average cost of new group

b. Elimination of Insensitive Cost Elements

Consider an application in which the design configuration (higher modular assemblies, modules, etc.) is already specified and the contractor would like to determine the optimum maintenance and logistics support posture. Since the design is fixed, there will be no cost differences in the following cost elements:

- All design costs except special test equipment costs
- PMEL costs - PMEL requirements will not change
- Cost of consumables will remain constant

c. Elimination of Unfeasible Support Alternatives

Suppose there is an extremely short requirement for mean time to restore and a requirement for base self-sufficiency. The short mean time to restore will probably make the maintenance action of on-line part repair of higher module assemblies unfeasible. The base self-sufficiency requirement will probably eliminate factory and depot level maintenance.

2.4 Operation and Support Cost Calculations (Step 4)

To determine the least cost support posture for a given configuration, four major cost factors must be considered: acquisition costs, cost of consumables, organization and field personnel costs, and the costs associated with the best maintenance/logistics (M/L) policy (see DN 9C1, SN 2(2) for the practical M/L alternatives). Each of these factors may be considered and treated as independent of one another. Except for M/L costs, the computational mechanics are relatively straightforward with minimal trade-off considerations to be made.

a. Maintenance/Logistics Cost

SN 2.4(1) has been designed to aid in the selection of the optimum logistics and maintenance policies for each item type by relating the various cost elements in tabular form. Inputs from the following substeps are used to complete the table.

(1) Enter item indicator at top of SN 2.4(1). (Item indicator is part (p), module (m), or higher assembly (h) and nomenclature or part number identification.)

(2) Determine cost of sparing (Row 1-11, and 14 of SN 2.4).

Step a - Initialize SN 2.4(1) by entering N_i and λ_i into rows 1 and 2, respectively, for each column.

Step b - For each column, multiply row 1 by row 2 and enter resulting product into row 3.

Step c - Compute: $t_{max} = Q/N_i \lambda_i$

where:

$$Q = \text{unreadiness} = \frac{\text{allowable downtime}}{\text{total uptime}}$$

(1) If t_{max} is greater then the one-way transportation time from the depot to the site, then spares need not be carried at the site and only sparing at the depot should be considered; i.e., ignore the "Site" and "Site/Depot" sections of SN 2.4(1) and compile only the "Depot" section.

(2) If t_{max} is less than the one-way transportation time from the depot to the site, then some sparing is required at the site and sparing at the depot only is unfeasible; i.e., ignore "Depot" section of SN 2.4(1) and compile the "Site" and "Site/Depot" sections.

Step d - For "Depot" and the depot side of "Site/Depot", multiply row 3 by the number of sites (V) for each column and enter into row 4.

Step e - Enter Z_i and W_i into rows 5 and 6, respectively.

Step f - For discard maintenance only, determine the cost of item consumed by computing $L \cdot V \cdot N_i \lambda_i c_i$ and enter into row 7.

Step g - For "Depot" and depot side of "Site/Depot" sparing compute $V \cdot L \cdot N_i \lambda_i c_i Z_i$ and enter in row 8. Compute $V \cdot L \cdot N_i \lambda_i c_i (1-Z_i) W_i$ and enter in row 10.

Step h - For "Site" and the site side of "Site/Depot" sparing, compute $V \cdot L \cdot N_i \lambda_i c_i Z_i$ and enter into row 9. Compute $V \cdot L \cdot N_i \lambda_i c_i (1-Z_i) W_i$ and enter into row 11.

SUB-NOTE 2.4(1) Repair/Discard Logistics Cost

Row	Item													
	Sparing Location	Site (Organization/Field)					Depot				Site/Depot			
	Disposition	Discard	Site Repair	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair
1	N_i													
2	λ_i													
3	$N_i \lambda_i$													
4	$V \cdot N_i \lambda_i$										S D	S D	S D	S D
5	Z_i													
6	W_i													
7	$V \cdot L \cdot N_i \lambda_i c_i$													
8	$V \cdot L \cdot N_i \lambda_i c_i Z_i$													
9	$V \cdot L \cdot N_i \lambda_i c_i Z_i$													
10	$V \cdot L \cdot N_i \lambda_i c_i (1-Z_i) W_i$													
11	$V \cdot L\ N_i \lambda_i c_i (1-Z_i) W_i$													
12	$C_{i\theta m}$													
13	$C_{i\theta t}$													
14	$L \cdot V \cdot N_i \lambda_i \overline{N}_p \overline{c}_p$													
15	C_{ie}													
16	Total C_z													
17	Min Total C_z													

Input Definitions

N_i = Total number of type i items (piece parts, modules, or higher assemblies) in the subject equipment per site

λ_i = Mean failure rate of type i item

L = Anticipated operational life of the equipment

V = Number of sites acquiring the equipment

$C_{i\theta m}$ = Personnel costs for type i item at maintenance echelon θ

$C_{i\theta t}$ = Cost of a round trip for type i item between the site and maintenance echelon θ

C_{ie} = Cost of unique test equipment wholly chargeable to repair of item i

$\overline{N}_p$ = Average number items (parts, modules, etc.) replaced per repair of the i type item

c_i = Cost of the i type item

$\overline{c}_p$ = Average cost of replaced item (parts, modulns, etc.) used in repairing the i type item

Z_i = 1 for discard of item i at failure; 0 for repair of item i at failure

W_i = Condemnation rate of item i expressed as percent

Step i - For repair maintenance only (site, depot, factory, PMEL), determine the cost of parts used in repairing the item by computing $L \cdot V \cdot N_i \cdot \lambda_i \bar{N}_i \bar{c}_i$ and enter into appropriate column of row 14.

(3) Determine cost of consumable.

<u>Input Definitions</u>

$C_{\theta fu}$ = cost of utilities (power) per year

$C_{\theta fm}$ = cost of materials for maintenance of facilities and operating equipment per year

$C_{\theta ft}$ = cost of materials for maintenance of test equipment per year

L = anticipated operational life of the equipment

V = number of sites

8766 = number of hours per year

θ = maintenance echelon (organization, field, etc.)

Normally, these are negligible and can be neglected, or, often, they will cancel out when differential costs are considered. Where they are needed, estimates should be made using the best available information.

Step a - C_{fu}, estimate total power for equipment, air conditioning, etc. Where power is generated on site, use delivered cost of fuel per watt. Otherwise, use KWH rates for commercial sources.

Step b - C_{fm}, estimate cost of material used in maintaining the facilities.

Step c - C_{ft}, treat same as operating equipment and determine cost in conjunction with the operating equipment where there are common parts.

Step d - Compute: $\left(C_{\theta fu} + C_{\theta fm} + C_{\theta ft}\right)$ L/8766 and enter total into the summary (SN 2.9(1)) under the proper maintenance echelon θ.

(4) Determine cost of transportation.

Transportation costs between field and organization for repairable items are negligible, as it is generally assumed that field and organization are at the same site. Therefore only round trip transportation costs from the site (organization/field) to depot, factory, and PMEL need be evaluated.

Input Definitions

N_i = total number of type i items (repairable modules or higher assemblies) in the considered equipment per site

λ_i = mean failure rate of type i item

$\bar{c}_{\theta t}$ = mean cost of a round trip between the site and maintenance echelon θ

L = anticipated operational life of the equipment

V = number of sites to acquire the equipment

Step a - Initialize SN 2.4(2) by making the N_i, λ_i, and $\bar{c}_{\theta t}$ entries for each item type i (where i = 1,...,n) under each feasible repair maintenance echelon θ.

SUB-NOTE 2.4(2) Cost of Transportation

Item	1			2			N		
Repair Facility	Depot	Factory	PMEL	Depot	Factory	PMEL	Depot	Factory	PMEL
N_i									
λ_i									
$\bar{c}_{\theta t}$									
$L \cdot V \cdot N_i \cdot \lambda_i \cdot \bar{c}_{\theta t}$									

Step b - Compute and enter $L \cdot V \cdot N_i \cdot \lambda_i \cdot \bar{c}_{\theta t}$ for each maintenance echelon under each item type i.

Step c - Transfer the results of step b to SN 2.4(1), row 13 ($C_{i\theta t}$). The entries should be made under the appropriate column headings: Depot Repair, Factory Repair, and PMEL Repair for all sparing location alternatives - Site, Depot, and Site/Depot.

(5) Determine personnel costs.

Two sets of procedures for obtaining personnel costs are required: one descriptive of the standby/work situation prevalent at the site and the other characterizing the constant workload environment typical of depot, factory, and PMEL.

The only personnel trade-offs between the site and the remote facilities (depot, factory, and PMEL) that may be conducted involve those personnel assigned to the repair of the Line-Replaceable Units (LRU's).

Under the constant workload environment, personnel requirements may be directly related to a given repair transaction; i.e., personnel charges may be related to actual repair time spent on a given item. However, the standby/work situation requires the presence of personnel, at all times, whether repair work is immediately available or not. Thus, the cost of personnel at the site cannot be directly related to a specific service demand.

The approach taken in these procedures to resolve this problem is to initially assume a constant workload condition at the site and determine an average labor rate in the manner that would be done for the remote facilities. Using this labor rate, trade-offs between repair facilities may be made and an initial selection made for each item group. Following consideration of all item groups, the item groups are categorized by their respective maintenance skills. An estimate of the total man-hours necessary for the initially designated site repaired item groups and the number of men required at the site may be made. If one or more men appear justified, the personnel charges are converted to integer manning values and treated along with the other maintenance and operations personnel requirements. When less than one man is required a new (higher) labor rate is determined, and the entire process is repeated until it is shown that it is less costly to site repair no items or that a man under a partial workload is justified.

<u>Repair Facility Personnel Cost Input Definitions</u>

N_i = total number of type i items (modules or higher assemblies) in the considered equipment per site

λ_i = mean failure rate of type i item

μ_i = mean repair rate of type i item

$\bar{c}_{\theta m}$ = mean labor rate (direct and indirect costs) at maintenance echelon θ - site (S), depot (d), factory (y), PMEL (p)

L = anticipated operational life of the equipment

V = number of sites to acquire the equipment

C_i = line item cost

$C_{i\theta m}$ = personnel costs for type i item at maintenance echelon θ

Step a - For each item type i (where i = 1,...,n), enter N_i, λ_i, μ_i, and $\bar{c}_{\theta m}$ under each feasible repair maintenance - rows 1, 2, 3, and 4 of SN 2.4(3), respectively.

Step b - Compute $L \cdot V \cdot N_i \lambda_i \cdot \bar{c}_{\theta m}/\mu_i$ and enter into row 5 for each item type i.

Step c - Compute and enter (row 6) for depot only, the depot line item costs for each item type i.

The cost of line item (C_{dl}) can be represented by

$$C_{dl} = \left(N_{RL} L \cdot R/8766\right) + N_R D$$

where

R = cost, per unit time, of maintaining a stock item in the master repair system (MRS)

N_{RL} = number of different types of modules and higher assemblies repaired by depot

SUB-NOTE 2.4(3) Personnel and Line Item Costs for Repair Actions at Site/Depot/Factory/PMEL

	Item No.	1				2				n			
Row	Repair Facility	Site	Depot	Factory	PMEL	Site	Depot	Factory	PMEL	Site	Depot	Factory	PMEL
1	N_i												
2	λ_i												
3	μ_i												
4	$\bar{C}_{0m}$												
5	$L \cdot V \cdot N_i \lambda_i \cdot \bar{C}_{0m} / \mu_i$												
6	C_{d1}	X		X	X	X		X	X	X		X	X
7	Total (C_{i0m})												

L - anticipated life of subject equipment (hr)

N_R = total number of maintenance actions at depot during equipment life

D = debit and credit costs associated with inventory, accountability, and storage for items repaired at the depot.

The total number of maintenance actions (N_R) at depot during equipment life may be obtained as follows:

$$N_R = L \cdot V \left(\sum_n N_n \lambda_n + \sum_h N_h \lambda_h \right)$$

Step d - (1) For depot, add the results of steps b and c and enter into total ($C_{i\theta m}$) for each item type i.

(2) For site, factory, and PMEL, enter results of step c directly into total ($C_{i\theta m}$) for each item type i.

Step e - Enter each total ($C_{i\theta m}$) in row 12 of SN 2.4(1). The entries should be made under the appropriate column headings: Site Repair, Depot Repair, Factory Repair, and PMEL Repair for all sparing locations - site, depot, and site/depot.

(6) Determine cost of special test equipment.

Step a - Enter the cost of special test equipment (C_e) in row 15 of SN 2.4(1) which can be uniquely identified with this group for the sole purpose of repairing items within this group and which the repairing echelon must specifically procure for this purpose.

(7) Determine total logistic costs.

Step a - In reference to SN 2.4(1), for each column, sum rows 8 through 15, and enter the sum into totals (C_z), row 16. For site/depot, the divided blocks of rows 7 and 11 should be treated as a single block when summing each column; i.e., under a given column, the right side of the block in rows 8 and 10, the left side of the block in rows 9 and 11, and rows 12 through 15 are to be summed and entered into row 16.

(8) Determine minimum logistics cost per item.

Step a - Select the minimum C_z for item i and enter into row 17 - Min. Total (C_z min).

Step b - Go to next item and compile new SN 2.4(1) by repeating (1) through (8).

2.5 Determine Overall Minimum Logistics Cost (Step 5)

Step a - When all items for a given configuration have been evaluated and their respective $C_{z_{min}}$ selected, identify the items that are to be site repaired. For each site repaired item's SN 2.4(1) (treating the site repair column only), subtract row 7 from row 17 and enter the difference back into row 17.

Step b - Sum all $C_{z_{min}}$ for the given configuration and enter the sum into SN 2.9(1) under Maintenance/Logistics.

2.6 Determine Organization and Field Personnel Costs (Step 6)

Input Definitions

G_{ij} = number of men with skill level i in an operation and maintenance unit j (To obtain the values of G_{ij} requires a manpower analysis effort covering operations and maintenance personnel requirements.)

X_{ij} = average expense per unit time incurred by the government as a result of the manning with skill i in unit j

F = the administrative and service costs per unit time for an operating and maintenance unit of size $\sum_j \sum_i G_{ij}$

L = anticipated operational life of the equipment

Step a - In reference to SN 2.6(1), enter manning requirements G_{ij}, in row 1 in each column corresponding to a specific task demanding a particular skill level i - n possible skills, where n is the maximum number of skills for all m units.

SUB-NOTE 2.6(1) Cost of Personnel - Tabular Evaluation Form

Unit No.	Input Name	Skill i = / Row No. \ Col No.	1	2	3	4	...	n-1	n	$\sum_i G_{ij} \cdot X_{ij} + F$
			1	2	3	4		n-1	n	n+1
1	G_{i1}	1								
	X_{i1}	2								
	$G_{i1}X_{i1}$	3								
2	G_{i2}	1								
	X_{i2}	2								
	$G_{i2} \cdot X_{i2}$	3								
⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮
j	G_{ij}	1								
	X_{ij}	2								
	$G_{ij} \cdot X_{ij}$	3								
⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮
m	G_{im}	1								
	X_{im}	2								
	$G_{im} \cdot X_{im}$	3								

F	
Sum = $\sum_i \sum_j G_{ij} \cdot X_{ij} + F$	
Sum • V·L	
Total	

Step b - Enter the cost of manning X_{ij}, one unit at skill level i in row 2, in columns corresponding to each particular skill level.

Step c - Enter administrative and service cost, F, into column.

Step d - For each column, 1 through n, multiply rows 1 and 2 and enter the product in row 3.

Step e - Sum all elements of row 3 and enter result in column n + 1, row 3.

Step f - If there is a remaining operating and maintenance unit to be considered, return to step 1 and begin row 1 on next row; otherwise, continue to step g.

Step g - Sum all elements of column n + 1 and multiply by V•L. Enter result in total as designated.

Step h - Enter total in summary SN 2.9(1) in first row of block corresponding to applicable maintenance level; i.e., organization or field.

2.7 Determine Repair Facility Personnel Costs at Site (Step 7)

Input Definitions

N_i = total number of type i items (modules or higher assemblies) in the considered equipment at the site to be site repaired.

λ_i = mean failure rate of type i item

μ_i = mean repair rate of type i item

Step a - For all items to be site repaired, group their respective repair/discard logistic cost tables (SN 2.4(1)) by repairman skill.

Step b - List each item, for a given skill level, in SN 2.7(1).

SUB-NOTE 2.7(1) Site Manning for Repair Services

Skill Level				
i	N_i	λ_i	μ_i	$L \cdot V \cdot N_i \lambda_i / \mu_i$
1				
2				
3				
.				
.				
.				
.				
.				
.				
.				
.				
.				
i				
.				
.				
.				
.				
n				
			Sum	

Step c - Enter for each item N_i, λ_i, and μ_i.

Step d - Compute and enter $L \cdot V \cdot N_i \lambda_i / \mu_i$.

Step e - Sum the results of step d and enter into Sum.

2.8 Determine Acquisition Costs (Step 8)

Step a - Compute the acquisition cost of design (C_D), fabrication (C_F), installation (C_I), manuals (C_m), test equipment ($C_{T_o} + C_{T_f}$), tools and test fixtures ($C_{Xo} + C_{Xf} + C_{Xd}$), line item entry (C_L) + facilities (C_B), base stock or initial spares (C_S), and pipeline spares (C_P).

Categorically, the acquisition costs are predeployment costs, while the support costs are those attributed to the post-deployment phase. The acquisition cost factors considered in developing the detailed cost as associated with the following equation are as follows:

$$A = C_D + C_F + C_I + C_M + C_T + C_X + C_L + C_B + C_S + C_P$$

The development (D) costs include the basic design, test, and demonstration of the equipment.

The fabrication (F) costs include the costs associated with the build, test, and inspection of the equipment.

The installation (I) costs include the costs for emplacement, hookup, and checkout of equipment at the facility or site location.

The manual (M) costs include the costs of operator and maintenance manuals prepared for each level of maintenance. Pertinent factors in relation to this item are page count, format type, type of product (draft, final, etc.), number of manual types, and other charges associated with their preparation (travel, material, validation, verification, etc.).

The test equipment (T) costs include the costs for development and/or acquisition of special test equipment at organizational and field levels to maintain the item in an operational status. Do not include test equipment considered in step 4a(6).

Tools and fixtures (X) costs include the costs for development and/or acquisition of the tools and fixtures identified to maintain the item in an operational status. Detailed maintenance analysis of the item and review of existing inventory will facilitate reduction of this item cost.

The line item (L) documentation costs include the costs for establishing the supply control function for the item and entering the item in the federal catalog.

The facility (B) costs include all buildings, land, shelters, runways, hangars, storage areas, etc., and all utilities providing power, water, sewerage, air conditioning, heating, etc. These costs include the "real property" (additional land acquisition, new construction, renovation, modernization, expansion, and/or modification requirements) and "other facilities" (government furnished equipment, commercially available items, and other development items).

The base stock level or initial spares (S) costs include the costs for spares for organizational, field, or depot procured for the item in sufficient quantity to fill the storage levels for the designated supply time for each of the supply points. Replenishment costs are associated with the support (S) costs and based on failures of the item. Information related to the item are supply period allocations, number of locations, quantity of equipment, failure rate of item, maintenance concept, etc.

The pipeline spare (P) costs are the initial spares costs associated with filling the pipeline to ensure availability of spares due to repair time attributed to the turnaround time at the repair facility. The detailed formula for the calculation is:

$$C_P = \Sigma c_i \left(\mu_i + K \sqrt{\mu_i} \right)$$

where

C_i = cost of item

μ_i = average number of failures of module or higher assembly during turnaround time period

K = probability that item i will be available when needed; value is obtained from the list below or is determined, using an interpolation process.

Protection Level (%)	Coefficient K
75	0.67
85	1.04
95	1.65
99	2.33

where $\mu_i = \lambda_i \, T_{T_i} \cdot N_i \, V$

λ_i = failure or usage rate of item i

T_{T_i} = turnaround time in hours

N_i = number of items i in equipment per site

V = number of sites

Step b - Enter computed cost in SN 2.9(1)

2.9 Determine Total Cost of Configuration (Step 9)

To determine the least cost support posture for a given configuration, two major cost factors are considered: acquisition and support. SN 2.9(1) is used to summarize and compare total costs for the system. Summarization of the acquisition cost A( ) and operation and support cost S( ) is entered into the total cost row and selection made on a cost effectiveness basis.

SUB-NOTE 2.9(1) Cost Decision Elements

Cost Element (C)	Subscript	Refer to Step No.	Refer to SN No.	Configuration A( )	A( )	A( )	A( )
Design	D	8					
Fabrication	F	↑					
Installation	I						
Manuals	M						
Test Equipment	T						
Organization	T_o						
Field	T_f						
Tools and Fixtures	X						
Organization	X_o						
Field	X_f						
Depot	X_d						
Line Item Documentation	L						
Facilities	B						
Spares							
Base Stock/Initial	S	↓					
Pipeline	P	8					
				S( )	S( )	S( )	S( )
Organization	o						
Personnel Op	om	6	SN 2.6(1)				
Maint		7	SN 2.7(1)				
Consumables	of						
Field	f						
Personnel	fm	6	SN 2.6(1)				
Consumables	ff	4a (3)					
Maintenance/Logistics*	z_{min}	4a(2), 4a(4), 4a(5), 4a(6), 5	SN 2.4(1)				
Total Cost				T( )	T( )	T( )	T( )

*M/L includes the cost factors for spares, transportation, repair facility personnel plus line item entry, and special test equipment.

SECTION 9D

THE MULTIPLEXER SET DAFM ANALYSIS EXAMPLE

This section contains an example of the use of the procedures described in Section 9C to analize the DAFM of the Multiplexer Set.

SECTION 9D — THE MULTIPLEXER SET DAFM ANALYSIS EXAMPLE

DESIGN NOTE 9D1 - MULTIPLEXER SET DAFM ANALYSIS

DESIGN NOTE 9D1 **MULTIPLEXER SET DAFM ANALYSIS**

1. GENERAL

In DN 7D1, a trade-off was conducted to determine the breakeven point, in terms of deployment quantities of multiplex sets, for depot repair versus DAF of all types of cards and modules.

In this example of conducting a trade-off, by the systematic model, the deployment quantities are known and the data desired from the use of the model is what the net savings will be, using updated data, for the most cost effective decision.

It is worthwhile to mention that the use of the model as a tool for conducting a trade-off precludes omission of potentially sensitive parameters because the omitted ones are excluded by exception from the total. Furthermore, once a decision is made, all the values for the candidate selected could be inserted into the model to determine an absolute value of life cycle cost for that candidate.

2. DAFM PROCEDURE

2.1 Input Specification (Step 1)

The general data related to the Multiplexer Set and required to initiate the evaluation procedure is identified as follows:

- Number of sites (V) - 25
- Number of Multiplexer Sets per site - 4
- Anticipated equipment operational life (L) - 10 years
- Operational unreadiness (Q) - 0.0083
- Mean time to repair card at depot - 1.3 hours
- Mean time between failure (MTBF) - 3,300 hours
- Number of cards per set - 126
- Average distance between sites and depot - 2,500 miles
- Cost per card (See SN 2.2(1).)
- Failure per card (See SN 2.2(1).)

[illegible] Design Configuration

Line Item Identification Name	Assembly Family Name	Failure Rate λ_h	Number of Items in Equipment N_h	Cost per Item (Dollars)	Item Repair Rate μ_h	Classification of Printed Circuit Cards	[illegible] M	[illegible] D	[illegible] A	[illegible] L	[illegible] Cost M	[illegible] Cost E	[illegible] Cost A	[illegible] Cost L
Line driver module	Multiplexer	[illegible]	1	225	0.33	M	1.100				[illegible]			
Line receiver module		1.178	20	280		M	17.560				5600			
Rate comparison buffer		[illegible]	20	430		E		43.[illegible]				[illegible]		
Source-transmission rate converter		2.022	1	47[illegible]		D		8.466				1425		
Transition encoder		[illegible]	1	520		D		3.6[illegible]				[illegible]		
Main reference timer		[illegible].454	1	60[illegible]		A			[illegible].454				[illegible]00	
Port sequencer		[illegible]	1	475		E		[illegible]				475		
Input output module sequencer		[illegible]	1	445		E		[illegible].743				445		
Speed clocks		2.[illegible]	1	44[illegible]		D		2.013				44[illegible]		
Input output module sequencer diagnostics		1.76[illegible]	1	44		D		1.763				44[illegible]		
Overhead enable generator		[illegible]	1	4[illegible]		D		0.713				400		
Overhead data generator		[illegible]		[illegible]		D		3.51[illegible]				[illegible]20		
Main [illegible] function generator		[illegible]		52[illegible]		E		3.5[illegible]				520		
Main channel error readout		[illegible]		51		D		3.[illegible]				510		
Data multiplexer		[illegible]	1	510		E		3.373				510		
Main remote alarms		[illegible].54	1	350		A			1.54[illegible]				350	
Main lamp driver card		[illegible].713	[illegible]	40[illegible]		D		1.426				800		
Strapping switches		[illegible].14[illegible]	1	4[illegible]		F				3.14[illegible]				4[illegible]
Power supply monitor	Multiplexer	[illegible]	1	7[illegible]		A			[illegible].135				700	
Line driver module	Demultiplexer	1.156	2[illegible]	250		M	[illegible].120				5000			
Line receiver module		[illegible].170	1	305		M	2.170				305			
Smoothing buffer, low-speed		[illegible].726	17	520		D		63.34[illegible]				[illegible]040		
Smoothing buffer, high-speed		3.4[illegible]1	[illegible]	475		E		10.2[illegible]3				1425		
Transmission-source rate converter, high-speed		3.921	1	550		D		3.921				550		
Transmission-source rate converter, low-speed		3.6[illegible]	2	475		E		7.372				[illegible]50		
Transition decoder		[illegible].586	1	51		[illegible]		3.58[illegible]				51[illegible]		
Alarm lamp driver		[illegible].783	1	400		D		0.783				4[illegible]		
Port sequencer		3.373	1	505		E		3.373				505		
Variable length shift register		[illegible]	[illegible]	475		D		5.766				950		
Input output module sequencer		[illegible].743	1	475		E		2.743				475		
Minor frame sync.		3.583	1	510		E		3.583				51[illegible]		
Speed clocks		[illegible].013	1	44		D		2.013				44[illegible]		
Input output mode sequencer diagnostics		1.763	1	465		E		1.763				465		
Channel error readout		[illegible]	1	44		E		2.65[illegible]				44[illegible]		
[illegible] frame generator		3.105	1	55		D		3.105				550		
[illegible] decoder														
[illegible] and overhead [illegible] generator		[illegible].233	1	485		E		[illegible].233				485		
[illegible] time generator		3.825	1	[illegible]		E		[illegible].825				550		
Remote alarms		[illegible].536	1	400		A			2.536				400	
[illegible] resizer		2.[illegible]**	1	500		A			2.000				500	
[illegible] distribution		2.[illegible]**	1	400		F				2.[illegible]				400
[illegible] carrier		2.[illegible]**	1	750		A			2.000				750	
Timing generator No. 1		4.[illegible]31	1	550		D		4.031				550		
Timing generator No. 2		2.941	1	475		D		2.941				475		
Timing distribution matrix		3.100	1	420		F				3.100				420
Strapping switches		3.348	1	430		L				3.348				430
Power supply monitor	Demultiplexer	6.135	1	550	0.33	A			6.135				550	
	Σ		126				54.038	211.157	25.0	11.79[illegible]	$11,130	$34,675	$3850	$1700

* [illegible] 10^6 hours
** [illegible] estimate

2.2 Input Data (Step 2)

The design configuration specific input data is defined as shown in SN 2.2(1). The detailed substeps of this procedure permit the completion of columns 1 through 6.

2.3 Simplification of Parameters (Step 3)

a. Grouping

In order to simplify the DAFM model for manual computation, the system printed circuit cards were classified into the following groupings:

- Digital (D)
- Electromechanical (E)
- Analog (A)
- Module (M)

The numbers of items in each group were 73, 4, 7, and 42 for groupings D, E, A, and M, respectively.

These items are identified in column 7 of SN 2.2(1). In order to obtain an average failure rate of the grouping, the entries in column 3 are multiplied by the entries in column 4 and entered in column 8 for M, D, A, E groupings, respectively. The average failure rate is as follows:

$$\lambda_{i\,(avg)} = \frac{\sum_i \text{column 8}}{\sum_i \text{column 4}}$$

where i = grouping (M, D, A, E)

λ_i for modules, digital, analog, and electromechanical is the following:

$$\lambda_M = \frac{54.038}{42} = 1.287$$

$$\lambda_D = \frac{211.157}{73} = 2.893$$

$$\lambda_A = \frac{25.800}{7} = 3.686$$

$$\lambda_E = \frac{11.796}{4} = 2.949$$

In order to identify the average cost per printed circuit card for each of the groupings, the entries in column 4 are multiplied by the entries in column 5 and entered in column 9 for M, D, A, E grouping, respectively. The average (avg) cost is calculated as follows:

$$c_{i(avg)} = \frac{\sum_i \text{column } 9_i}{\sum_i \text{column } 4_i}$$

where i = grouping (M, D, A, E)

$$c_M = \frac{11130}{42} = \$265$$

$$c_D = \frac{34675}{73} = \$475$$

$$c_A = \frac{3850}{7} = \$550$$

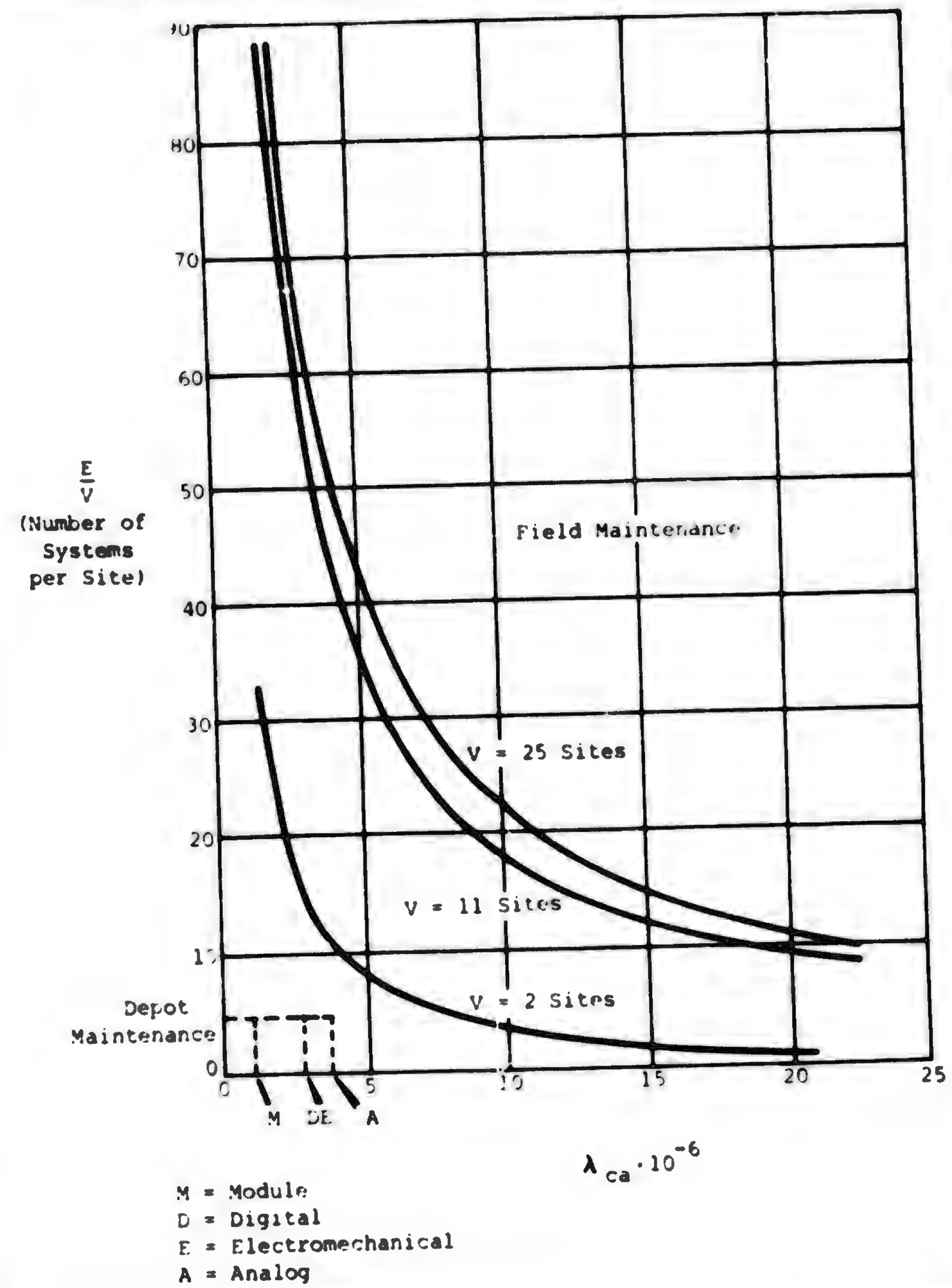
$$c_E = \frac{1700}{4} = \$425$$

b. Elimination of Insensitive Cost Elements

The design of the printed circuit cards for the Multiplexer Set is specified. Based upon previous trade study information (see Chapter 7) and the results as delineated in SN 2.3 (1), it is determined that based on the average failure rate and the number of systems (Multiplexer Sets per site), depot maintenance is selected. This is shown in the shaded portion (lower left-hand corner) of SN 2.3 (1). The breakeven curves are shown in SN 2.3 (1) for V = 2 sites, V = 11 sites, and V = 25 sites. Based on this, the following can be eliminated.

- Design costs
- PMEL costs - No calibration required on the printed circuit cards.
- Factory costs - Same for all, whether DAFM or repair. Facilities at factory are for manufacturing process, test, checkout, etc.
- Line item cost for cards - Only the cost of the repair components need be considered. In reference to Section 7D, Paragraph 34, this is estimated at $25.

SUB-NOTE 2.3(1) Field versus Depot Repair



c. Elimination of Unfeasible Support Alternatives

The high reliability of the system, the repair of the system by printed circuit card replacement, and the positive detection and isolation of card failure eliminated the requirement for base self-sufficiency as related to total repair of failure which includes repair of cards. In keeping with the Air Force philosophy of intermediate or depot repair, the trade study in Chapter 7 considered both these levels. Top level analysis dictated depot level maintenance.

2.4 Operation and Support Cost Calculations (Step 4)

a. Maintenance/Logistics Costs

The maintenance/logistics costs are calculated with the use of SN 2.4 (1).

(1) Enter Item Indicator

The items considered in this study are the printed circuit cards, herein referred to as modules (digital (MD) module, electromechanical (ME) module, analog (MA) module, and module (MM)) as related to their grouping. Since the four groupings are being considered, separate sheets are completed for each grouping.

(2) Determine Cost of Sparing

Step a. The total number of type i items in the subject equipment per site and the average failure rate of the item are entered into rows 1 and 2. The numbers of cards per group per Multiplexer Set are 73, 4, 7, and 42 for MD, ME, MA, and MM, respectively. There are from step 1, four sets per site for a total of 292 MD's, 16 ME's, 28 MA's, and 168 MM's, respectively. The average failure rate for the groupings is obtained from step 3.

Step b. Row 1 is multiplied by row 2 and the resulting product entered in row 3. For calculation purposes, this product is rounded off to the next whole number.

SUB-NOTE 2.4(1) (Sheet 1 of 4 sheets) Repair/Discard Logistics Costs

Row	Item	Module (Digital)												
	Sparing Location	Site (Organisation/Field)					Depot				Site/Depot			
	Disposition	Discard	Site Repair	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair
1	N_i	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	292	292	N/A	N/A
2*	λ_i										2.893	2.893		
3*	$N_i\ \lambda_i$										845	845		
4*	$V \cdot N_i\ \lambda_i$	X	X	X	X	X					S: X / D: $1,100	S: X / D: $1,100	S: X / D:	S: X / D:
5	Z_i										1	0		
6	W_i	X					X				X	0.05		
7	$V \cdot L \cdot N_i \lambda_i c_i$		X	X	X	X		X	X	X	$879,613	X	X	X
8	$V \cdot L \cdot N_i \lambda_i c_i Z_i$	X	X	X	X	X					S: X / D: $879,613	S: X / D:	S: X / D:	S: X / D:
9	$V \cdot L \cdot N_i \lambda_i c_i Z_i$						X	X	X	X	S: $879,613 / D: X	S: / D: X	S: / D: X	S: / D: X
10	$V \cdot L \cdot N_i \lambda_i c_i\ (1-Z_i)\ W_i$	X	X	X	X	X	X				S: X / D: X	S: X / D: $43,981	S: X / D:	S: X / D:
11	$V \cdot L\ N_i \lambda_i c_i\ (1-Z_i)\ W_i$	X					X	X	X	X	S: X / D: X	S: $43,981 / D: X	S: / D: X	S: / D: X
12	C_{i0m}										——	$75,384		
13	C_{i0t}										——	$3851		
14	$L \cdot V \cdot N_i \lambda_i \bar{N}_p \bar{c}_p$	X					X				X	$41,666		
15	C_{ie}										——	$205,600		
16	Total C_s										$879,613	$370,482		
17	Min Total C_s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A	N/A

*Quantities in rows 2 through 4 are expressed in terms of 10^{-6}

SUB-NOTE 2.4(1) (Sheet 2 of 4 sheets) Repair/Discard Logistics Costs

Row	Item / Sparing Location / Disposition	Site (Organization/Field): Discard	Site (Organization/Field): Site Repair	Site (Organization/Field): Depot Repair	Site (Organization/Field): Factory Repair	Site (Organization/Field): PMEL Repair	Depot: Discard	Depot: Depot Repair	Depot: Factory Repair	Depot: PMEL Repair	Site/Depot: Discard	Site/Depot: Depot Repair	Site/Depot: Factory Repair	Site/Depot: PMEL Repair
	Module (Electromechanical)													
1	N_i	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	16	16	N/A	N/A
2*	λ_i										2.949	2.949		
3*	$N_i \lambda_i$										47	47		
4*	$V \cdot N_i \lambda_i$										S: — D: 1175	S: — D: 1175	S: — D:	S: — D:
5	Z_i										1	0		
6	W_i											0.05		
7	$V \cdot L \cdot N_i \lambda_i c_i$										$43,775			
8	$V \cdot L \cdot N_i \lambda_i c_i Z_i$										D: [illegible]	D: 0		
9	$V \cdot L \cdot N_i \lambda_i c_i Z_i$										S: [illegible]	S: 0		D: [illegible]
10	$V \cdot L \cdot N_i \lambda_i c_i\ (1-Z_i)\ W_i$											D: [illegible]		
11	$V \cdot L\ N_i \lambda_i c_i\ (1-Z_i)\ W_i$											S: [illegible]		
12	C_{i0m}										—	$6575		
13	C_{i0t}										—	$215		
14	$L \cdot V \cdot N_i \lambda_i \overline{N}_p \overline{c}_p$											$2318		
15	C_{ie}										—	$17,550		
16	Total C_s										$43,775	$28,847		
17	Min Total C_s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A	N/A

*Quantities in rows 2 through 4 are expressed in terms of 10^{-6}

SUB-NOTE 2.4(1) (Sheet 3 of 4 sheets) Repair/Discard Logistics Costs

Row	Item	Module (Analog)												
	Sparing Location	Site (Organization/Field)					Depot				Site/Depot			
	Disposition	Discard	Site Repair	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair
1	N_i	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	28	28	N/A	N/A
2*	λ_i										3.686	3.686		
3*	$N_i \lambda_i$										103	103		
4*	$V{\cdot}N_i \lambda_i$	X	X	X	X	X					S: X; D: 2575	S: X; D: 2575	S: X; D:	S: X; D:
5	Z_i										1	0		
6	W_i	X					X				X	0.05		
7	$V{\cdot}L{\cdot}N_i\lambda_i c_i$		X	X	X	X		X	X	X	$124,148	X	X	X
8	$V{\cdot}L{\cdot}N_i\lambda_i c_i Z_i$	X	X	X	X	X					S: X; D: [illegible]	S: X; D: 0	S: X; D:	S: X; D:
9	$V{\cdot}L{\cdot}N_i\lambda_i c_i Z_i$						X	X	X	X	S: [illegible]; D: X	S: 0; D: X	S: ; D: X	S: ; D: X
10	$V{\cdot}L{\cdot}N_i\lambda_i c_i\ (1-Z_i)\ W_i$	X	X	X	X	X					S: X; D: X	S: X; D: [illegible]	S: X; D:	S: X; D:
11	$V{\cdot}L\ N_i\lambda_i c_i\ (1-Z_i)\ W_i$	X					X	X	X	X	S: X; D: X	S: [illegible]; D: X	S: ; D: X	S: ; D: X
12	C_{i0m}										——	$12,555		
13	C_{i0t}										——	$470		
14	$L{\cdot}V{\cdot}N_i\lambda_i\overline{N}_p\overline{c}_p$	X					X				X	$5079		
15	C_{ie}										——	$17,550		
16	Total C_s										$124,148	$41,861		
17	Min Total C_s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A	N/A

*Quantities in rows 2 through 4 are expressed in terms of 10^{-6}

SUB-NOTE 2.4(1) (Sheet 4 of 4 sheets) Repair/Discard Logistics Costs

Row	Item	Module (Module)												
	Sparing Location	Site (Organisation/Field)					Depot				Site/Depot			
	Disposition	Discard	Site Repair	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair	Discard	Depot Repair	Factory Repair	PMEL Repair
1	N_i	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	168	168	N/A	N/A
2*	λ_i										1.287	1.287		
3*	$N_i\ \lambda_i$										216	216		
4*	$V \cdot N_i\ \lambda_i$										S: — D: 5400	S: — D: 5400	S: — D:	S: — D:
5	Z_i										1	0		
6	W_i											0.05		
7	$V \cdot L \cdot N_i \lambda_i c_i$										$125,441			
8	$V \cdot L \cdot N_i \lambda_i c_i Z_i$										S: — D: [illegible]	S: — D: 0		
9	$V.L.N_i \lambda_i c_i Z_i$										S: [illegible] D: —	S: 0 D: —		
10	$V \cdot L \cdot N_i \lambda_i c_i\ (1-Z_i)\ W_i$											S: — D: [illegible]		
11	$V \cdot L\ N_i \lambda_i c_i\ (1-Z_i)\ W_i$											S: [illegible] D: —		
12	C_{i0m}										—	$15,205		
13	C_{i0t}										—	$986		
14	$L \cdot V \cdot N_i \lambda_i \overline{N}_p \overline{c}_p$											$10,651		
15	C_{ie}										—	$10,000		
16	Total C_g										$125,441	$43,114		
17	Min Total C_g	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			N/A	N/A

*Quantities in rows 2 through 4 are expressed in terms of 10^{-6}

Step c. The operation of the Multiplexer Set is essentially continuous, with downtime being incurred only for corrective and preventive maintenance. The equipments are evenly divided between oversea and stateside locations. The allowable corrective and preventive maintenance downtime in a 24-hour period is 12 minutes. Calculating Q = unreadiness yields

$$Q = \frac{12}{24 \cdot 60} = \frac{12}{1440} = 0.0083$$

The average transportation time from depot to the site is 1 week (168 hours). Calculating t_{max} for MD, ME, MA, and MM, respectively, yields

$$t_{max} = Q/\lambda_i \; N_i$$

where $\lambda_i \; N_i$ is obtained from step 4 (2) b

$$t_{max\ MD} = \frac{0.0083}{845 \cdot 10^{-6}} = 9.82 \text{ hours}$$

$$t_{max\ ME} = \frac{0.0083}{47 \cdot 10^{-6}} = 176.59 \text{ hours}$$

$$t_{max\ MA} = \frac{0.0083}{103 \cdot 10^{-6}} = 80.58 \text{ hours}$$

$$t_{max\ MM} = \frac{0.0083}{216 \cdot 10^{-6}} = 38.42 \text{ hours}$$

Since t_{max} for each grouping is less than the one-way transportation time from the depot, which is assumed to be 1 week (168 hours), then sparing is required at the site and depot. Sparing at depot only is unfeasible, and thus the "Depot" section of SN 2.4 (1) can be ignored.

Step d. Multiply row 3 by the number of sites (V). The value of V is obtained from the input specification and is 25. Enter the product in row 4.

Step e. Enter Z_i, 1 for discard and 0 for repair, in row 5 and enter W_i in row 6. W_i, washout or condemnation rate of item i, was assumed to be 5 percent. This is washout of the item due to unrepairability.

Step f. For discard maintenance only, the cost of card discard is calculated based on total failures per life of equipment times the average cost per card. The calculation is as follows:

$$\text{Discard}_i = L \cdot V \cdot N_i \lambda_i \; c_i$$

$$\text{Discard}_{MD} = (10 \cdot 8766) \cdot 25 \cdot 292 (2.893 \cdot 10^{-6}) \; \$475 = \$879,613$$

$$\text{Discard}_{ME} = (10 \cdot 8766) \cdot 25 \cdot 16 (2.949 \cdot 10^{-6}) \; \$425 = \$43,775$$

$$\text{Discard}_{MA} = (10 \cdot 8766) \cdot 25 \cdot 28 (3.686 \cdot 10^{-6}) \; \$550 = \$124,148$$

$$\text{Discard}_{MM} = (10 \cdot 8766) \cdot 25 \cdot 168 (1.287 \cdot 10^{-6}) \; \$265 = \$125,441$$

c_i is derived from step 3. Enter these values in row 7.

Step g. For the "Depot" side of "Site/Depot", compute

$$V \cdot L \cdot N_i \lambda_i \; c_i \; Z_i$$

Values are the same as in step f and enter in row 8.

Compute the value of

$$V \cdot L \cdot N_i \lambda_i \; c_i \; (1 - Z_i) \; W_i$$

Values are entered in row 10.

$$MD = 25 \; (10 \cdot 8766) \cdot 292 \; (2.893 \cdot 10^{-6}) \; \$475 \; (1-0) \; (0.05) = \$43,981$$

$$ME = 25 \; (10 \cdot 8766) \cdot 16 \; (2.949 \cdot 10^{-6}) \; \$425 \; (1-0) \;)0.05) = \$2,189$$

$$MA = 25 \; (10 \cdot 8766) \cdot 28 \; (3.686 \cdot 10^{-6}) \; \$550 \; (1-0) \; (0.05) = \$6,207$$

$$MM = 25 \; (10 \cdot 8766) \cdot 168 \; (1.287 \cdot 10^{-6}) \; \$265 \; (1-0) \; (0.05) = \$6,272$$

Step h. For the site side of "Site/Depot" sparing, the values for $V \cdot L \cdot N_i \lambda_i \; c_i \; Z_i$ and $V \cdot L \cdot N_i \lambda_i \; c_i \; (1-Z_i) \; W_i$ are computed and entered in rows 9 and 11, respectively. These values are the same as those derived in step g.

Step i. For repair maintenance only, the cost of parts used in repairing the item is calculated by

$$L \cdot V \cdot N_i \lambda_i \; \overline{N}_i \; \overline{c}_i$$

where

$\overline{N}_i$ = average number of parts replaced for type i item failure; average number of parts is assumed to be three.

$\overline{c}_i$ = average cost of replacement parts for type i item failure; average cost is assumed to be \$7.50.

The value for each of the groupings is calculated and entered in the "Depot Repair" column of row 14.

$$MD = (8766 \cdot 10) \cdot 25 \cdot 292\ (2.893 \times 10^{-6}) \cdot 3 \cdot \$7.50 = \$41,666$$
$$ME = (8766 \cdot 10) \cdot 25 \cdot 16\ (2.949 \times 10^{-6}) \cdot 3 \cdot \$7.50 = \$2,318$$
$$MA = (8766 \cdot 10) \cdot 25 \cdot 28\ (3.686 \times 10^{-6}) \cdot 3 \cdot \$7.50 = \$5,079$$
$$MM = (8766 \cdot 10) \cdot 25 \cdot 168\ (1.287 \times 10^{-6}) \cdot 3 \cdot \$7.50 = \$10,651$$

(3) Determine Cost of Consumables

The cost of consumables at a depot facility for repair of the printed circuit cards is considered negligible. If calculated, they would be entered on the summary matrix under the proper maintenance echelon.

(4) Determine Transportation Cost

The transportation cost for the printed circuit cards from the site to depot repair facility is calculated based on the following formula:

$$\text{Avg transportation cost} = L \cdot V \cdot N_i \lambda_i \bar{c}_{\theta t}$$

where

$\bar{c}_{\theta t}$ = mean cost of round trip between site and the maintenance echelon, this cost was assumed to be \$1.04 one way.

$$\text{Avg transportation cost}_{MD} = (10 \cdot 8766)\ 25 \cdot 292\ (2.893 \cdot 10^{-6})\ \$2.08 = \$3851$$
$$_{ME} = (10 \cdot 8766)\ 25 \cdot 16\ (2.949 \cdot 10^{-6})\ \$2.08 = \$215$$
$$_{MA} = (10 \cdot 8766)\ 25 \cdot 28\ (3.686 \cdot 10^{-6})\ \$2.08 = \$470$$
$$_{MM} = (10 \cdot 8766)\ 25 \cdot 168\ (1.287 \cdot 10^{-6})\ \$2.08 = \$986$$

The matrix as previously presented may be used to facilitate the calculation of these values; however, with only one consideration for depot, this matrix was not used. The values as calculated above are entered in row 13 of SN 2.4 (1) in the "Depot Repair" section.

(5) Determine Personnel Cost

The depot repair personnel cost is based upon the number of failures for each module grouping for the life of the system, the mean repair rate (μ), and the mean labor rate ($\bar{c}_{\theta m}$). The repair time is 1.33 hours, or a rate of repair (μ) of 0.751 units per hour. Labor rate is assumed to be \$10.00 per man-hour. The cost calculation for personnel for each of the module groupings is:

$$L \cdot V \cdot N_i \lambda_i \bar{c}_{\theta m}/\mu_i$$

$$c_{MD} = (10 \cdot 8766)\ 25 \cdot 292\ (2.893\text{x}10^{-6})\ \$10/0.751 = \$24{,}624$$
$$c_{ME} = (10 \cdot 8766)\ 25 \cdot 16\ (2.949\text{x}10^{-6})\ \$10/0.751 = \$1375$$
$$c_{MA} = (10 \cdot 8766)\ 25 \cdot 28\ (3.686\text{x}10^{-6})\ \$10/0.751 = \$3005$$
$$c_{MM} = (10 \cdot 8766)\ 25 \cdot 168\ (1.287\text{x}10^{-6})\ \$10/0.751 = \$6305$$

The cost of line item (C_{dl}) is based upon the number of different types of modules repaired by depot (N_{RL}), the cost of maintaining a stock item in the Master Repair System (R), the total number of maintenance actions at depot during the equipment life (N_R), and debit and credit costs associated with inventory, accountability, and storage for items repaired at the depot (D). Because the modules have been grouped into four basic types, in calculating C_{dl} the actual total of distinct types within each group must be entered for the term N_{RL}.

Cost of line item (C_{dl}) is calculated from the following formula:

$$C_{dl} = (N_{RL} L \cdot R/8766) + N_R D$$
$$C_{dl} \text{ digital} = (31 \cdot 87660 \cdot \$104/8766) + (1852 \cdot \$10) = \$50{,}760$$
$$C_{dl} \text{ electromechanical} = (4 \cdot 87660 \cdot \$104/8766) + (104 \cdot \$10) = \$5200$$
$$C_{dl} \text{ analog} = (7 \cdot 87660 \cdot \$104/8766) + (227 \cdot \$10) = \$9550$$

C_{d1} module = (4·87660·$104/8766) + (474·$10) = $8900

$C_{i\theta m}$ = cost of personnel at depot + cost of line item

$C_{i\theta m}$ digital = $24,624 + $50,760 = $75,384

$C_{i\theta m}$ electromechanical = $1375 + $5200 = $6576

$C_{i\theta m}$ analog = $3005 + $9550 = $12,555

$C_{i\theta m}$ module = $6305 + $8900 = $15,205

Enter costs in row 12 of the applicable repair/discard logistics cost worksheet (SN 2.4 (1)).

(6) Determine Cost of Special Test Equipment

The cost of test equipment wholly chargeable to the repair of the cards under consideration is as follows:

- Digital cards - $205.6K
- Electromechanical and analog cards - $35.1K
- Modules - $10.0K

These costs are entered in line 15 of the applicable repair/discard logistics cost worksheet.

(7) Determine Total Logistics Costs

Sum rows 8 through 15 on each of the repair/discard logistics cost worksheets and enter the total in row 16. This completes the necessary entries in the repair/discard logistics cost worksheets.

2.5 Determine Overall Minimum Logistics Cost (Step 5)
Substep a can be skipped, since neither of the support candidates include site repair of defective cards. Transfer the total logistics costs to the cost decision table (SN 2.9 (1)) referenced in Step 9.

2.6 Determine Organization and Field Personnel Costs (Step 6)

Since there is no delta cost between the two candidates as regards organization and field personnel, this step need not be completed in the example trade-off.

2.7 Determine Repair Facility Personnel Costs at Site (Step 7)

This step is not applicable to the example trade-off. Proceed to step 8.

2.8 Determine Acquisition Costs (Step 8)

The development cost (C_D), cost of fabrication (C_F), and cost of installation (C_I) are constant for the two candidates under consideration; therefore, for this example they should not be considered.

The cost of manuals (C_M) need not consider manuals required to operate and maintain the system at the site, since these are necessary for both candidates under consideration. Manuals necessary to operate and maintain the special test fixture at the depot for repair of the modules are shown in DN 7D1 under AGE Support Cost to have an estimated cost of $37,500.

The test equipment cost (C_T) associated with the test equipment required for support of the depot repair philosophy is shown in DN 7D1 under Depot or SRA Repair AGE to be $11,300. This value does not include the special test equipment cost considered in step 4a(6).

It is not anticipated that there would be any additional tools or fixtures required for one candidate over the other. C_X need not be considered in the example trade-off.

Line item documentation cost (C_L) need only consider those components of the modules which are new to the Federal Supply System. Using the values presented in chapter 7, 25 additional items will be introduced into the supply system solely for repair support. Using the cost factor of $171 for introduction of a new item into the Federal Supply System, entry cost for the 25 items would be $4275.

Facilities costs (C_B) need not be considered in the example trade-off.

The base stock level cost (C_S) includes the cost of initial spares to fill the storage levels for each of the supply points. The supply points for the multiplexer system will be the same for each candidate under consideration with no difference in stockage levels; therefore, this cost would be equal for each candidate and need not be included in the calculations.

The pipeline cost (C_P) is associated only with the depot repair candidate and must be included in the calculations. Pipeline costs are computed, using the following formula:

$$C_P = \sum c_i \left(\mu_i + K\sqrt{\mu_i}\right)$$

For the purpose of this example, it is assumed that a 95 percent confidence level is desired to ensure that the needed item is normally available when required. The value of K for a 95 percent confidence level is shown in DN 9C2 to be 1.65. Average turnaround duration is estimated in Chapter 7 to be 2.25 months or 1644 hours. Calculate the pipeline cost for each module by first calculating the average number of failures for each module during the turnaround period, using the formula

$$\mu_i = \lambda_i T_{T_i} N_i V$$

digital module $\mu = 2.893 \cdot 10^{-6} \cdot 1644 \cdot 292 \cdot 25$
$= 34.7$ failures

electromechanical module $\mu = 2.949 \cdot 10^{-6} \cdot 1644 \cdot 16 \cdot 25$
$= 1.9$ failures

analog module $\mu = 3.686 \cdot 10^{-6} \cdot 1644 \cdot 28 \cdot 25$
$= 4.2$ failures

module module $\mu = 1.287 \cdot 10^{-6} \cdot 1644 \cdot 168 \cdot 25$
$= 8.9$ failures

Substituting the average number of failures of the modules into the pipeline cost formula, we get:

digital module $C_p = \$475\ (34.7 + 1.65\sqrt{34.7})$
$= \$21{,}099$

electromechanical module $C_p = \$425\ (1.9 + 1.65\sqrt{1.9})$
$= \$1775$

analog module $C_p = \$550\ (4.2 + 1.65\sqrt{4.2})$
$= \$9670$

module module $C_p = \$265\ (8.9 + 1.65\sqrt{8.9})$
$= \$3662$

$C_p = \$21{,}099 + \$1775 + \$9670 + \$3662$
$= \$36{,}206$

Enter the computed cost in the cost decision element worksheet (SN 2.9 (1)).

2.9 Determine Total Configuration Cost (Step 9)

Summarize all of the acquisition and support costs on the cost decision element worksheet (SN 2.9 (1)) for each of the candidate configurations and support postures.

Total costs are compared for selection of the least total cost candidate. In this example, the total cost of the considered cost elements for the discard candidate is $1,172,977, whereas the corresponding total cost of the depot repair candidate is $573,585. The more cost-effective support posture of the two candidates would be depot repair of the defective modules.

SUB-NOTE 2.9 (1) Cost Decision Elements

Cost Element (C)	Subscript	Refer to Step No.	Refer to SN No.	Support Candidate	
				Discard	Repair
Design	D	8		N/A	N/A
Fabrication	F				N/A
Installation	I				N/A
Manuals	M				$37,500
Test Equipment	T				$11,300
Organization	T_o				N/A
Field	T_f				
Tools and Fixtures	X				
Organization	X_o				
Field	X_f				
Depot	X_d				N/A
Line Item Documentation	L				$4275
Facilities	B				N/A
Spares					
Base Stock/Initial	S				N/A
Pipeline	P				$36,206
Organization	o				N/A
Personnel Op Maint	om				
Consumables	of				
Field	f				
Personnel	fm	6			
Consumables	ff	4a (3)		N/A	N/A
Maintenance/Logistics*	Z_{min}	4a(2), 4a(4), 4a(5), 4a(6), 5		$1,172,977	$484,304
Total Cost T ( )....T ( )				$1,172,977	$573,585

*M/L includes the cost factors for spares, transportation, repair facility personnel plus line item entry, and special test equipment.

CHAPTER 10

MAINTENANCE CONCEPT

This chapter contains sections outlining the maintenance concept and the type of data contained in the concept, with an example of the Multiplexer Set maintenance concept, including the AGE requirements identification.

CHAPTER 10

MAINTENANCE CONCEPT

SECTION 10A

MAINTENANCE CONCEPT INTRODUCTION

This section contains a description of the maintenance concept by describing the type of data required to develop a concept, with guidelines and methodology.

SECTION 10A — MAINTENANCE CONCEPT INTRODUCTION

DESIGN NOTE 10A1 — DETAILED TASK DESCRIPTION

1. GENERAL

To prevent haphazard approaches to maintainability design, a definitive concept or plan of system maintenance is essential. Such a concept would define the repair philosophy to be used and would guide support planning and provide a basis for defining support requirements.

The maintenance concept is the second stage of planning for the maintenance and support of a system/equipment in the operational environment. The first stage is the maintenance philosophy, and the third stage is the maintenance plan.

The maintenance philosophy is the customer-directed general maintenance approach and constraints (see DN 1B3, Chap 1) and is limited in detail. The maintenance concept implements the maintenance philosophy, sometimes taking exception to the philosophy, as the level of detail of implementation increases. The maintenance concept evolves through repetitive analysis into a detailed maintenance plan for supporting the operation of the system equipment in the planned operational environment.

The maintenance concept is developed concurrently and iteratively with the operational and design concept to assure the compatibility and cost effectiveness of the system/equipment with the military organization.

2. THE MAINTENANCE CONCEPT

The maintenance concept is a description of the planned general scheme for maintenance and support of an item in the operational environment. The maintenance concept provides a practical basis for influencing design, layout, and packaging of the system and its test equipment, and establishes the scope of maintenance responsibility for each level of maintenance and the personnel resources required to maintain the system.

Maintenance concepts for the system are established, using prior feasibility studies and maintainability trade-offs between support elements. These concepts provide guidance for the definition of support requirements. Maintenance concepts should include:

- Projected levels and locations of maintenance
- Fault isolation and system testing approach
- Component repair by maintenance level and location
- Scheduled maintenance requirements and location
- Facilities required at each location
- Support equipment and tools required (AGE) at each location
- Skill levels, types, and numbers of personnel required at each location
- Supply considerations at each location
- Technical documentation requirements at each location

DESIGN NOTE 10A2 GUIDELINES AND METHODOLOGY

1. GENERAL

In selecting a maintenance concept which meets or exceeds the operational requirements at the minimum life cycle cost, the general case is that the operational requirements only influence decisions relative to organizational maintenance insofar as maintenance time is concerned.

Once it is assured that each candidate concept meets the operational requirements (including the maintenance constraints), the candidate should be selected which results in the lowest life cycle cost.
It is important to note that the selection of the maintenance concept must be done in conjunction with the selection of the design concept to achieve the optimum result.

The detailed procedures for selecting the maintenance concept for a system are covered in Chapter 7 (trade-offs) and Chapter 9 (maintainability model). As mentioned previously, the maintenance concept decisions should be made at the same time as the maintainability design decisions.

2. MAINTENANCE CONCEPT PLANNING

The maintenance concept is the basic document for support planning, and it is imperative that a preliminary approach be developed as soon as the system concept is established.

The description of operational requirements from which quantitative maintainability requirements are derived for the system also provides the logistic support planning criteria on which to base maintenance concepts appropriate to the maintainability requirement. The maintenance concept, which basically defines criteria governing the scope and proposed methods of repair at each level of maintenance, attempts to satisfy jointly the quantitative maintainability requirement derived for the system, and the planned logistic support environment within which the system is to operate.

The maintenance concept should be developed concurrently and interatively with the derivation of quantitative maintainability requirements for the system. Since the organizational level repair policy to be defined for the system must be compatible with the maintainability indices requirement, the maintenance concept applicable to the organizational level is first established. Maintenance concepts and policies for the intermediate and depot levels of maintenance are then evolved to support the organizational level concept.

3. LEVELS OF MAINTENANCE

Air Force maintenance is divided into three basic levels: organizational, intermediate, and depot.

Each level of maintenance corresponds to both the skill of available personnel and the degree of difficulty inherent in the maintenance work to be done. These levels can be categorized as on site (organizational), base support (intermediate), and repair depot and/or contractor facility.

4. ORGANIZATIONAL LEVEL MAINTENANCE

Maintainability, as treated in this notebook, is concerned first with the ease, rapidity, and economy of system maintenance by personnel who use the system. This is the organizational (or user) level of maintenance at which a repair-by-replacement concept is usually adopted to enhance operational effectiveness and minimize maintenance resource requirements (personnel, training, facilities, special tools and test equipment, spare parts, etc.).

Maintenance at the organizational level should be depicted by the maintenance concept and should be compatible with the equipment design. Organizational level maintenance consists of preventive maintenance and corrective maintenance.

4.1 Organizational Corrective Maintenance

Corrective maintenance tasks at the organizational level of maintenance should be limited, as a general rule, to system testing, fault isolation, and only the simpler repair tasks such as replacement of replaceable units and modules, replacement of specifically designated components comparable in interchange task complexity to modular replacement, and minor equipment adjustments and alignments. The basic corrective maintenance procedure for organizational maintenance should employ fault detection and isolation by automatic means as the normal method for determining the repair task. When automatic means fail, manual techniques (outlined in step-by-step form in instructional material) should be provided. When the fault can be isolated to a replaceable unit, maintenance technicians remove the defective item and replace it with a spare taken from the storeroom. The defective element may then be removed to the maintenance shop for repair or disposition.

4.2 Organizational Preventive Maintenance

Preventive maintenance, as defined herein, consists of those scheduled maintenance tasks which are required to prolong system operation and useful life, i.e., inspection, cleaning, calibrating, etc. These tasks are performed with limited dismantling of equipment. The preventive maintenance plan for a system should strive to minimize the complexity and frequency of required servicing, while providing maximum system performance and prolonged operational life. As a design objective, the inability to perform scheduled maintenance due to operational commitments over extended period of time should not restrict system operation or contribute to permanent damage of system components.

5. INTERMEDIATE LEVEL MAINTENANCE

Intermediate maintenance is performed by specially trained technicians of skill levels adequate to effect repair of end items and replaceable units in support of the using organization on a return-to-user basis. The user or using organization refers to the operating location of the equipment. Intermediate level maintenance performed by the repair maintenance shops includes the interchange of major components or subsystems, replacement of electronic parts, etc. Maintainability requirements in terms of time for repair are not as stringent at the intermediate level as they are at the organizational level, except for turnaround time required to effectively support the user. Field support teams of specialists on a particular item of equipment, stationed at a central location, may also be utilized to effect on-site repairs of equipment that is beyond the capability of the on-site maintenance personnel. Such personnel may be government maintenance specialists or contractor engineers.

6. DEPOT LEVEL MAINTENANCE

Replacement items that are not repairable at the shop (intermediate level) are returned to a depot for overhaul or repair. Depot level maintenance is performed by a limited number of facilities comprised of highly skilled specialists, special handling equipment, tools, and test equipment to perform complicated repairs, modifications, and factory type adjustments using primary or secondary standards. Maintainability requirements for the depot level are oriented to minimize logistic support resources, requirements, and costs.

SECTION 10B

SELF-REPAIR AND SELF-SUPPORT CONCEPTS

This section contains an analysis of a design approach for a self-repair concept, and discusses a self-support concept.

SECTION 10B SELF-REPAIR AND SELF-SUPPORT CONCEPTS

DESIGN NOTE 10B1 - SELF-REPAIR CONCEPT

DESIGN NOTE 10B2 - SELF-SUPPORT CONCEPT

DESIGN NOTE 10B1

SELF-REPAIR CONCEPT

1. GENERAL

This design note summarizes an analysis of a new equipment design approach, permitting electronic self-repair of component faults by built-in adaptive spares. While increasing equipment complexity and acquisition cost by 30 percent to less than 50 percent the resultant reliability and availability are those of at least five complete parallel systems in stand-by redundancy.

2. BASIC SELF-REPAIR CONCEPT

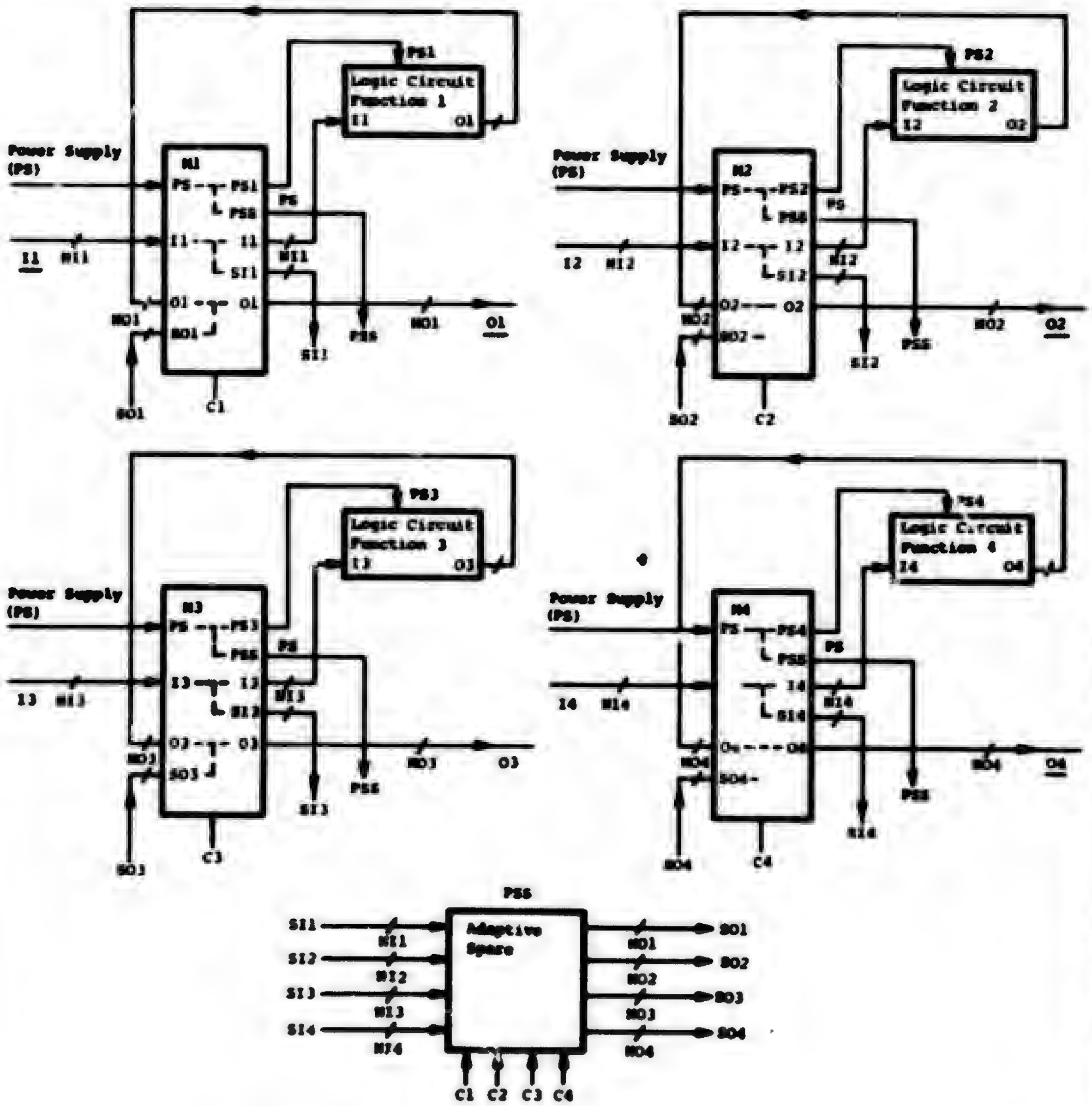
The basic concept is illustrated in SN 2 (1). The overall equipment is partitioned into self-repairable modules. Each of these consists of three to eight, (usually similar) circuit sections, and a single spare of approximately the same complexity as one of the circuit sections. If built-in test equipment or external performance monitoring detects a fault in a given module, the faulty circuit section is electronically disconnected from the signal path and power supply, and the spare is switched in its place. The spare design is adaptive so that the original operating circuit sections covered by a given spare may perform different functions.

3. DESIGN TRADE-OFF

The main factors to be considered in the design of self-repair equipment are:

- The number of self-repairable modules into which the equipment is to be partitioned. Each module should typically not be smaller than 100 logic gates or equivalent.
- The number of circuit sections into which each module is partitioned and which are covered by a single spare. More circuit sections require a smaller spare, but more multiplexers, and vice versa. The complexity of the spare should typically not be less than 20 logic gates or equivalent.

SUB-NOTE 2 (1) Basic Principle of Self-Repair by Adaptive Spares



If a failure occurs in any original operating logic circuit of this four-section (plus spare) module, it is disconnected from the signal path and power supply by a multiplexer and a built-in spare is switched in its place. The spare circuitry is adaptable to any number of different functions, so that only one spare is required for every four to 10 original logic circuits. This increases the overall equipment complexity by not more than 20 to 50 percent but provides reliability equivalent to that of three or more parallel systems in standby redundancy.

Since no firm design guidelines for self-repair equipments presently exist, it is necessary to compare different candidate designs as to their resultant reliability, complexity, cost, size, weight, and power consumption, using a computer-aided effectiveness analysis.

4. SELF-TEST AND SELF-REPAIR MULTIPLEXERS

The original circuitry and spare are typically built-in, standard integrated circuit technology. The multiplexers, however, which connect and disconnect the original circuitry and the spares to and from the signal path and which adapt the spare to its various functions, require a new design. Analysis shows FET switches with IC drivers to be the most effective solution, and they have been used throughout this Study.

The reliability analysis has shown that a single multiplexer failure must not cause the module to become inoperative or nonrepairable. This can be achieved by a serially redundant multiplexer which assures the ability to disconnect a faulty element, or keep the spare disconnected from the signal path when it is not needed. Any other overall module design which makes its performance tolerant to a single multiplexer failure is equally acceptable. The various possibilities in this area have not yet been fully explored, leaving room for further development work.

5. SELF-TEST AND SELF-REPAIR SOFTWARE

The software required for self-repair is similar to that of any built-in or external fault location system, except that the code which identifies the fault position is now used to switch in the spare. In many cases, the fault location software is greatly simplified by using the spare itself to simultaneously locate and repair a fault. Thus only end-to-end testing of major logic assemblies is needed to detect an overall malfunction. The spares are then successively rotated through all available positions, until the malfunction has been remedied. The spare position identifies the location of the original fault which can be later repaired during periodic preventive maintenance, with only minimum or no downtime. (With suitable design, many faults can be repaired by circuit-board replacement without shutting down the equipment power.)

6. TACMOD DISPLAY SYSTEM REDESIGN FOR SELF-REPAIR

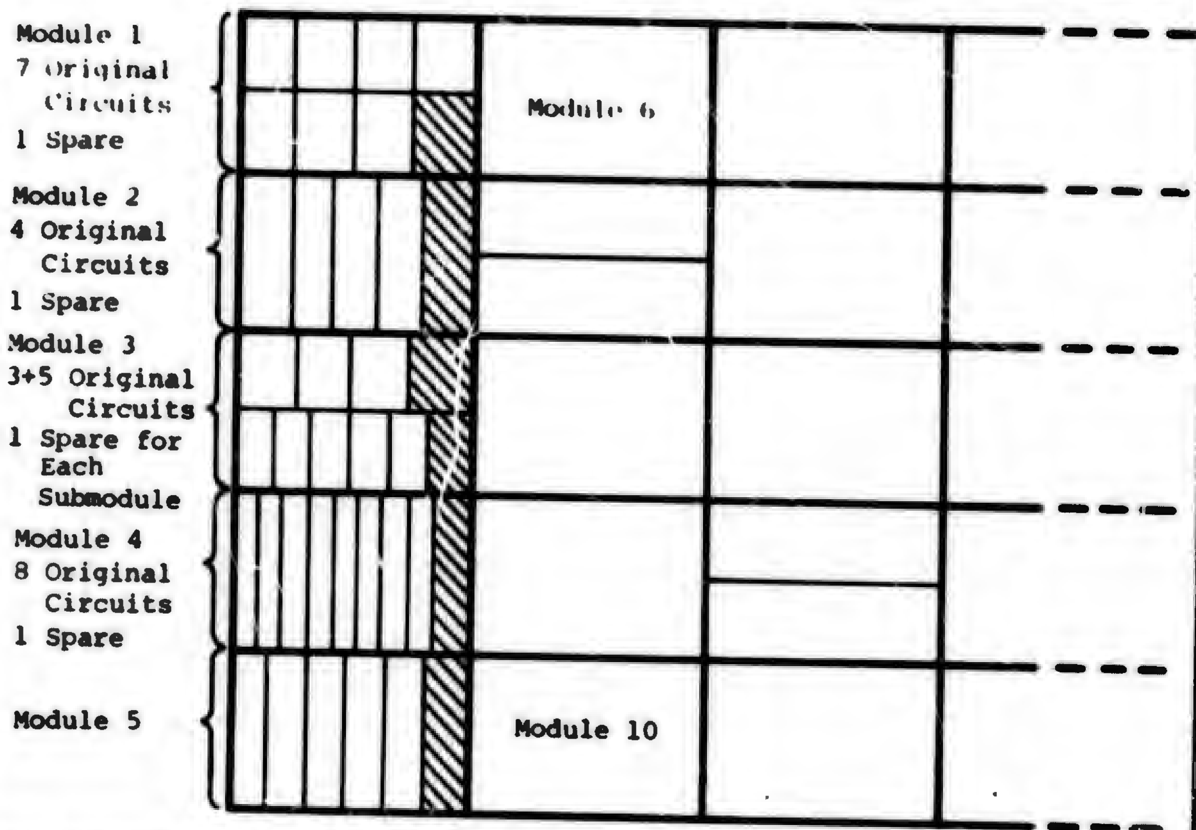
To test the concept against a real-world situation, a modular Tactical Situation Display System with approximately 3,000 microcircuits was redesigned for self-repair. It was first partitioned into 124 self-repairable modules as shown in SN 6 (1).

Each module contains from three to eight original circuits. In 87 modules they are covered by a single spare, in 36 modules they are covered by two spares each, and one module contains three spares. Detailed logic drawings of the redesigned equipment have been delivered to RADC. The troubleshooting procedure of the original equipment was used for fault location. Self-repair is accomplished by means of the self-repair control unit, whose front panel is shown in SN 6 (2). The operator first enters the address of the module to be repaired, and subsequently inputs the position which the spare is to assume within the module. The spare is stepped through all positions in the faulty module till the malfunction is corrected.

In an emergency, a "quick-fix" procedure can be used whereby the spares of all modules are rotated through all their positions in parallel until the malfunction is corrected, requiring a maximum of only eight trials until any fault is repaired.

To assess the benefits derived from and the penalties paid for the self-repair design, a detailed effectiveness analysis has been carried out in which the reliability and the added complexity, cost, size, weight, and power consumption of the new equipment are compared with those of the original design. A summary of the complexity (in multiples of IC gates), the failure rate, acquisition cost, power consumption and normalized size and weight for all original circuitry, all spares, and all multiplexers in each module is given in SN 6 (3). One observes an increase in complexity of 44 percent, an increase in cost of 51 percent, an increase in power consumption of 27 percent and an increase in size and weight of 63 percent. Much of the increase is due

SUB-NOTE 6 (1) Schematic of Equipment Partitioning for Self-Repair



Blank rectangles indicate original circuit sections; shaded areas symbolize spares. The total TACMOD display equipment has been partitioned into 124 modules of which 87 are covered by a single spare, 36 by two spares, and one module by three spares.

to the multiplexers, for which pessimistic figures were assumed, since multiplexers specifically optimized for self-test and self-repair applications are presently not available. The reliability of the redesigned equipment has been calculated, using the reliability model of SN 6 (4); the results are shown in SN 6 (5). The graph indicates that whereas the original equipment (N=1) had an MTBF of approximately 500 hours, the self-repair system still has a probability of mission success of 80 percent for a mission time of 2,000 hours; i.e., better than five parallel systems in stand-by redundancy. The MTBF of the new equipment is therefore at least five times longer than that of the original equipment.

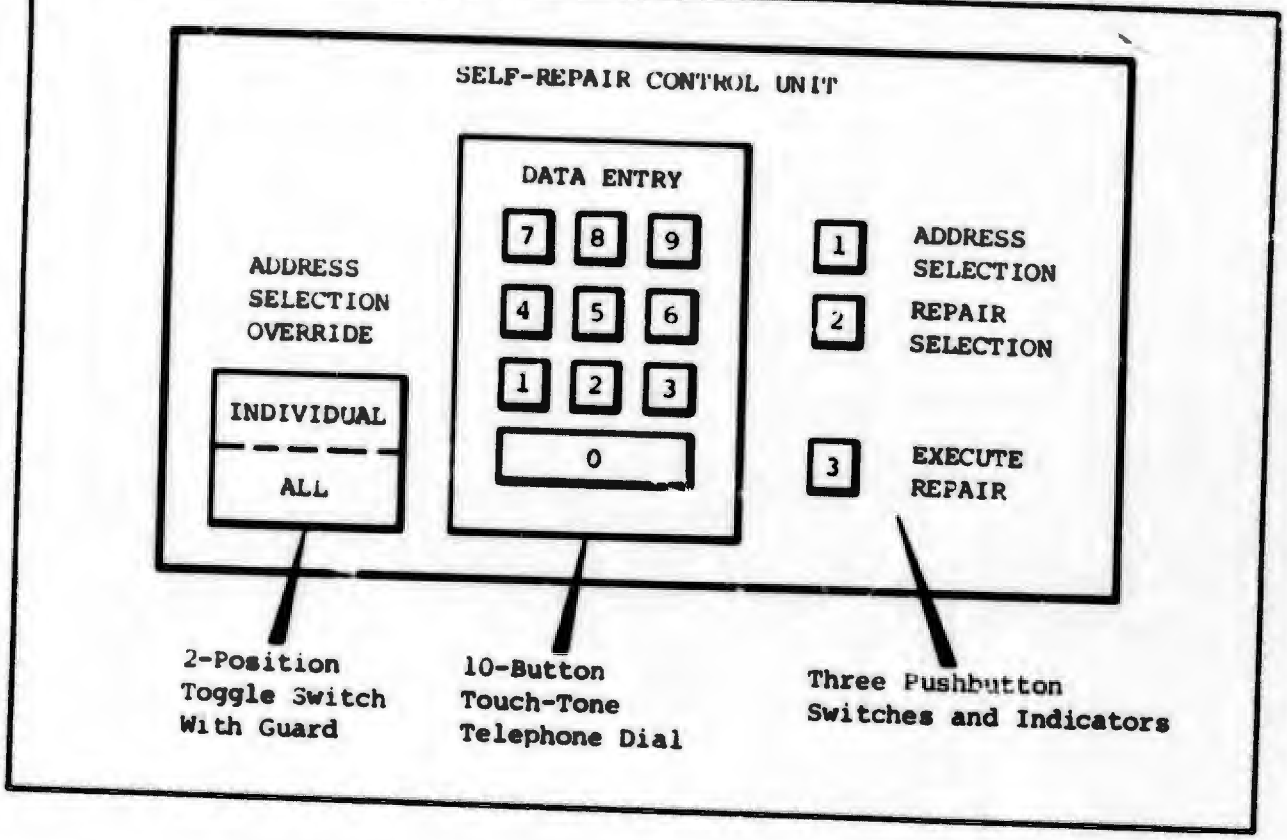
The equipment is designed so that at any time a self-repair has been made, the original fault has been located for preventive maintenance. Even while the system is still fully operational, preventive maintenance itself can be accomplished in such a short time (by replacing the previously identified faulty board) that the availability of the self-repair equipment is essentially equal to unity, provided the equipment is accessible for rapid preventive maintenance at least once every 100 to 200 hours (assuming an MTBF greater than 2,000 hours, MTTR less than 10 minutes). One also notices that with preventive maintenance every 100 to 200 hours of operation, a mission reliability of over 99 percent can be achieved for a 100-hour mission.

Thus the MTBF, the availability, and the mission reliability up to a mission time of several hundred hours are much higher in the self-repair equipment than in any nonredundant design.

Also, the number of spares to be carried for preventive maintenance to support mission times up to 2,000 to 3,000 hours is greatly reduced.

Finally, in properly designed self-repair equipment with high commonality, only a small number of different types of adaptive logic modules will be used, which greatly simplifies the logistics support and lowers its cost.

SUB-NOTE 6 (2) Self-Repair Control Unit, Front Panel

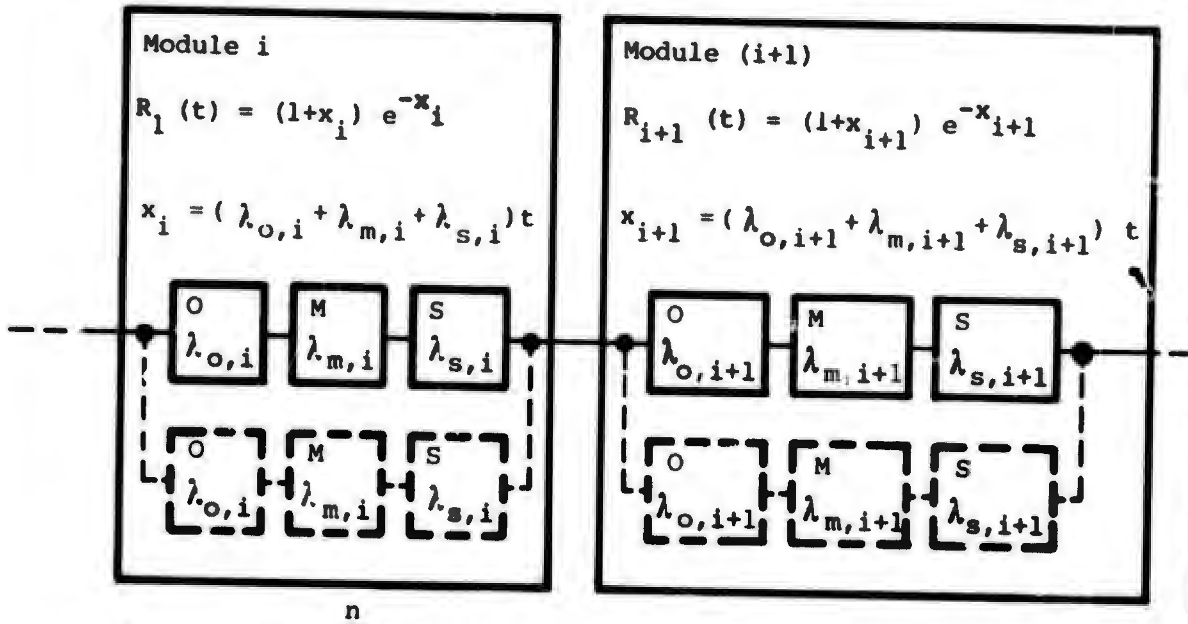


SUB-NOTE 6 (3) Summary Effectiveness Figures for Entire Equipment

		Complexity	Failure Rate	Cost	DC Power/MW	Size-Weight
Totals	O	10718.8437	1893.2031	16491.6484	150208.0000	3024.8926
Totals	S	1697.7996	271.0879	2372.6094	22249.0000	418.1499
Totals	M	2982.0000	909.6680	5986.0000	17784.0000	1497.5000
Totals	T	15398.6133	3073.9619	24850.2812	190241.0000	4940.5234
		Complexity	Failure Rate	Cost	DC Power/MW	Size-Weight
Totals	O	100.0000	100.0000	100.0000	100.0000	100.0000
Totals	S	15.8394	14.3190	14.3867	14.8121	13.8236
Totals	M	27.8202	48.0491	36.2972	11.8396	49.5059
Totals	T	143.6593	162.3683	150.6840	126.6517	163.3287

NOTE: Top: Actual numbers; bottom: effectiveness
Figures as percentages of figures for original equipment.
O,S,M, and T mean original equipment, spares, multiplexers, and total self-repair equipment, respectively.

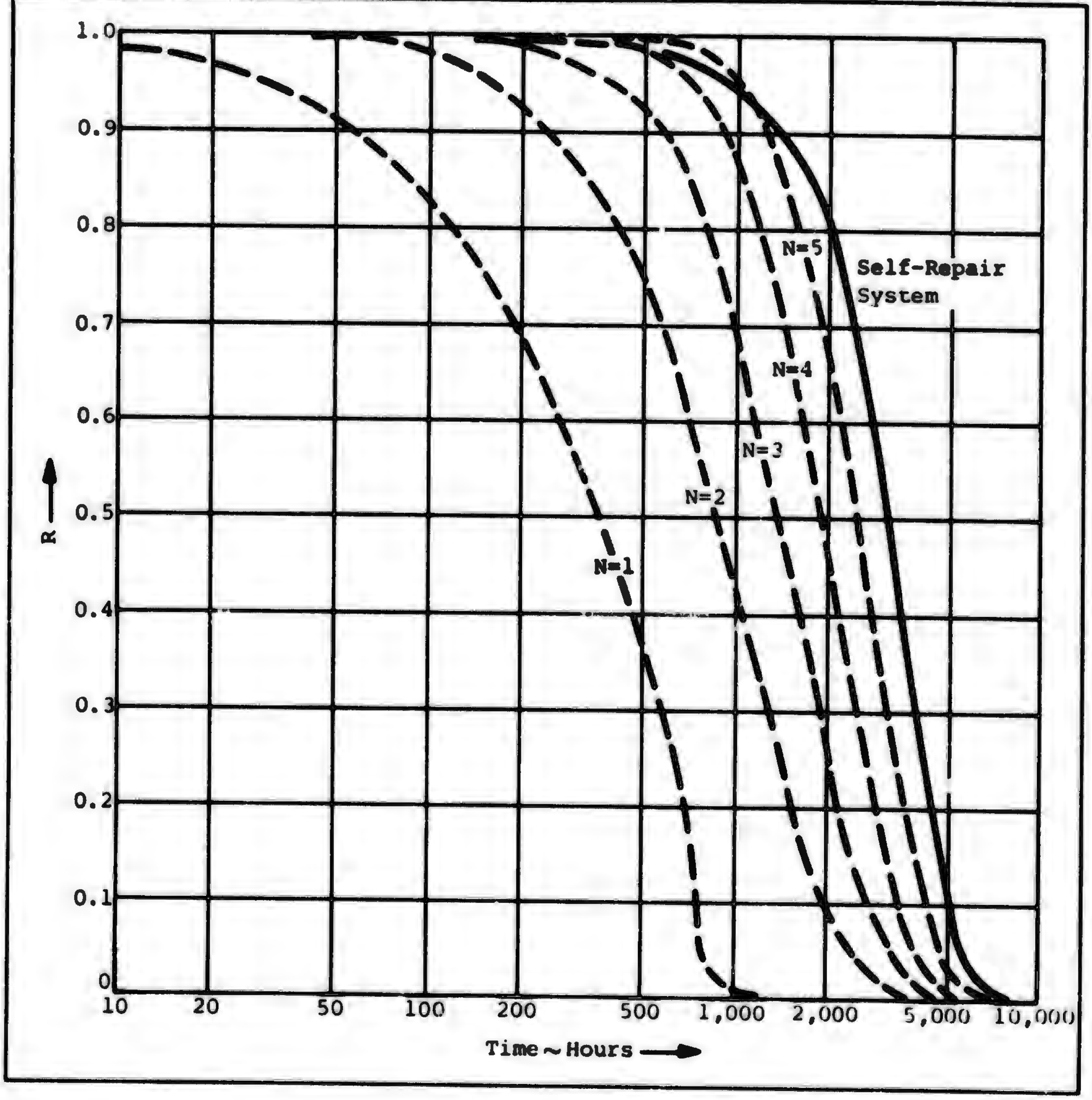
SUB-NOTE 6 (4) Reliability Model and Equations for Self-Repair System With N Self-Repairable Modules in Series.



$$R_{System}(t) = \prod_{i=1}^{n} R_i(t)$$

The individual modules are designed such that the first failure in the original circuitry, spare, or multiplexer does not render the module inoperative or nonrepairable. O, M, and S denote original, multiplexer, and spare circuitry, respectively.

SUB-NOTE 6 (5) Comparison Between Reliabilities of N Parallel Systems in Standby Redundancy for N=1,...5, and Reliability of Self-Repair System



7. DESIGN AND CONSTRUCTION OF SELF-REPAIRABLE MULTIFUNCTION LOGIC UNIT

To demonstrate the self-repair principle, a logic unit has been designed and constructed which proves the validity of the design approach and shows that self-repairable logic equipment can be built efficiently with present microcircuit technology, except that it appears desirable to develop fully integrated special self-test and self-repair multiplexers.

Specifically, a 4-bit parallel arithmetic unit with TTL microcircuit logic has been selected as the demonstration circuit, with the complexity and capability of one-quarter of a typical minicomputer (minus memory). It contains 72 microcircuit packages and its backplane holds 1,300 wirewrap connections. In addition to the four operating bits, two independent spare bits have been built into the unit which can be switched individually to take the place of any of the operating bits if these develop a fault.

To be able to demonstrate the self-repair capability, manually movable jumper connections are used to create an open circuit, a short circuit to ground, and a short circuit to B+ for a total of 108 different faults.

In addition, all microcircuits are mounted in sockets and can be removed to simulate additional malfunctions. These demonstration features, of course, increase the volume of the unit four to six times what it would be for a military self-repair equipment built in state-of-the-art flat-pack technology. The Self-Repair Multifunction Logic Unit has been equipped with interface circuitry and a connector to be operated by a Hewlett-Packard computer, to show absolutely "hands-off" self-test and self-repair capability as is projected for any advanced avionics equipment.

The significance of a demonstration model is that it shows that the design concept of fully automatic self-repair can be implemented with today's technology to a point where it is absolutely clear that any avionics logic system could be designed and built to be self-repaired by an (always available) on-board central computer system.

8. APPLICATIONS

It appears that self-repair design would be beneficial to all future equipment simply because of the reduced number of different types of spares required, the reduced frequency of preventive maintenance, and the shorter MTTR.

Particularly advantageous is the approach when there is a premium on mission reliability, availability, and spares support.

This includes avionics equipment critical to navigation, and foul-weather landing aids, missile equipment with 100 percent availability requirement, equipment for remote-area operation with minimum maintenance facilities, and equipment for weeks of unattended operation.

While the obvious application of the approach is to digital equipment, it also seems to be well suited for analog equipment with high commonality among modules, such as phased array antennas.

9. CONCLUSIONS

This analysis has shown that the self-repair concept based on the switching of built-in adaptive spares is a technologically and economically viable concept which, for a maximum increase of 50 percent in equipment, complexity, size, and acquisition cost, provides MTBF's and availability equal to those of at least five parallel systems in stand-by redundancy. It also greatly reduces the frequency of preventive/corrective maintenance and the number of different types of spares required.

DESIGN NOTE 10B2 SELF-SUPPORT CONCEPT

1. SUPPORT CONCEPTS INTRODUCTION

There are three general supply concepts: (1) sparing at one level with periodic resupply; (2) sparing at more than one level with periodic resupply; and (3) self-support (initial provisioning of spares for the planned equipment lifetime). Each of these concepts can have variations in cycle periods (except self-support), level of confidence, types of spares, and storage locations. The self-support concept is basically the same as periodic resupply, with the cycle period equal to the planned equipment life. The selection of a support concept is based on achieving the desired level of equipment availability at the lowest cost. Controlling factors are other elements of the overall maintenance concept and aspects of the support system that have been predetermined.

2. SELF-SUPPORT

The self-support concept involves a number of techniques by which sufficient spares are provided when the equipment is delivered to keep the equipment operational throughout its useful life. This can be accomplished by providing spare replaceable units separately, by mounting spare parts on each module of the equipment, or by providing sufficient redundancy to preclude equipment failure. With present circuit reliabilities and costs, the latter two methods will probably not be feasible in most applications. However, with certain types of equipment (highly repetitive part types (integrated circuits) and high reliability), it may be feasible to provide spares as part of each installed module.

The number of separate spares required initially to ensure (to a desired level of confidence) that there will be no equipment downtime from lack of spares has been calculated for various unit reliabilities and equipment complexities. The calculations are based on an assumption of a constant failure rate for the parts under consideration; the probability, then, of having r or fewer failures in time t is given by

$$P(r) = \sum_{N=0}^{r} \frac{(\lambda t)^N}{N} e^{-\lambda t}$$

where

N = number of failures

λ = failure rate of parts being considered

t = operating time

SN 2 (1) illustrates the results of these calculations for an equipment life of 2×10^4 hours (approximately 2 years). The captions used in the table are defined as follows:

Equipment Life - Required equipment operating life (hours)

Part MTBF, Hours - Mean time between failures (hours) of each part

Probability Level - Probability that the equipment will not have any failures for which a spare part is not available during the required equipment life

Total Parts per Equipment - The total number of parts used in the equipment

Number of Part Types - Number of different types of parts used in the equipment

Two numbers appear for each probability level listed in the table. The upper number is the number of spare circuits required for maximum use of a single circuit type. For example, if the equipment contains a total of 100 circuits of 10 different types, the upper number represents the spare circuits required when one circuit type is used 91 times and each of the other 9 types is used once. The lower number represents the number of spares needed for equal use of all circuit types. While these two situations may not necessarily correspond to the part-type combinations for absolute maximum and minimum spare-parts requirements, they do represent extremes that will include most combinations of part types.

The use of the table is illustrated below, with the following conditions assumed:

- Required equipment life: 2×10^4 hours
- Part MTBF. 10^7 hours
- Probability level: 0.99
- Total parts per equipment: 5,000
- Number of circuit types: 250

The part MTBF is located in the first column. The probability level is located next in the second column. The "total parts per equipment" is located under one of the next six major column headings, and under this column for the number of circuit types is located. Thus the two spares quantities for the conditions assumed are listed as 500 and 266. These numbers correspond to extreme combinations of circuit-type usage, and most usage will fall between these two extremes.

No more than 15 percent of the total equipment parts would be required as spares for either extreme combination of circuit types. Two other points are of interest: (1) there is little difference in the spare-parts requirements for probabilities of equipment survival of 0.90, 0.95, and 0.99; and (2) the spares requirement usually increases at a slower rate than the number of circuits.

Self-support can also be accomplished by providing at least one spare for each part type in a module. These spares are mounted in the same manner as the active circuits and can be used to replace failed IC's by soldering jumper wires.

SUB-NOTE 2.1(1) Spare Parts Requirements for Logistic Self-Support (Equipment Life = 2 X 10^4 Hours)

MFM MTBF Hours	Probability Levels	Total Parts per Equipment: 100			Total Parts per Equipment: 500					Total Parts per Equipment: 1000					Total Parts per Equipment: 5000					Total Parts per Equipment: 10,000				
		Number of Part Types			Number of Part Types					Number of Part Types					Number of Part Types					Number of Part Types				
		1	10	100	1	10	100	250	500	1	10	100	250	500	1	10	100	250	500	1	10	100	250	500
10^5	.50	20	40	200	100	150	400	750	1000	200	270	600	1000	1500	1000	1150	1000	2750	3500	2000	2210	3100	4250	5500
		-	28	-	-	109	279	551	-	-	210	380	653	1110	-	1014	1183	1461	1935	-	2017	2185	2467	2951
	.75	23	50	200	107	160	500	750	1500	209	290	700	1250	2000	1021	1190	1900	2750	4000	2030	2270	3200	4500	6000
		-	32	-	-	119	287	569	-	-	224	392	684	1609	-	1044	1209	1540	2434	-	2060	2223	2579	3450
	.90	26	60	300	113	180	500	1000	1500	218	300	800	1250	2000	1041	1230	2000	3000	4500	2057	2330	3200	4500	6500
		-	42	-	-	130	389	818	-	-	235	495	933	1612	-	1059	1318	1789	2441	-	2076	2336	2828	3460
	.95	27	60	300	117	190	600	1000	1500	223	310	800	1250	2000	1052	1260	2000	3250	4500	2074	2370	3300	4750	6500
		-	44	-	-	134	393	818	-	-	241	500	933	1618	-	1072	1331	1789	2458	-	2095	2353	2828	3485
	.99	30	80	300	124	200	600	1250	2000	233	320	900	1500	2500	1074	1300	2100	3500	5000	2104	2430	[illegible]	5000	7000
		-	45	-	-	149	401	1067	-	-	259	513	1182	2120	-	1100	1360	2038	2968	-	2131	2394	3077	4000
10^6	.50	2	10	100	10	30	100	250	500	20	40	200	500	500	100	150	400	750	1000	200	70	600	1000	1500
		-	2	-	-	10	107	254	-	-	21	117	264	509	-	102	197	344	590	-	203	297	445	691
	.75	3	10	100	12	30	200	250	500	23	50	200	500	1000	107	160	500	750	1500	209	290	700	1200	2000
		-	4	-	-	14	109	256	-	-	25	120	267	512	-	113	204	352	598	-	218	301	455	702
	.90	4	20	100	14	40	200	500	500	26	60	300	500	1000	113	180	500	1000	1500	218	300	800	1200	2000
		-	13	-	-	23	111	258	-	-	35	123	270	517	-	122	211	360	613	-	227	317	467	724
	.95	5	30	100	15	40	200	500	1000	27	60	300	500	1000	117	190	600	1000	1500	223	310	800	1200	2000
		-	13	-	-	24	113	261	-	-	36	125	275	1016	-	126	216	372	1112	-	233	324	484	1223
	.99	6	30	200	18	50	300	500	1000	30	80	300	750	1000	124	200	600	1250	2000	233	320	900	1500	2500
		-	15	-	-	27	213	510	-	-	39	226	524	1016	-	133	319	621	1112	-	243	429	733	1223
10^7	.50	0	0	0	1	10	100	250	500	2	10	100	250	500	10	30	100	250	500	20	40	200	500	500
		-	0	-	-	1	1	1	-	-	2	2	3	500	-	10	11	12	508	-	20	21	23	518
	.75	0	0	0	2	10	100	250	500	3	10	100	250	500	12	30	200	250	500	23	50	200	500	1000
		-	0	-	-	2	2	250	-	-	3	4	252	501	-	12	14	261	510	-	23	26	272	521
	.90	1	10	100	2	10	100	250	500	4	20	100	250	500	14	40	200	500	500	26	60	300	500	1000
		-	1	-	-	2	101	250	-	-	4	103	252	501	-	14	113	263	512	-	26	125	274	524
	.95	1	10	100	3	10	100	250	500	5	20	100	250	500	15	40	200	500	1000	27	60	300	500	1000
		-	1	-	-	3	101	251	-	-	5	103	253	502	-	16	114	264	513	-	28	126	276	525
	.99	2	10	100	4	20	100	250	500	6	30	200	250	500	18	50	300	500	1000	30	80	300	750	1000
		-	11	-	-	13	102	252	-	-	15	105	254	503	-	27	117	266	516	-	39	129	279	528
10^8	.50	0	0	0	0	0	0	0	0	1	10	100	250	500	4	20	100	250	500	9	20	100	250	500
		-	0	-	-	0	0	0	-	-	1	1	1	1	-	4	4	5	6	-	9	9	10	11
	.75	0	0	0	1	10	100	250	500	1	10	100	250	500	6	20	100	250	500	11	30	200	250	500
		-	0	-	-	1	1	1	-	-	1	2	2	500	-	6	6	8	505	-	11	12	14	510
	.90	0	0	0	1	10	100	250	500	2	10	100	250	500	7	30	100	250	500	13	40	200	500	500
		-	0	-	-	1	2	250	-	-	2	3	251	500	-	7	9	257	506	-	13	18	263	511
	.95	1	10	100	2	10	100	250	500	3	10	100	250	500	8	30	200	250	500	14	40	200	500	1000
		-	1	-	-	2	101	250	-	-	3	102	251	501	-	8	108	257	507	-	14	115	263	513
	.99	1	10	100	3	10	100	250	500	4	20	100	250	500	10	40	200	500	1000	17	50	300	500	1000
		-	2	-	-	3	101	251	-	-	5	102	252	502	-	12	109	259	508	-	18	115	265	515

For large-scale integration, spare circuit elements can be provided that replace the operating devices through external jumpers. Redundancy can be used as a self-support method by providing two or more IC's or LSI's for each device required by the equipment. With proper selection of the redundancy configuration and with a sufficient number of alternate paths, an equipment can be designed to have a very low probability of failure during its useful life. In applying redundancy to IC's, extreme caution is necessary to ensure that certain failure modes do not cause failure of the alternate paths or associated circuits.

SECTION 10C

MULTIPLEXER SET MAINTENANCE CONCEPT AND AGE REQUIREMENTS EXAMPLE

This section contains an example of the maintenance concept for the Multiplexer Set and an example of the data generated for AGE requirements.

SECTION 10C — MULTIPLEXER SET MAINTENANCE CONCEPT AND AGE REQUIREMENTS EXAMPLE

DESIGN NOTE 10C1

MULTIPLEXER SET EXAMPLE OF THE MAINTENANCE CONCEPT

1. MAINTENANCE PHILOSOPHY

The basic maintenance philosophy for the Multiplexer Set is based upon the detection, isolation, and replacement of failed subassemblies in the field. To this end, the equipment incorporates automated and semiautomated diagnostic circuits and a highly modular packaging arrangement. Combined, these characteristics enable correction of approximately 95 percent of all failures via subassembly exchange. Remaining failures will occur in discrete chassis-mounted components and in replaceable subassemblies not treated by the diagnostic function. Correction of failures in these items will entail conventional troubleshooting and repair techniques.

Failed discrete components are considered nonreparable. Malfunctioning subassemblies may be repaired to the discrete component level, provided the repairing activity is equipped with appropriate fault isolation and testing equipment.

2. EQUIPMENT FEATURES

The Multiplexer Set incorporates built-in fault detection and isolation provisions, modular packaging arrangements and maintenance aids such as test points and jacks. These features permit equipment maintenance with a mean corrective time ($\overline{M}_{ct}$) of 12.0 minutes, and a maximum corrective time ($M_{max\ ct}$) of 36.0 minutes (95th percentile). The built-in fault isolation provisions enable fault isolation to a card or module level without the use of special instruction books or charts. The stability and reliability of the equipment is such as to require a minimum of auxiliary AGE for operation or alignment. Current reliability predictions indicate a mean time between failures (MTBF) of 2507 hours. The required MTBF is 2200 hours. The design of the Multiplexer Set enables performance of required preventive maintenance without incurring equipment downtime.

3. MAINTENANCE CONCEPT

3.1 Operator and Organization Level Maintenance

The MTBF and $\bar{M}_{ct}$ demands of the Multiplexer Set dictate that low-level maintenance by the operator using built-in fault isolating diagnostics, be effective 95 percent of the time. Skill in using this capability is necessary, along with an ability in setting up equipment, analyzing performance, and initiating actions to correct malfunctions.

a. Corrective maintenance at the organizational level is performed, using built-in diagnostic functions for the detection and isolation of equipment malfunctions. Repair is accomplished by replacement of modular subassemblies.

b. Preventive maintenance at the organizational level is performed by means of periodic self-test of integral diagnostic circuits. Scheduled visual inspection and required cleaning operations are performed, as well as replacement of items having predictable service life characteristics.

3.2 Intermediate Level Maintenance

Skill in operation, equipment configuration, and use of built-in fault-finding capability of the equipment is mandatory. In addition, manual diagnosis of the multiplexer set is required in the correction of malfunctions not detected and/or correctly isolated by the integral diagnostic provisions. This diagnosis will entail the examination and analysis of high speed switching logic waveforms and logic timing relationships.

Skill in performing periodic calibration of reference timing sources in the multiplexer and demultiplexer units will be required to assure continued bit rate integrity.

It is considered that limited corrective maintenance of the wiring plane will be required over the Multiplexer Set service life. This maintenance may include the removal/replacement of malfunctioned connector pins, and will therefore require skill in the connection/disconnection of selected signal wires, using wire-wrap repair techniques.

The preprogrammed nature of the built-in diagnostic circuits is such that the source of a detected fault will always be noted as one or more readily replaceable subassemblies. This precludes a proper display of fault location for those infrequent cases where interconnecting wiring or hard wired components have malfunctioned. Skill in the detailed isolation of such malfunctions will be required, using conventional waveform, continuity, voltage and resistance measurements.

a. Corrective maintenance at the intermediate shop level is performed by isolation and repair of malfunctions occurring in components and subassemblies not treated by the integral diagnostic functions. Fault isolation is accomplished by using reference material contained in the equipment technical manual. This material is comprised of "cause-effect" tabulations and conventional theory, and schematic and wiring data. Such isolation may entail the use of standard test equipment such as meters and oscilloscopes. Repair is via subassembly and/or discrete component replacement as applicable. Isolation and repair is performed while equipment is in its normally installed position.

b. Preventive maintenance at the intermediate shop level is performed by periodic calibration and required adjustment of equipment reference timing sources.

3.3 Depot Level Maintenance

With the possible exception of replaceable module or subassembly repair, requirements for routine depot level maintenance are not anticipated. Recommendations regarding disposition of such modules or subassemblies will be prepared upon the basis of an analysis of design details available during the latter stages of the Multiplexer Set development cycle, and upon guidance provided by the procuring activity.

DESIGN NOTE 10C2 — MULTIPLEXER SET EXAMPLE OF AGE REQUIREMENTS

1. GENERAL

Maintenance requirements dictate the incorporation of built-in fault detection and isolation provisions, modular packaging arrangements, and maintenance aids such as test points and jacks. In combination, these provisions must enable equipment maintenance within a mean corrective maintenance time ($\bar{M}_{ct}$) of 12.0 minutes, and a maximum corrective maintenance time ($M_{max\ ct}$) of 36.0 minutes (95th percentile). Built-in fault isolation provisions must enable failure isolation to a small section of the equipment without the use of instruction books or charts. Further, the stability and reliability of the equipment must be such as to require a minimum of auxiliary AGE for operation or alignment. A mean time between failures (MTBF) of 2200 hours is required. If possible, the design shall enable required preventive maintenance without incurring equipment downtime. Mechanical arrangement of the equipment must enable removal of major equipment components or modules without requiring their disassembly or the use of special tools.

2. EQUIPMENT CRITERIA-AGE RELATIONSHIPS

From the preceding discussion of equipment criteria having maintenance impact, several factors can be concluded:

a. Equipment maintenance to the module (or printed circuit card) level must be a simple, expedient process.

b. This process must be tailored to the utilization of maintenance personnel having limited training and/or exposure to the Multiplexer Set equipment.

c. Allowable maintenance times dictate an effectiveness of built-in fault isolation and detection provisions in the 95 percent range.

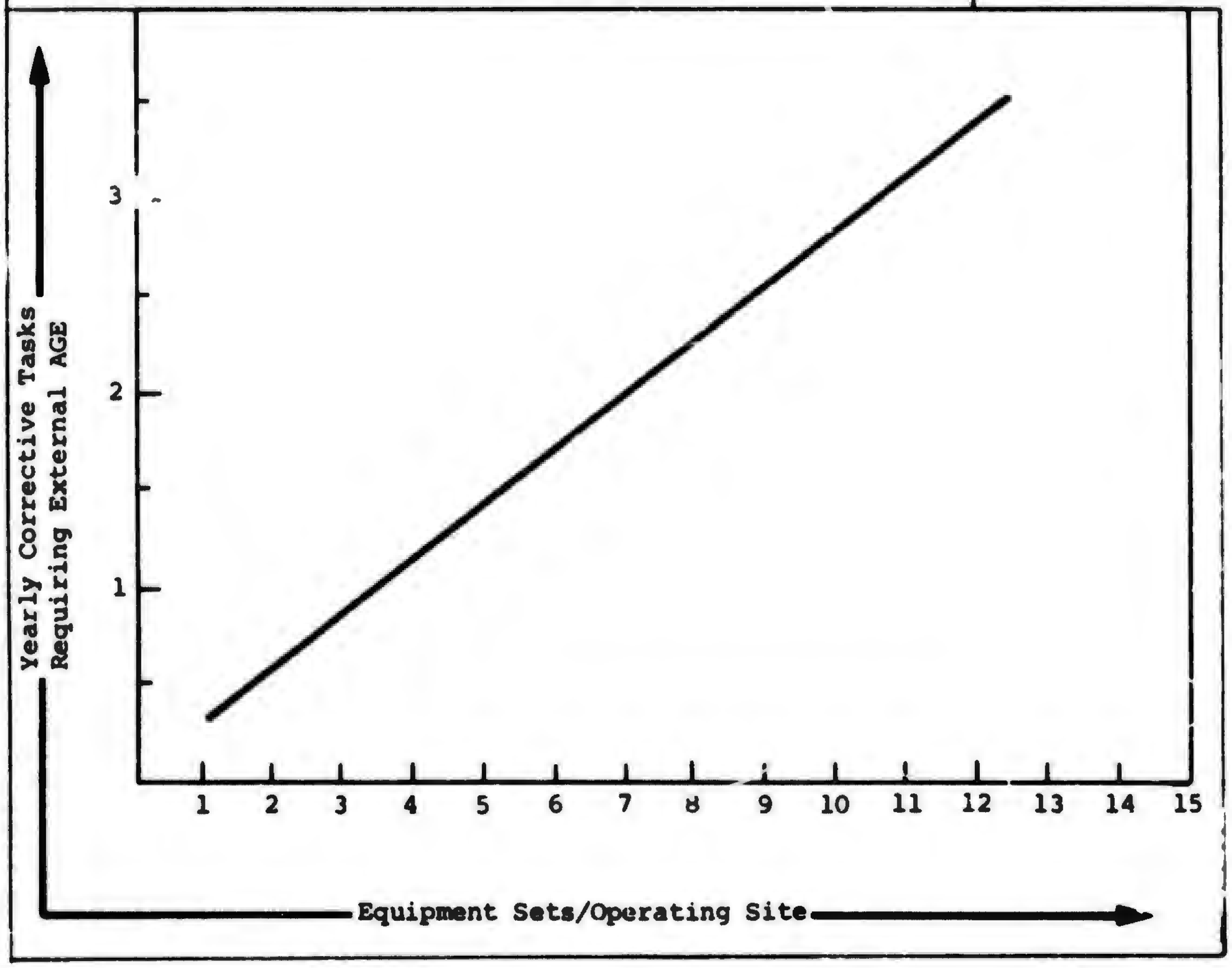
The above factors, when viewed in terms of the specified MTBF, indicate that the average interval between corrective maintenance requirements for nonintegral test equipments is approximately 30,800 operating hours, or more than 3.5

years. Where more than one multiplexer set is used at a given location, this interval decreases linearly as a function of quantity. SN 2(1) depicts the expected number of corrective maintenance actions per year requiring nonintegral test equipments as a function of single location multiplexer set quantity.

The average quantity of multiplexer sets per operating location is expected to be five or less. With such a situation, SN 2(1) indicates a total of approximately 1.4 failures/year/site involving the use of external AGE. Preventive maintenance tasks, such as calibration of reference timing signals, are expected more frequently than those of a corrective nature; however, specific intervals remain undefined, pending further design detail.

Because the Multiplexer Set is but one of many equipments employed in the overall Defense Communications System, it is reasonable to expect the presence of other related equipments at a given operating location. On this basis, with appropriate consideration for the minimal AGE utilization demands which the Multiplexer Set imposes, it would appear highly advantageous to share existing (on location) AGE to the greatest extent possible. On the other hand, because the Multiplexer Set is a digital time division multiplexing equipment, internal switching speeds and data bit rates employed may exceed the capabilities of standard and common AGE available at existing operating locations. These two offsetting considerations are expected to impact subsequent recommendations for the Multiplexer Set AGE.

SUB-NOTE 2 (1) Yearly Corrective Tasks



3. ASSUMPTIONS PERTINENT TO AGE SELECTION

Detailed Multiplexer Set deployment and utilization planning information remains to be defined. Since the selection and recommendation of AGE must consider such factors, certain assumptions are required to permit initiation of the AGE selection effort.

The following is a listing of assumptions used in preparation of this document, and to be used in subsequent AGE selection efforts. The list content is preliminary and subject to revision based upon procuring activity direction.

a. Mean time between failures (MTBF) of the Multiplexer Set and ancillary equipments comprising the Multiplexer Set is 2200 hours.

b. Built-in fault detection and isolation features are effective for 95 percent of all failures.

c. An average of five Multiplexer Set equipments will be located at a given operating location.

d. Operating sites are located worldwide. Quantity of such sites may exceed 100.

e. Operating locations possess existing field level maintenance resources for equipments of a related type. Maintenance of the Multiplexer Set can involve utilization of these facilities on an "as required" basis.

f. Organizational and intermediate level maintenance functions may be performed while the Multiplexer Set equipment is physically and electrically installed within its normal operating facility.

g. Selection of standard and common items of AGE will be made from the following sources in the order of preference listed:

- MIL-HDBK-300
- USAF Specification Bulletin 140
- Other military sources identified by the contractor or the procuring activity
- Commercial sources

h. Recommendations for any AGE peculiar to the Multiplexer Set will be made consistent with one or more of the following criteria:

- Need for the item is established by contractual requirements.
- Need for the item is dictated by peculiar physical or electrical design characteristics which preclude utilization of standard and common items.

- Use of the item would offer support resource economy over the Multiplexer Set life cycle.

i. Overhaul of the Multiplexer Set will not be required during the specified interval of useful life.

j. Equipment operating locations/sites will consist of:

- Central office-type complexes equipped with permanent equipment shelters.
- Remote sites with transportable van-type equipment shelters.

k. In addition to the Multiplexer Set equipments, operating locations/sites will possess:

- Other operating equipments of similar or related type and function.
- Supporting elements such as supply and PMEL units.

l. Electrically powered AGE should be operable from those power sources employed by the Multiplexer Set equipment.

m. Each Multiplexer Set operating site will be provided with sufficient AGE to enable field level isolation of malfunctions not isolated by built-in automatic test provisions.

4. MAINTENANCE GROUND AREAS

4.1 Operating Complex

Corrective and preventive maintenance associated with the Multiplexer Set will be performed while the equipment is installed within its normal operating complex. This maintenance will be accomplished by personnel representing both organizational and intermediate level elements, dependent upon task type and complexity.

4.2 Depot

With the possible exception of replaceable module or subassembly repair, requirements for routine depot level maintenance are not anticipated. Recommendations regarding disposition of such modules or subassemblies will be prepared based upon an analysis of design details available during the latter stages of the Multiplexer Set development cycle, and upon guidance provided by the procuring activity.

5. MAINTENANCE FUNCTIONS

As discussed in previous paragraphs, the majority of the Multiplexer Set corrective maintenance will be accomplished by using fault detection and isolation capabilities integral to the equipment design. Incorporation of such capabilities is dictated by both quantitative and qualitative performance requirements as set forth in the contract work statement and technical specifications.

There is, however, a requirement for ancillary AGE in the accomplishment of the Multiplexer Set maintenance. This AGE will be used for four basic purposes:

- Isolation of failures not treated by integral testing provisions.
- Repair and/or replacement of malfunctioning items.
- Routine inspection and cleaning.
- Periodic adjustment and/or certification of internal operating signals.

The following paragraphs address the utilization of AGE for these purposes at each maintenance ground area and echelon.

5.1 Operating Complex Maintenance Functions

5.1.1 Organizational Maintenance Functions

Organizational level maintenance functions performed within the operating complex are as follows:

- Isolation of equipment failures using built-in fault isolation provisions.

- Repair of failures thus isolated.
- Periodic inspection and cleaning of a routine nature.

5.1.2 Organizational Maintenance AGE

Accomplishment of the respective organizational maintenance functions listed in paragraph 5.1.1 will require the following AGE:

- No AGE required.
- Tool kit, radar and radio, FSN 5180-690-4452 (or equivalent).
- Tool kit, radar and radio, FSN 5180-690-4452 (or equivalent).

5.1.3 Intermediate Maintenance Functions

Intermediate level maintenance functions performed within the operating complex are as follows:

- Isolation of detected equipment malfunctions which cannot be located by using integral testing provisions.
- Equipment repair involving replaceable items of plug-in and nonplug-in configurations.
- Periodic calibration of reference timing signals.

Manual isolation of failures within the Multiplexer Set equipment will require the analysis of various logic signals, voltage measurements, and conventional continuity checking.

Data rates presented to the multiplexer input can be within the range of 75 bits per second to approximately 3×10^6 bits per second. In the worst case (3×10^6 bits per second multiplexer input rate), certain circuits comprising the demultiplexer smoothing buffer function may be required to operate at a rate exceeding 60×10^6 Hertz.

The repair function will consist of conventional assembly and disassembly tasks, and of certain more unique tasks as dictated by component requirements and manufacturing processes. More specifically, repair of wire-wrapped back-plane interconnections and input/output connectors may require tools not currently available in Air Force or other military inventories.

Output data rate from the multiplexer is established by an internal reference timing module, or by a source external to the multiplexer. Timing frequency range is from 155 bits per second to 10^7 bits per second. When generated by an internal timing module, this frequency is manually adjustable to one part in 10^7, and must exhibit a long-term stability of one part in 10^6 per month.

It is expected that internally generated reference timing signals (multiplexer), and other timing signals such as those used in the demultiplexer smoothing buffer function, will require adjustment and/or calibration on a periodic basis.

5.1.4 Intermediate Maintenance AGE

Accomplishment of intermediate maintenance functions listed in paragraph 5.1.3 will require the following types of AGE.

(1) Fault Isolation

A. Oscilloscope

1 100×10^6 Hertz vertical bandwidth.

2 2 to 4 nanoseconds risetime.

3 Calibrated sweep speeds up to 5 nanoseconds/division.

4 Calibrated sweep delay.

5 Dual trace capability.

6 Accessory probes and cables.

NOTE: Required oscilloscope is functionally similar to Tektronix Type 454.

B. Voltmeter, Electronic, Portable

1 Accuracy of 3 to 5 percent of full scale.

2 Accessory probes and cables.

C. Volt-Ohmmeter, Portable

1 Accuracy to 3 to 5 percent of full scale.

2 Accessory probes and cables.

D. Module/printed circuit extender device.

(2) Repair

A. Tool kit, radar and radio, FSN 5180-690-4452 (or equivalent).

B. Tool kit, special, consisting of:

1 Wire-wrap repair tools.

2 Connector/connection repair tools.

3 Other Multiplexer Set peculiar tools as required.

(3) Calibration/Adjustment Electronic counter or other device capable of frequency measurement over range of 155 to 75 x 10^6 Hertz. Minimum accuracy to be twice (quadruple preferred) that of signal being measured/adjusted.

NOTE: Requirement for calibration/adjustment is subject to change pending availability of greater design detail.

5.1.5 Depot Maintenance Functions and AGE

Definition of depot maintenance functions and associated AGE requirements are currently undefined, pending completion of module and printed circuit card disposition mode analysis.

CHAPTER 11

GOVERNMENT FURNISHED EQUIPMENT (GFE) INTEGRATION

This chapter contains a description of the system equipment integration task of government furnished equipment (GFE) and associate contractor supplied equipment.

CHAPTER 11 GOVERNMENT FURNISHED EQUIPMENT (GFE) INTEGRATION

SECTION 11A - DESCRIPTION

Design Note 11A1 - System Equipment Integration

SECTION 11A

DESCRIPTION

This section contains a description of the maintainability requirement associated with system equipment Integration of government furnished equipment (GFE) and associate contractors supplied equipment.

SECTION 11A DESCRIPTION

DESIGN NOTE 11A1 - SYSTEM EQUIPMENT INTEGRATION

1. GENERAL
2. SOURCE OF MAINTAINABILITY PARAMETER VALUES
3. SUPPORT OF GFE OR ASSOCIATE CONTRACTOR EQUIPMENT

DESIGN NOTE 11A1 SYSTEM EQUIPMENT INTEGRATION

1. GENERAL

When items other than system/equipment contractor's items are integrated into the system, such as government furnished equipment (GFE) or associate contractor supplied equipment, the contractor should request maintainability parameter values from the procuring agency and should use these values in the maintainability analysis to arrive at the maintainability values to be entered in the contract specifications. If these maintainability values are unavailable or unknown, the contractor should estimate the maintainability parameter values. If the estimates or furnished values are incompatible with the intended use, or analysis indicates that the system/equipment will not satisfy the operational or maintainability requirements based upon these values, the contractor should identify these problems areas, advise the procuring activity, propose alternative courses of action or revised statements of requirements, and estimate those values which will allow the maintainability and operational requirements to be met. These values, subject to the approval of the procuring activity, should be used to determine the quantitative requirements to be entered in contract specifications, and as the basis for determining the contractor's compliance with the quantitative maintainability requirements during the maintainability demonstration.

2. SOURCE OF MAINTAINABILITY PARAMETER VALUES

The maintainability parameter values furnished by the procuring agency for GFE or associate contractor supplied equipments should be derived from the best data available. Demonstration data is considered to be the best data, and should be utilized for this purpose, if it is available.

3. SUPPORT OF GFE OR ASSOCIATE CONTRACTOR EQUIPMENT

In integrating this equipment into a new system, analysis should be performed to make the most cost effective decisions regarding its support. In this analysis, candidates such as providing maintenance in an already established facility or acquiring the resources to support it with the rest of the system should be considered. Typically, the relative geographical location of the existing support facility will influence this decision. Some mix of these two candidates may become a viable candidate.

CHAPTER 12

MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION INPUTS

This chapter contains a task description of the maintainability design criteria and examples of specification inputs, with guidelines, methodology, and procedures for developing specification inputs. Examples of the design criteria and specifications are included for the Multiplexer Set.

CHAPTER 12 — MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION INPUTS

SECTION 12A

MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION INTRODUCTION

This section contains detailed task descriptions, with guidelines, methodology, and procedures for the maintainability design criteria and the specifications.

SECTION 12A MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION INTRODUCTION

3. MAINTAINABILITY REQUIREMENTS IN SUBCONTRACTOR AND VENDOR SPECIFICATIONS

3.1 Subcontractor and Vendor Control (Contractor Specification Preparation)

1. MAINTAINABILITY DESIGN CRITERIA

1.1 General

The major objectives of a maintainability program for systems and equipment when installed at the user environment are that the equipment will contribute a minimum amount of downtime due to direct maintenance and will reduce the support requirements and attendant costs.

To ensure that equipment meets these objectives, the proposed concepts for the equipment or system are to be analyzed in terms of the following:

- Interface with other equipment
- Function of the equipment/system
- Requirements stated or implied
- Percentage that the item contributes to total maintenance
- Operational usage

As a result of allocations, trade-offs, special analysis, and modeling, a firm basis is established for the selection of quantitative and qualitative specification requirements,

1.2 Quantitative Criteria

Quantitative criteria or requirements are definitive statements of the allowable resources or the time to be required to perform a given type of support task. For example:

> The (equipment name) shall have a mean time between failure of (number) hours, and shall have a mean corrective maintenance time of (number) minutes. The preventive maintenance shall not exceed (number) hours within a specified period.

Quantitative criteria for the components of a new system are derived by the apportionment of the top level system requirements to lower levels of system hardware. This top level requirement is based upon specified requirements or initial estimates of the system maintenance downtime. The allocation of this time is based on design concepts and the resources available.

1.3 Qualitative Criteria

Qualitative criteria or requirements are general nonquantitative statements of desired criteria, features, or characteristics to be incorporated in the design of a system.

These are the design criteria identified during the trade-offs and special analysis of proposed concepts required to provide an optimum equipment design to achieve ease and economy in the maintenance support of the equipment. The maintainability qualitative requirements are selected as specified below.

a. To minimize downtime due to maintenance by using:
   - Maintenance-free design
   - Standard and proven design and components
   - Simple, reliable, and durable design and components
   - Fail-safe features to reduce failure consequences
   - "Worst case" design techniques and tolerances which allow for use and wear over item life.

b. To minimize maintenance downtime, by design for rapid and positive:
   - Prediction or detection of malfunction or degradation
   - Localization to the affected assembly, rack, or unit
   - Isolation to a replaceable or repairable module or part
   - Correction by replacement, adjustment, or repair
   - Verification of correction and serviceability
   - Identification of parts, test points, and connections
   - Calibration, adjustment, servicing, and testing.

c. To minimize maintenance costs by design for minimum:

- Hazards to personnel and equipment
- Special implementation for maintenance
- Requirement for depot or factory maintenance
- Consumption rates and costs of spares and materials
- Unnecessary maintenance
- Personnel skills.

d. To minimize the complexity of maintenance by design for:

- Compatibility among system equipment and facilities
- Standardization of design, parts, and nomenclature
- Interchangeability of like components, material, and spares
- Minimum maintenance tools, accessories, and equipment
- Adequate accessibility, work space, and work clearances

e. To minimize the maintenance personnel requirements by design for:

- Logical and sequential function and task allocations
- Easy handling, mobility, transportability, and storability
- Minimum numbers of personnel and maintenance specialities
- Simple and valid maintenance procedures and instructions

f. To minimize maintenance error by design to reduce:

- Likelihood of undetected failure or degradation
- Maintenance waste, oversight, misuse, or abuse
- Dangerous, dirty, awkward, or tedious job elements
- Ambiguity in maintenance in labeling or coding

The design criteria must be developed to assist the maintainability analyst in the selection of maintainability quantitative design features to enhance the incorporation of optimum maintainability into the design of systems and equipment.

2. SPECIFICATIONS

The primary guideline for the maintainability engineer in the development of specifications is as follows: If a qualitative or quantitative criterion is required and if it can be tested or verified, then state the criterion in the specification. In the evolution of specifications from criteria, the wording must also reflect the definitive nature of the requirement. All effort must be extended to eliminate the use of such vague wording as minimize, maximize, etc. The specification should contain the following:

a. Definitive statements with no ambiguity in wording. The statement, "The (equipment name) shall be packaged with plug-in modules" is more definitive than "The (equipment name) shall be packaged with plug-in modules to the maximum extent possible."

b. Realistic quantitative and qualitative requirements consistent with the state of the art and cost constraints.

c. Requirements which can be verified or demonstrated.

It is the responsibility of the maintainability engineer to ensure that the maintainability inputs and requirements are submitted for incorporation into the legal contract documents. These inputs are as follows:

- Quantitative and qualitative requirements
- Demonstration and verification requirements
- Specific maintainability tasks to be conducted (trade-offs, etc.) during performance of the contract
- Maintainability documentation requirements
- Maintainability task schedule.

The quantitative, qualitative, and verification and demonstration requirements are stated in the Configuration Item specifications; the task schedule and documentation requirements should be stipulated as part of the Statement of Work.

3. SUBCONTRACTOR AND SUPPLIER CONTROL

The prime contractor's maintainability program must provide controls for assuring adequate maintainability of purchased hardware. Such assurance is achieved through the following:

- Selection of subcontractors from the standpoint of demonstrated capability to produce a maintainable product
- Development of adequate design specifications and test requirements for the subcontractor produced product
- Development of proper maintainability and quality program requirements to impose on each subcontractor
- Close technical liaison with the subcontractor (both in design and maintainability areas) to minimize communication problems and to facilitate early identification and correction of interface or interrelation design problems
- Continuous review and assessment to assure that each subcontractor is implementing his maintainability and quality assurance programs effectively

Maintainability assurance requirements must be imposed on subcontractors and suppliers on the basis of the criticality of the hardware item being supplied. Similarly, the depth of these requirements should determine the amount of effort expended by the contractor to verify that the subcontractor is performing his assurance function adequately.

For suppliers of major components and subsystems, the prime contractor must evaluate each subcontracted item independently to determine the type of maintainability program needed. He must then impose appropriate requirements on each subcontractor.

Each major subcontractor should submit a maintainability program plan, and the contractor should monitor program implementation to assure compliance with the plan and to assess the timeliness and adequacy of individual tasks. The subcontract must contain surveillance provisions to permit such monitoring. This procedure places the contractor maintainability group in a situation very similar to that of the procuring activity's evaluators in monitoring and evaluating maintainability program performance. Therefore, the procedures for monitoring and evaluating various program elements apply to the contractor-subcontractor relationship in the same way that they apply to the procuring activity's evaluation of the contractor's program.

DESIGN NOTE 12A2 — GUIDELINES AND METHODOLOGY

1. MAINTAINABILITY DESIGN CRITERIA

System and equipment designs should incorporate features which enable cost effective maintenance support throughout a deployed hardware life. Such maintenance characteristics should be based on prescribed utilization concepts, and should be fully compatible with ultimately expected system densities, mission profiles, and georgraphical dispersement patterns. Some examples of maintainability design criteria are as follows:

a. All repair part items having the same part numbers shall be functionally and physically interchangeable without modification or adjustment of the items or the system or equipment in which they are used.

b. Maintenance adjustment or alignment shall not be required.

c. Preventive (scheduled) maintenance requirements, including calibration, shall be eliminated.

d. Physical and functional maintenance access shall be provided to any active component upon opening or removal of access entries, and shall not require the prior removal or movement of other components.

e. Devices securing access entrances and maintenance replaceable items shall be the captive, "quick-release" type.

f. Special (system or equipment peculiar) tools shall not be required in the performance of user or intermediate level maintenance tasks.

Unless otherwise dictated by customer imposed constraints, the following should be defined by total system trade studies prior to initiation of detailed system or equipment design.

- A baseline maintenance concept.
- Primary and secondary fault isolation methods, quantitatively expressed in terms of failure rate percentages and callout resolution for each level of maintenance.

- The number and complexity of hardware levels comprising the system or equipment, with the lowest being consistent with a cost effective, discard-at-failure maintenance concept.
- The required degree of intersystem and intrasystem commonality at each hardware level.
- Whenever applicable, an optimized means of interfacing mission and maintenance requirements with existing systems and equipments.

DESIGN NOTE 12A3

PROCEDURES

1. PREPARATION OF SPECIFICATIONS

The standard formats and typical language for preparation of specifications are included in MIL-STD-490.

The specification consists of the following major categories:

- Scope
- Applicable documents
- Requirements
- Quality assurance provisions
- Preparation for delivery
- Notes

1.1 Scope

The scope is a general statement of purpose of the document and a brief description of general use of the Configuration Item (CI).

1.2 Applicable Documents

All documents listed within the body of the specification, as well as other applicable reference documents, are included in this category. These documents should be available upon request by the contractor and in the file of the procuring organization making the reference.

1.3 Requirements

This category contains the performance and design requirements for the CI. The performance is specified in terms of functional requirements and includes those requirements which establish the efficiency and effectiveness of the CEI. The CI is defined in terms of the mechanical and functional relationship of the CI to other equipments, the identification of individual components incorporated in the CI that require individual specifications, and identification of requirements for manuals peculiar to and identifiable with the CI.

General design features, as well as detailed standards and specifications which must be satisfied by the design and construction of the CI, are also included in this category.

1.4 Quality Assurance Provisions

Requirements for formal verification of performance, design, and construction of the CI are included in this category. This category includes requirements for the following test/verification functions:

- Engineering test and evaluation
- Qualification inspection
- Reliability test and analyses
- Maintainability test and analyses
- Engineering critical component qualification
- Visual examination and performance test

1.5 Preparation for Delivery

This category is applicable to a production-type specification. In the design and development specification, requirements pertinent to transportation and handling of the CI which must be incorporated in design are specified in the requirements category.

1.6 Notes

This category includes information that is stated for administrative convenience only and is not part of the specification in a contractual sense.

2. MAINTAINABILITY CRITERIA FOR SPECIFICATION INPUT EXAMPLE

This portion of the design note presents examples of the type of statements that would be developed for maintainability criteria for specification inputs.

2.1 Maintainability/Maintenance Requirements (Select as Applicable)

The equipment specified herein shall be designed and manufactured for ease of economy in all maintenance functions and the availability of the equipment shall be at least (number) percent. The equipment design shall comply with the maintainability and maintenance requirements contained within paragraphs (number) througn (number).

2.1.1 Maintenance and Repair Cycles

Maintenance and repair cycles for the equipment shall consist of preventive and corrective maintenance as defined in MIL-STD-721B and shall be as follows:

a. Preventive Maintenance

The equipment design shall be such that it complies with the following requirements:

( ) Preventive maintenance downtime shall not be more than (number) hours within a (number) day period. Preventive maintenance shall be capable of accomplishment during the released status. Preventive maintenance shall be limited to the following:

( ) Maintenance calibration.

( ) Preventive maintenance man hours per (number) operating hours shall be no greater than (number) hours.

( ) The equipment frequency of preventive maintenance shall be such that the operational duration of the equipment will result in no downtime from a state of sustained operational readiness for **(number) hours of continuous operation.**

( ) Preventive maintenance on the equipment shall not be required.

( ) The equipment shall be capable of being restored to operation at the (name) level of maintenance within (number) minutes during any preventive maintenance function.

( ) The equipment shall be replaced every (number) hours of operation at the (name) level of maintenance within a mean time of (number) hours.

b. Corrective Maintenance

The equipment design shall be such that it complies with the following requirements:

( ) The mean active corrective maintenance downtime ($\bar{M}_{ct}$) of the equipment at organizational level shall not exceed (number) hours. $\bar{M}_{ct}$ shall include time required for diagnosis, repair, and checkout as defined below.

(1) Time for Diagnosis - The time for diagnosis shall begin with the recognition of improper operation and terminate when the diagnosis process indicates the item(s) to be replaced.

(2) Time for Repair - The time for repair shall begin with the completion of the diagnosis and terminate when the repair is complete. This time includes the removal and replacement of all necessary access or protective covers and all mechanical assemblies.

(3) Time for Checkout - The time for checkout shall begin with the completion of repair and shall terminate when the checkout procedure indicates that the equipment is operational.

( ) Corrective maintenance limitations are as follows:

Maintenance Level	Organizational	Intermediate	Depot
Percentage of all failures that shall be correctable at the specified level	____	____	____
Mean time ($\bar{M}_{ct}$)	____ hours	____ hours	____ hours
Maximum time (M_{max})	____ hours	____ hours	____ hours

2.1.2 Level of Diagnosis

The equipment design shall be such that it complies with the following requirements:

( ) Automatic/semiautomatic fault isolation of (number) percent or more of **the total single failures occurring within the lowest level plug-in, replaceable electronic/electro-mechanical/etc., subassembly/component/etc., which comprise the item under test, within the following limits:**

( ) Electronic subassembly isolation shall be to (number) or less subassemblies.

( ) Electro-mechanical subassembly isolation shall be to (number) or less subassemblies.

( ) Fault isolation without the use of oscilloscopes, meters, or external test equipment. All automatic/semiautomatic test equipment shall be designed as an integral part of the equipment.

( ) The fault isolation techniques shall not use part substitution or exchange to enhance malfunction isolation. Only after the error has been detected and isolated shall any module, card, part, assembly, etc., be replaced.

( ) Provide built-in test points to isolate all other single failures per unit time occurring within hardware other than electronic/mechanical/etc.; i.e., wires, connector pins, sockets, etc.

( ) Provide test point plug(s) for each assembly/subassembly, etc., to allow the assembly/etc., to be fault isolated to the (number) level while in the equipment or on the bench.

( ) Internal/external automatic/semiautomatic diagnostic capabilities shall be designed for the equipment so as to allow fault isolation within (number) minutes at the (name) level of maintenance to within (number) or less assemblies/subassemblies/etc., for a minimum of (number) percent of the failures and to (number) or less of the assemblies/subassemblies/etc., for (number) percent of the failures.

2.1.3 Maintenance Personnel

Equipment design shall be such that maintenance can be performed in accordance with the following:

( ) All equipment maintenance shall be capable of being performed by personnel possessing a skill level no higher than (name) as described in (reference).

( ) (number) percent or more of the total single equipment failures per unit time shall be correctable at the organizational level by no more than (number) maintenance men possessing skill levels no higher than (name) as defined in (document).

( ) (Number) percent or more of the single equipment failures per unit time shall be correctable at the field level by no more than (number) maintenance men possessing skill levels no higher than (name) as defined in (document).

( ) The remaining (number) percent of the single equipment failures per unit time shall be correctable at the depot level by maintenance men possessing skill levels no higher than (name) as defined in (document).

2.1.4 Categories of Maintenance

Categories of maintenance for the equipment shall be as defined in (document).

2.1.5 Service and Access

Service and access design for the equipment shall be in accordance with (document) and the following:

a. Packaging and Mounting

( ) That portion of the hardware which accounts for (number) percent or more of the total equipment failures per unit time shall be packaged in throwaway replaceable subassemblies with a replacement cost goal of $(number), but not to exceed $(number). The number of different types of plug-in subassemblies shall not exceed (number). The size of the subassemblies shall not exceed (number) high by (number) wide by (number) long.

( ) Throwaway value for each subassembly type shall be individually established, based upon failure rate, density, and acquisition and support cost.

( ) Hoisting provisions shall be provided on all removable equipment which cannot be readily handled by (number) men.

( ) No hardware item subject to maintenance below the depot level shall be permanetly mounted; i.e., riveted, welded, etc.

( ) All fastening devices securing access entries shall be captive or hand operated, or designed for operation by use of a standard bladed screwdriver, and shall be the quick-release, partial-turn type.

( ) No portion of the equipment, other than throwaway items, shall be hermetically sealed, nor shall any portion of the equipment require pressurization.

( ) Design shall be such as to permit operation of the equipment with all maintenance access covers, plates, doors, etc., removed or opened.

( ) Interconnecting wiring within the equipment shall be accessible without removing panels, covers, plates, etc., other than those provided for access to subassemblies.

( ) Access to any subassembly shall be attained upon removal of a single access cover, plate, door, etc., secured by not more than (number) quick-fastening devices.

( ) All indicators shall be designed and mounted such that their illuminating elements are replaceable from the front of the display.

( ) Circuit breakers, utilized as protective devices only, shall be located so as to prevent their use as control devices.

( ) All connectors shall be mounted such that a minimum space of (number) inches exists between adjacent connectors or other obstructions.

( ) Access to subassemblies shall not require disassembly of hardware other than removal or opening of service access panels, covers, plates, doors, etc., provided for such access.

( ) Safety wiring shall not be required to supplement primary securing devices at any hardware level.

( ) Any maintenance replaceable portion of the equipment in excess of (number) pounds shall be fitted with handles or other suitable carrying and handling devices.

( ) (number) convenience outlets shall be provided. These outlets shall supply (number) volts, (number) Hz.

( ) (number) inches shall be between replaceable (equipment name) to accommodate insertion and extraction tools.

( ) The equipment shall be designed so that (equipment name) may be replaced within (number) minutes.

b. Displays, Controls, and Indicators

( ) A lamp test capability shall be provided for all indicator lights.

( ) Maintenance indicator groups shall be functionally arranged and displaced from operator indicator groups.

( ) The equipment shall have individual elapsed time meters which will record, separately, the functioning time of the (equipment name), (equipment name), etc., up to a maximum of (number) hours.

c. Adjustments

( ) The equipment shall not require periodic field electrical or mechanical adjustment and/or alignment at any time during its specified service life. The equipment may contain adjustable electrical or mechanical piece parts provided they are the factory set and sealed type.

( ) Component parts that require field adjustment shall not be used without prior approval of the procuring agency.

( ) There will be no maintenance adjustments on the equipment unless justified by total system trade-offs and approved by the procuring agency.

d. Maintenance Calibration

( ) The equipment shall require no calibration.

( ) The equipment shall require no calibration that cannot be performed by (name) maintenance personnel. The accuracy ratio of calibrated test and measuring equipment to the unit being checked must not be less than (number) to (number).

( ) The equipment shall not require calibration in less than a (number) day interval or in less than (number) operating hours. The calibration time shall not exceed a mean of (number) hours.

e. Self-Test

The equipment shall have the capability of performing a complete automatic/semiautomatic self-test to verify that it is working correctly at the beginning of operation and during operation upon demand. It shall be capable of automatically/semiautomatically halting and signaling the existence of a malfunction. It shall be capable of performing the self-testing without jumper cables and without supplementary equipment. The time required for self-testing shall not exceed (number) minutes.

f. Identification

( ) All test points incorporated within the equipment shall be identified by test point number and signal characteristic; i.e., TP30 +28V.

( ) Each subassembly and each receptacle shall be reference designation marked to assist rapid maintenance replacement.

( ) Subassembly reference designations shall be identified on each next higher assembly.

g. Tools

( ) The equipment shall be capable of being maintained at the (name) maintenance level by the use of standard mechanical hand tools. Standard tools are defined as tools already available through the Federal Supply System.

( ) Special tools shall be designed to withstand the intended use throughout the life of the equipment. Special tools required shall be mounted within the equipment. The following tools shall be provided: card removal and insertion tool, etc. Any additional special tools shall be approved by the procuring agency.

h. Maintenance Safety

( ) All connectors having voltage potentials in excess of (number) volts which may be disconnected while the equipment is in operation shall be female type of connectors.

( ) Nonskid finish shall be provided for work platform surfaces.

( ) All sharp edges of maintenance access openings, printed circuit cards, etc., shall be eliminated.

( ) Locate all internal controls and adjustments away from voltage potentials in excess of (number) volts.

( ) Design circuits to preclude secondary trouble created by the following types of malfunctions:

(1) Short circuits to ground
(2) Short circuits to adjacent leads and/or terminals
(3) Faulty relays, transformers, and other components
(4) Excessive temperature rise
(5) Etc.

( ) Securely tie down high pressure lines and flexible tubing every (number) inches to prevent whipping of line in event of tube or connector failure.

( ) Locate all overflow and vent ports where they will not constitute a hazard to equipment and operating personnel.

i. Test Equipment

Test equipment shall be designed to withstand the intended use throughout the life of the equipment. Test equipment required shall be stored within the (name). The following test equipment shall be provided: digital counter, etc. Any additional test equipment shall be approved by the procuring agency.

2.2 Logistic Critical Components

Note: This paragraph will list the logistics critical components within the end item. Logistics critical components or component equivalents (those with long procurement leadtime, sole source procurement, high dollar value, etc.) require individual descriptions and specifications. Logistics critical components will be identified herein by their nomenclatures, descriptions, or specification numbers and, if appropriate, part numbers.

2.3 Interchangeability and Replaceability

Each equipment assembly, subassembly, or piece part which is subject to replacement at any maintenance level shall be an interchangeable item. Interchangeable items are those items having the same manufacturer's or Federal Stock number, which, when interchanged or substituted for each other without modification, adjustment, or selection, shall provide the same physical and functional characteristics required of the original items.

3. MAINTAINABILITY REQUIREMENTS IN SUBCONTRACTOR AND VENDOR SPECIFICATIONS

MIL-STD 470 states: Based on the results of maintainability analysis, the contractor should include appropriate quantitative maintainability requirements in specifications for subcontractor and vendor items procured for the system/equipments. These requirements must be stipulated in terms suitable for demonstration in accordance with MIL-STD-471 or other method approved by the procuring activity. Specifications for subcontractor and vendor items will include, where applicable, such information as:

a. System/equipment constraints and requirements.
b. Maintenance concepts and support requirements.
c. Standardization and interchangeability requirements.
d. Maintainability demonstration requirements and procedures.

A program for procedures should be stipulated for assuring that the subcontractor's and vendor's maintainability procedures are consistent with overall system/equipment requirements and that adequate surveillance of the subcontractors and vendors will be maintained to enforce compliance with all maintainability requirements specified.

3.1 Subcontractor and Vendor Control (Contractor Specification Preparation)

Subcontractor and vendor supplied items are primarily controlled by means of the specification. This control is the responsibility of the contractor, who must ensure compliance with the overall requirements stated by the procuring agency for the end item.

Vendor items are usually comprised of piece parts and subassemblies; subcontractor items are usually major component items such as assemblies. In the case of the subcontractor items, due to the complexity of the item acquired, a more rigorous means of control is utilized. In this case, in addition to a specification, a scope of work governing design and development is prepared by the maintainability group for inclusion in the overall subcontractor data package. This scope of work in most cases requires the subcontractor to provide a maintainability effort on the subcontracted item similar to the one the contractor provides to the procuring agency on the system.

SECTION 12B

EXAMPLES OF THE MULTIPLEXER SET MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION

This section contains examples of the design criteria and specifications for the Multiplexer Set.

SECTION 12B — EXAMPLES OF THE MULTIPLEXER SET MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATIONS

DESIGN NOTE 12B1 — MULTIPLEXER SET MAINTAINABILITY DESIGN CRITERIA

1. GENERAL

Maintainability performance requirements imposed upon the Multiplexer Set design fall into two basic categories: (1) quantitative requirements expressed in terms of allowable maintenance time, and (2) qualitative requirements expressed in terms of specific electrical or mechanical characteristics to be exhibited by the design. These characteristics frequently have direct influence upon the attainment of quantitative requirements.

2. QUANTITATIVE REQUIREMENTS

Maintenance of the Multiplexer Set will take two forms: corrective or unscheduled maintenance, and preventive or scheduled maintenance. As the names imply, the former is accomplished on a random demand basis as malfunctions are detected. Preventive maintenance can be accomplished on a preplanned basis, and includes a number of tasks ranging from routine cleaning and inspection to the periodic calibration and adjustment of reference timing signals.

2.1 Quantitative Requirements - Corrective Maintenance

The quantitative requirements associated with the Multiplexer Set corrective maintenance are described below.

The mean corrective maintenance time ($\bar{M}_{ct}$) for the fully configured Multiplexer Set shall not exceed 12.0 minutes. This time is measured from the time a malfunction is detected until normal equipment operation has been restored. It includes the following:

- Time required to isolate the cause of failure.
- Time required to replace or repair the defective item.
- Time required to verify that the repair process has been effective and the equipment is capable of return to normal operation.

Not included in this time interval are administrative delays such as time spent in waiting for the repairman to arrive, or time expended in obtaining replacement parts from other than the immediate maintenance area.

The $\overline{M}_{ct}$ is computed by combining predicted or demonstrated times for completing equipment maintenance tasks on the basis of their expected frequency of occurrence. The frequency of occurrence is directly related to the failure rate distribution within the set, and is established by reliability analysis.

The maximum corrective maintenance time ($M_{max\ ct}$) for the fully configured Multiplexer Set shall not exceed 36.0 minutes at the 95th percentile. Simply stated, this means that when maintenance task times are combined on the basis of their frequency of occurrence, 95 percent must have been completed in 36.0 minutes or less.

Observed maintenance task times for electronic equipments are generally accepted as being distributed in a log-normal manner. Computation of the $M_{max\ ct}$ value is accomplished based upon the standard deviation of the logarithms of the observed maintenance task time, and is expressed as:

$$M_{max\ ct} = \text{antilog}\ (\overline{\log M}_{ct} + 1.645 \log M_{ct})$$

where: $\delta \log M_{ct}$ is the standard deviation of the logarithms of the observed task times, and $\overline{\log M}_{ct}$ is the average logarithm of the observed task times.

2.2 Quantitative Requirements - Preventive Maintenance

The quantitative requirements associated with the Multiplexer Set preventive maintenance are described below.

The design shall be such that downtime will not be required for preventive maintenance. Stability of the internal reference timing module shall be such as to preclude adjustment at intervals more frequently than each 30 days.

3. QUALITATIVE REQUIREMENTS

In summary, the Multiplexer Set must incorporate built-in automatic fault detection and isolation provisions, a highly modular packaging arrangement, and other maintenance aids such as test points and jacks.

The following paragraphs identify the predominant maintainability qualitative requirements and discuss the resulting design implications.

3.1 Fault Detection and Isolation

3.1.1 Requirements

Fault detection and isolation provisions shall:

- Be automatic to the extent possible (cost effective).
- Be integral to the design.
- Insure proper equipment operation (detect improper operation) and isolate faults on a degraded and failed basis.
- Isolate faults to a relatively small portion of the equipment.
- Require no external or internal equipment connections (as a part of the detection or isolation process) or added components (such as an isolation device which is added to the equipment after a fault is detected).
- Require the use of no instruction books or charts in accomplishing the detection/isolation process.
- Be operable without interfering with normal system operation.
- Follow the normal order of signal flow.
- Be physically mounted upon a separate plug-in panel.

3.1.2 Design Implications

The allowable mean corrective maintenance time ($\bar{M}_{ct}$) of 12.0 minutes dictates that the primary fault isolation approach be an automated design. That the hardware implementing this design be integral to the equipment is given as a requirement.

The effectiveness required of the diagnostic design is large dictated by the $M_{max\ ct}$ constraint and the expected failure rate distribution. Taken literally, meeting the $M_{max\ ct}$ constraint means that no more than 5 percent of expected Multiplexer Set failures can be corrected in elapsed times exceeding 36.0 minutes.

It is unreasonable to expect that a malfunction in an equipment as complex as The Multiplexer Set can be manually diagnosed by means of conventional trouble-shooting techniques and repaired within a 36.0-minute interval. This is particularly true when it is considered that automated diagnostic designs are generally incapable of distinguishing between failure modes which they can and cannot accurately diagnose. Thus before any attempt is made to manually diagnose a fault, it must be established that the automated diagnosis was invalid. This fact is established by means of an elimination process (namely one of exchanging the erroneously indicated item) only to find that a fault indication remains. Thus a portion of the 36.0 minutes which could have been used for manual isolation and repair has already been expended in a fruitless attempt at fault correction.

Establishing the required effectiveness of the diagnostic design is accomplished in the following manner:

- Assume that manual diagnosis and repair of the Multiplexer Set malfunctions cannot be accomplished within the 36.0 $M_{max\ ct}$ constraint.
- Define those areas in which an automated diagnostic can be expected to be ineffective, and establish the percentage of total failures expected in these areas.
- Subtract this percentage from 100 percent and determine what portion of the remainder must be treated effectively by the diagnostic to enable isolation of 95 percent of the total equipment failures, using the automated diagnostic.

An automated diagnostic design is ineffective when isolating failures occurring in areas such as interconnecting wiring, connectors, cabling, and front panel components which comprise the machine side of the man-machine interface. Based upon the reliability predictions, approximately 2.9 percent of the total equipment failures are expected to occur in these areas. Conversely, 100.0 -2.9 or 97.1 percent of all equipment failures are expected to occur in areas which may be treated by an automated diagnostic. These failures will occur in areas such as card-mounted electronic circuits, line receiver and driver modules, and power supplies. The percentage of failures occurring in these areas which must be treated by the diagnostic can therefore be established by solving the following expression for X :

$$(0.971)\ (X) = 0.95$$

$$X = 0.978 \text{ or } 97.8 \text{ percent.}$$

Thus 97.8 percent of those failures which are candidates for automated diagnostic techniques must be so treated. A knowledge of how failures are expected to be distributed within the equipment may be helpful in assigning diagnostic design emphasis. SN 3.1.2 (1) reflects the failure rate distribution, in terms of percentage, based upon the reliability prediction.

SUB-NOTE 3.1.2 (1) Failure Rate Distribution Percentages

Item	Percent Total Failures
Card, Common Electronics	11.11
Card, RCB/SB	49.80
Card, Diagnostic	13.78
Module, Driver/Receiver	16.30
Power Supply	6.11
Others (Wiring, Connectors, etc.)	2.90
	100.00

While it has been assumed that manual isolation and repair of the Multiplexer Set faults cannot be accomplished within a 36.0-minute interval, there are some apparent exceptions, as follows:

a. Connector Failure - A predominant failure mode of the edge-loaded printed circuit card connector is an open circuit caused by contact contamination. Such a failure is typically corrected by removal and replacement of the affected card, thus wiping the contact area clean. While the automated diagnostic would erroneously indicate a card malfunction, the failure would be corrected by the action of replacing the indicated card.

b. Blower Failure - Improper operation of the cooling air blowers can be detected audibly. When a blower ceases to operate, the failure can be detected by the operator and corrected by replacement. This is an expedient process, capable of being accomplished within a 36.0-minute interval.

The above are examples of factors which could serve to lower the required diagnostic effectiveness, and which should be more fully examined as the design becomes firm.

Required diagnostic callout resolution is another factor having substantial impact upon the diagnostic design. The requirements that isolation be to "a relatively small portion of the equipment" and that isolation be accomplished "on a degraded and failed basis" both appear to have influence upon definition of required resolution. The term "relatively small portion of the equipment" is subject to interpretation, and can take on meanings ranging from a complete multiplexer or demultiplexer to an individual integrated circuit device. Similarly, the terms "degraded" and "failed" are subject to interpretation.

Because the equipment is capable of treating input data from as many as 31 discrete sources and of outputting to an equal number, the term "degraded" can be construed to mean a situation in which treatment of a particular input/output is erroneous while the remainder are properly processed. For purposes of this document, such an interpretation is assumed. Further, the Statement of Work establishes a sparing philosophy predicated upon field replacement of hardware at the module or printed circuit card level.

Based upon the assumed interpretation of the term "degraded" and the stated sparing philosophy, it can be concluded that the diagnostic callout should be comprised of one or more items of card or module complexity, and that a failure in one of the numerous input/output channels be diagnosed to no more than the number of cards or modules associated with that channel.

It is highly desirable to increase diagnostic resolution to a single card or module for reasons of logistical economy. Since only one of the replaceable items comprising a given callout is expected to have malfunctioned, replacement of more than one item will entail a process to determine its identity among the replaced group. This can be accomplished in several ways:

a. Discard or forward for repair the entire group of replaced items, recognizing that only one is actually at fault.

b. At some future time, when equipment operation can be interrupted, substitute the replaced group into the equipment one at a time until the defective item is identified.

c. Test the replaced group, using a card/module test set to identify the defective item.

It is obvious that certain disadvantages are inherent to each of the above processes, thereby supporting the desirability of a one-item callout. Emphasis should therefore be given to reduced callout sizes whenever design economy is not severely impacted.

Meeting the requirement that detection and isolation be accomplished without use of external or internal connections or added components is inherent to an integral diagnostic approach.

The requirement that instruction books or charts not be utilized in the detection and isolation process has significant influence upon design of those displays comprising the man-machine interface. The design must relate three basic items of information to the operator/repairman:

- That a malfunction has been detected.
- The type of malfunction involved (partial, complete).
- The location of the item(s) which must be repaired or replaced to restore normal equipment operation.

Recognizing that numerous design approaches will satisfy these requirements, it then becomes a matter of selecting one which is most efficient and least subject to human error. Decision-making on the part of the operator should be limited to one of whether or not he intends to do as instructed, not one of deciding what the instruction means. In accomplishing this objective, several guidelines are offered as follows:

a. Group all indicators and controls related to malfunction detection and isolation at a common area of the equipment, preferably upon the front panel.

b. Display the existence of a malfunction in a consistent, go/no-go manner, differentiating between those of a partial or complete kind.

c. Relate to the operator the type of item(s) he is expected to replace (i.e., card, module, power supply, etc.) so that he may obtain the necessary tools and otherwise plan for subsequent actions in the maintenance task.

d. Relate the specific location within the equipment at which the item(s) to be replaced may be found. This should be accomplished in such a manner that interpretation between the indication displayed and hardware marking is not required.

Mounting of items comprising the fault detection and isolation function upon a separate plug-in panel is required if feasible. The primary consideration in determining such feasibility is not necessarily one of a mechanical packaging kind. An automatic detection and isolation capability which satisfies effectiveness and callout resolution requirements tends to become relatively complex.

Because nearly 14 percent of all equipment failures can be expected to occur in circuits comprising the detection and isolation function, some degree of "checking the checker" is required in order to attain the required diagnostic effectiveness.

Diagnostic designs are notoriously incapable of assessing their own condition. When improper performance of diagnostic components must be recognized and identified in terms of replaceable item(s), special measures are required. A diagnostic for the diagnostic can be added, but tends to perpetuate rather than eliminate the diagnostic problem. The diagnostic can be separately located within the equipment and removed based on an elimination process once primary correction procedures have proven ineffective. This approach has an undersirable effect upon maintenance time. Finally, the diagnostic can be collocated with the function which it monitors and assesses. In such a case, failure of either the function being evaluated or the components which perform the evaluation will be properly identified in terms of a replaceable item. This approach conflicts with the requirement for a separate plug-in test panel, but would appear most desirable from the standpoints of cost, complexity, downtime, and diagnostic effectiveness. In essence, it is a most feasible approach, making others less feasible in a relative sense. Further, use of a common test circuit for all channel-related hardware appears not to be feasible from the standpoint of packaging. The cyclic tester approach described in the proposal requires that approximately eight lines be routed between each channel and the common tester. With 31 channels, this is a total of (8) (31)=248 lines. The connector to be used for interconnecting printed circuit cards with the wiring plane incorporates 80 pins. Thus a minimum of four cards would be required for the tester implementation due to connector pin limitations. The 248 pin count considers callout resolution to the affected channel only. Smaller callout sizes, which are obviously desirable, would significantly increase the required pin count, and therefore the quantity of cards which must comprise the test function.

Placement of channel-related test circuits upon a separate plug-in panel is therefore considered not to be feasible. Because of the limited relative complexity of the common electronics design, placement of all diagnostic circuits for this area upon a separate plug-in card should be considered.

3.2 Test Points and Jacks

3.2.1 Requirements

Test points and jacks must be short circuit protected and provided for those voltages and waveforms which are useful in maintenance and not metered or monitored by the integral test facility. The locations must be accessible from the front of the equipment.

Those voltages and waveforms which are metered or monitored by the integral test facility must be provided, and these must be located at the rear of the equipment.

Test points and jacks must also be provided for power supply dc voltages.

3.2.2 Design Implications

The proposal supplement notes that EMI/RFI requirements imposed by RFP changes would preclude compliance with the requirement for test points accessible from the front of the equipment. As an alternate approach, it was proposed that selected signals would be routed to test points located along the top edge of the printed circuit cards.

Ground rules applicable to incorporation of test points include the following:

a. Provide maximum visibility into the card function. Select points at outputs of combining functions such as multiplexer and register elements within the card functions and at the primary functional outputs of the total card.

b. To the extend possible, number selected points sequentially from card input to output, based upon logical function.

c. Physically correlate test point number and position along the card edge in a sequential manner, providing a maximum degree of consistency for the repairman.

It was also proposed (in the proposal supplement) that power supply dc voltages be routed to the equipment front panel and physically terminated in a female connector protected by a partial-turn, EMI/RFI gasketed cap. These test points will be of value primarily when power supply error sensing and switching circuits malfunction. Therefore, outputs from both the on-line and standby supplies should be provided.

3.3 Major Component Replacement

3.3.1 Requirements

Major components or modules shall be completely removable from enclosures without disassembly or requiring special tools.

3.3.2 Design Implications

The term "without disassembly" is interpreted to mean without disassembly of the major component or module. In the Multiplexer Set design, "major components or modules" are interpreted to include the following items:

- Printed circuit cards.
- Line driver and receiver modules.
- Power supplies (each, when multivoltage; each unit, when single voltage).
- Wiring plane.
- Front panel assembly (replacement of panel subassemblies such as a unitized strapping switch unit is desirable).

It should be noted that use of conventional tools can be employed in a remove/replace action. Special tools are those peculiar to the Multiplexer Set design. An example of a peculiar tool would be a printed circuit card extractor tool specifically designed for the selected card configuration.

3.4 Card Extender

3.4.1 Requirements

An extension plug-in shall be provided for maintenance.

3.4.2 Design Implications

Extenders are required for cards and modules whose connector pins are not accessible for probing in the normally installed position. The baseline packaging design, which mounts power supplies and switching relays in the area of card and module connectors, requires that extenders be provided for both cards and modules.

Extenders should be provided for each multiplexer and demultiplexer unit, with internal storage provisions provided in the form of a spare card connector or retaining clip.

DESIGN NOTE 12B2 — **MULTIPLEXER SET SPECIFICATION EXAMPLE**

1. SPECIFIED REQUIREMENTS

Maintainability requirements applicable to the Multiplexer Set are set forth in Specification RADC-5265 (ammended), paragraph 3.8, and Statement of Work PRC-9-2117 (ammended), Annex 2. Specification paragraph 3.8 incorporates Annex 2 requirements by reference. These requirements are as follows:

1.1 Corrective Maintenance Time (Annex 2, paragraph 3.1.1)

a. Mean corrective maintenance time ($\bar{M}_{ct}$) shall not exceed 12.0 minutes.

b. Maximum corrective maintenance time ($M_{max\ ct}$) shall not exceed 36.0 minutes (95th percentile).

c. Preventive Maintenance Time (Annex 2, paragraph 3.1.1.1)

The design will be such that downtime will not be required for preventive maintenance.

1.2 Service and Access (Annex 2, paragraph 3.1.1.2)

a. Ease of servicing and access will be a primary design consideration.

b. The equipment will be designed for rapid repair through the use of automatic fault location, plug-in modules, etc., to the extent practical.

c. The equipment design and construction shall be such that it can be maintained within the specified maintainability time constraints.

d. The stability and reliability of the equipment shall be such as to require a minimum of auxiliary test equipment, such as oscilloscopes and transmission measuring sets, for operation or alignment.

e. Integral metering facilities or other indicating devices shall be provided to insure proper operation of equipment and to isolate failures on a satisfactory, degraded and failed basis to a relatively small section of the equipment without requiring the use of external or internal connections, added components, instruction books or charts.

f. The integrated test facilities shall be designed such that they may be operated without interfering with normal system operation.

g. Monitoring with the test facilities shall follow in the normal order of signal flow.

h. Circuits for monitoring shall be placed on a separate test plug-in panel.

i. A plug-in extension board shall be provided for maintenance.

j. Major components or modules shall be completely removable from enclosures without disassembly or requiring special tools.

k. All voltages and waveforms used in the maintenance of the equipment shall be brought to a test point accessible from within the equipment enclosure.

l. Test points and metering facilities shall also be provided for the power supply d.c. voltages.

m. All test points shall be short circuit protected.

1.3 On-Line Maintenance (Annex 2, paragraph 3.1.1.2.1)

Equipment design shall enable the corrective replacement of the following items without requiring the prior removal of equipment operating power:

- Rate conversion buffers
- Smoothing buffers (both high-speed and low-speed)
- Source-to-transmission rate converters
- Transmission-to-source rate converters
- Transition encoders
- Transition decoders
- Source-to-equipment digital interface circuits
- Equipment-to-source digital interface circuits
- Either of the cooling blowers in both multiplexer and demultiplexer.

Removal and replacement of any of the above items shall not disrupt the proper operation of any equipment circuitry. A control shall be provided for the initialization of the circuits within the replaced item(s). The initialization shall be applied only to the data channels associated with the replaced item and shall not affect proper operation of any of the other equipment circuitry. Rapid and efficient removal of the cooling blowers shall be accomplished through the use of quick-disconnect type connectors.

CHAPTER 13

MAINTAINABILITY PREDICTIONS

This chapter contains a detailed task description, guidelines, methodology, and procedures to develop the maintainability predictions. It also contains an example of maintainability predictions on the Multiplexer Set using the procedures discussed in this chapter.

CHAPTER 13 MAINTAINABILITY PREDICTIONS

SECTION 13A

MAINTAINABILITY PREDICTIONS INTRODUCTION

This section contains a task description of the maintainability predictions, with guidelines, methodology, and procedures for developing early and detailed design maintainability predictions.

SECTION 13A — MAINTAINABILITY PREDICTIONS INTRODUCTION

DESIGN NOTE 13A1 - DETAILED TASK DESCRIPTION

DESIGN NOTE 13A2 - GUIDELINES AND METHODOLOGY

DESIGN NOTE 13A3 - PROCEDURES

DESIGN NOTE 13A1 **DETAILED TASK DESCRIPTION**

1. INTRODUCTION

To assure that established requirements for system maintainability have been met, it will be necessary to assess the system's maintainability characteristics periodically throughout the development process. Two principal techniques are available for this assessment process: prediction and design review. This chapter describes the prediction method. Design reviews are covered in Chapter 4. (Testing is another means of assessment; see Chapters 15 and 16 for a discussion of demonstration testing.)

During the planning phases, the predicted maintainability of the various systems proposed to meet an operational need are critical factors in selecting the optimum course of action. Since a limited quantity of specific data is available in this phase, maintainability predictions are based largely on experience with predecessor systems and on prediction techniques applicable during the planning phase.

During the early design phase of full-scale development, reliability and maintainability predictions can be used to determine the inherent availability of the proposed system, the effects of proposed changes on availability, and the optimum trade-off of equipment characteristics. Predictions made during this phase are generally more accurate than those made in the planning phase, since more specific system information is available. Because they are more accurate than assessments conducted during the planning phase, the predictions obtained during early full-scale development should be used to upgrade earlier predictions and the technique used to obtain them. This chapter and the following sections and design notes contain two procedures for use during the early design phase and the detailed design phase.

2. MAINTAINABILITY PREDICTION METHODS

Two methods are presented for predicting corrective maintenance times: one for use during the early design stage and one for use during detailed design. The early design prediction is intended for use early during the full-scale development phase, and the detailed design prediction is intended for use from the time a detailed functional block diagram and a complete packaging philosophy are available until the end of the design phase.

The basic procedure is to divide active downtime into several categories, to predict each category individually, and to combine these predictions and obtain active downtime. In addition, techniques are provided for accounting for the time spent on tasks when the reported failure is not verified (no trouble found) and for predicting maintenance man-hours.

2.1 Philosophy, Assumptions, and Summary

The underlying philosophy of these procedures is to divide active downtime into several categories, to predict each corrective maintenance time category individually, and to combine these predictions and obtain the active downtime. MIL-STD-721B recognizes seven time categories associated with the corrective maintenance process: (1) preparation, (2) fault location, (3) item obtainment, (4) fault correction, (5) adjustment/calibration, (6) checkout, and (7) cleanup. Within these time categories, there is considered to be a commonality of process between fault location and checkout times, and a similar relationship between fault correction and adjustment/calibration times. In the former case, the displays and test points used for fault location are also used to check the system for satisfactory operation. Also, the same type of thought process is involved in determing whether or not the system is operating properly. In the latter case, both fault correction and adjustment are manipulative tasks. Therefore, in these prediction techniques, the categories of active downtime are (1) fault location/checkout time (T_d), (2) fault correction/adjustment time (T_c), (3) preparation time (T_p), and (4) item obtainment time (T_i).

2.2 Applicability

The prediction techniques described below are applicable to both the early design and detailed design stage of equipment development. They are capable of predicting active corrective maintenance downtime for first echelon LRU (line replaceable unit) on-equipment repairs. Additionally, techniques are provided for estimating the time spent on "no trouble found" tasks and for estimating total maintenance man-hours.

The techniques produce estimates of average system downtime and average man-hours per system failure. The manner in which individual LRU data is used precludes developing quantitative estimates at the LRU level. It is, however, possible to identify LRU's which make significant contributions to system level results. Such identifications are qualitative, though, and not quantitative.

2.3 Point of Application

The early design prediction is intended to be used during the system concept phase, and the detailed design prediction is intended to be used from the time a detailed functional block diagram and a complete packaging philosophy are available. Specific information required for each technique is contained in DN 13A3.

2.4 Basis for Prediction Techniques

The data utilized for the development of the prediction procedure covered in DN 13A3 was obtained during the surveillance of four equipments of varying complexity, circuitry, use, maintenance, and packaging concepts.

The techniques were validated, on a limited scale, through application to both a ground electronic and an avionic equipment. A comparison of the predicted versus field observed mean corrective maintenance times for the validated equipments indicated agreement to within 10 percent.

Based on 15 systems, regression analyses were performed to generate prediction equations. The early design prediction equation has an R^2 value of 0.45 (R = 0.67), and the detailed design prediction equation has an R^2 value of 0.47 (R = 0.68). These values represent an improvement over previous approaches. Several factors which are not accounted for in the prediction parameters may contribute significantly to the standard error. These factors are the variability of the human element (maintenance technician), environmental factors, and basic failure rate variability. However, each of these factors also contributes, directly or indirectly, to the variability of other existing maintainability prediction metnods.

DESIGN NOTE 13A2 GUIDELINES AND METHODOLOGY

1. GENERAL

Guidelines have been developed for implementing the two procedures mentioned in DN 13A1. The guidelines are in the areas of symptom selection, symptom-fault analysis, and maintenance design checklist evaluation.

2. SYMBOLS AND NOTATIONS

The following symbols and notations are used in the prediction techniques described in DN 13A3. A bar is placed over a symbol to denote the average value of the parameter.

f_i	ith LRU in a system
$H(s,f)$	the average information associated with the occurence of a symptom (s) and a failure (f)
$\overline{M.M.}$	average man-minutes per maintenance task
P_{ij}	λ_{ij}/λ_t
S_i	ith system symptom
$\bar{T}$	average total active downtime
$\bar{T}'$	average total active downtime when "no trouble found" tasks are included
T_c	fault correction time
T_d	fault location/checkout time
T_i	item obtainment time
T_p	preparation time
T_{ci}	fault correction/adjustment time for ith LRU
$\bar{X}_t$	average maintenance design checklist score
X_{Ti}	total checklist score $(X_1+X_2+X_3+X_4)$ for ith LRU
X_1	test complexity checklist score
X_2	test measurement checklist score
X_3	test evaluation checklist score
X_4	test availability checklist score

λ_i	total failure rate of f_i
λ_T	total system failure rate
λ_{ij}	failure rate of jth LRU assigned to ith symptom in symptom-fault matrix

3. PREDICTION EQUATIONS

The analytic foundation of the prediction techniques consists of the development of mathematical models that relate active downtime to a set of design parameters. The prediction is made in terms of four major parameters as follows:

- Preparation time, T_p
- Fault location/checkout time, T_d
- Item obtainment time, T_i
- Fault correction/adjustment time, T_c

When summed, these time quantities equal total active downtime; that is,

$$\bar{T} = \bar{T}_p + \bar{T}_d + \bar{T}_i + \bar{T}_c$$

where a bar over a quantity denotes the system average.

The prediction equations for the parameters, for the average active downtime including "no trouble found" tasks, and for average man-hours per task are shown in SN 3 (1). Equations are presented for both ground and airborne systems.

4. FAULT LOCATION/CHECKOUT TIME (T_d)

Fault location/checkout time is a function of the number of diagnostic steps that must be taken and the time required for each step. The number of steps is a function of the troubleshooting technique, test philosophy, number of test modes, and number of replaceable items associated with each symptom. Similarly, checkout time is a function of the complexity of the characteristics being tested, the equipment necessary to measure the characteristic, the interpretation of the test result required, the availability of needed test

SUB-NOTE 3(1) Maintenance Downtime Prediction Equations

	Early Prediction	Detailed Prediction	
Time Category	Equations (all times in min)	Parameter	Equations (all times in min)
1a. Fault location/ checkout and fault correction/adjustment	$\ln(\bar{T}_d + \bar{T}_c) = 0.325 \ln \bar{X}_t + 0.805 \ln H(s,f) + 1.293$	1b. Fault location/ checkout	$\ln \bar{T}_d = 0.420 \ln \bar{X}_t + 0.802 \ln H(s,f) + 0.625$
		1c. Fault correction/ adjustment	$\bar{T}_c = \frac{\Sigma \lambda_i t_{ci}}{\Sigma \lambda_i}$
2. Preparation	$\bar{T}_p = 0.048\ (\bar{T}_d + \bar{T}_c)$ (ground) $= 0.093\ (\bar{T}_d + \bar{T}_c)$ (air)	$\bar{T}_p = 0.048\ \bar{T}_d$ (ground) $= 0.093\ \bar{T}_d$ (air)	
3. Item obtainment	$\bar{T}_i = 2.15$ (ground) $= 16.13$ (air)		
4. Total average active downtime	$\bar{T} = \bar{T}_d + \bar{T}_c + \bar{T}_p + \bar{T}_i$		
5. Total average active downtime (including "no trouble found" tasks)	$\bar{T}' = 0.718\ \bar{T} + 8.963$		
6. Average man-minutes	$\overline{M.M.}$ (minutes) $= 2.104\ \bar{T} - 14.20$		

points, and any mechanical hindrances that may impede the diagnostic process. Design parameters representing each of the above areas were developed so that a prediction expression could be formulated.

The design for maintenance is assessed by developing four design checklists which measure test complexity (X_1), test measurement (X_2), test evaluation (X_3), and test availability (X_4). By preparing a checklist summary for each LRU (replaceable unit) an $\overline{X}_t$ for the system is calculated by:

$$\overline{X}_t = \frac{\Sigma\lambda_i X_{Ti}}{\Sigma\lambda_i}$$

where: λ_i = the failure rate of the ith LRU

X_{Ti} = the total checklist score ($X_1+X_2+X_3+X_4$) for the ith LRU.

The other factor associated with $\overline{T}_d$ is H(s,f).

This parameter estimates how easily failures are traced to failed LRU's by measuring the average information associated with the occurrence of the symptom and the failure. It is determined in the following way. Let S_i i=1,2..., n be a set of failure symptoms for an equipment, let f_j j=1,2...n be a set of LRU's, let λ_{ij} be that part of the jth LRU's failure rate which produces symptom S_i, and let $p_{ij} = \lambda_{ij}/\lambda_T$ denote the probability of the joint occurrence of symptom i and the failure of f_j. Then

$$H(s,f) = \Sigma p_{ij} \log_2(p_{ij}) \qquad i=1,2,\ldots,n \quad j=1,2,\ldots,n$$

5. FAULT CORRECTION/ADJUSTMENT TIME (T_c)

Fault correction/adjustment time is that portion of the total maintenance time required to remedy the trouble, whether it requires a complete interchange of parts or only a minor adjustment.

In the early prediction technique, a single equation predicts the sum $\bar{T}_d+\bar{T}_c$. At the detailed prediction stage, more detail is available and the prediction of $\bar{T}_c$ has three steps:

a. Define the range of fault correction/adjustment tasks that must be performed.

b. Analyze a representative sample of fault correction tasks to determine the subtasks involved and apply time standards to determine time required.

c. Summarize the results of step b to establish the average fault correction time ($\bar{T}_c$) for the system.

$$\bar{T}_c = \frac{\Sigma\lambda_i\, t_{ci}}{\Sigma\lambda_i}$$

where: λ_i = failure rate of the ith LRU

t_{ci} = estimate of task time for ith LRU.

6. PREPARATION TIME (T_p)

The preparation time required for a maintenance action depends, to a great extent, on the maintenance environment and procedures that apply. However, this time category is also influenced by equipment design, which establishes requirements for tools and test and auxiliary equipment. The relationship between the design parameters and preparation time is determined by a ratio as seen in equation (2) of SN 3(1).

7. ITEM OBTAINMENT TIME (T_i)

Item obtainment time (T_i) is predicted by estimating the time required to perform a supply action in the proposed maintenance and supply environments and then multiplying this time by the observed number of item obtainment actions per maintenance task. The observed average number of item obtainment actions per task was 0.73 for airborne systems and 0.32 for ground sytems.

Where not enough information is available to estimate the time required for a supply action, this observed value may be used. These values for airborne and ground systems are 22.09 and 6.23 minutes, respectively. When the ratio of actions per task is combined with the average time per action, the result is an average item obtainment time of 16.13 minutes for airborne systems, and 2.15 minutes for ground systems. These are the figures shown in equation (3) of SN 3(1).

DESIGN NOTE 13A3 PROCEDURES

1. APPLICATION

Detailed procedures for applying both the early and detailed design prediction technique discussed in DN 13A1 and DN 13A2 are described in this design note.

2. EARLY DESIGN PREDICTION

The early design prediction technique is applicable to equipments in the early design phase of full-scale development. The following information is required to implement the technique:

- Maintenance concept
- Functional block diagrams
- Equipment theory of operation
- List of major equipment LRU's
- Reliability estimates at the LRU level.

Depending on the equipment under study, the maintenance concept and functional block diagrams may exist as part of a hardware specification or other contractual requirement. Other information will exist in the design groups, or may have been generated as part of a previous effort. Engineering judgment or design goals may be needed to fill in missing data. However, the material required for this prediction effort is sufficiently basic that the above information will generally be available soon after a preliminary design review (PDR) and most certainly by the time a contractor is prepared to hold a critical design review (CDR).

The following four steps, each of which is discussed in a subparagraph below, are associated with this prediction effort:

- Establish maintenance concept.
- Develop symptom-fault matrix.
- Determine maintenance design characteristics of the LRU's.
- Compute expected total active downtime.

2.1 Establish Maintenance Concept

Establishment of a maintenance concept requires that the analyst determine certain facts, including the following:

- Level of maintenance (flight line, shop, depot, etc.)
- Level of replacement (black box, assembly, module, or part)
- Test concept (manual, automatic, or combination)

This information provides the guidelines with which to conduct the analysis.

2.2 Develop Symptom-Fault Matrix

This activity is carried out in three steps:

- Prepare functional block diagram of the system.
- Perform reliability analysis.
- Determine effects of LRU failures on system operation.

2.2.1 Prepare Functional Block Diagram

The functional block diagram shows the relationship between system functions and hardware elements. In preparing the diagram, an analyst makes use of available design and specification data relating to the theory of system operation. The hardware description is obtained from the various design groups or perhaps from a configuration group which maintains the system breakdown or family tree. For a complex system, it will be useful to develop the diagram at more than one level. The highest order diagram will show a first order breakdown of system functions and major subsystem interfaces. Lower order diagrams will develop the functional areas in more detail. At the lowest level, the functional block diagram will show major LRU's on which the maintenance is to be performed and the signal paths between them. At all levels, the diagram should show system outputs to operators or other equipments and note where system signals are displayed or monitored by built-in test equipment.

2.2.2 Perform Reliability Analysis

Consistent with the equipment maintenance philosophy, the functional block diagram will identify the major LRU's for the system. A reliability estimate is now developed for each LRU. These estimates are normally generated as part of the reliability program. The basis for the estimates is as follows:

- Program preferred parts lists
- Component derating guidelines
- Preliminary parts and materials lists generated by designers
- Similar equipment description generated in previous programs.

If the required estimates are not available as an output of the reliability program or other contractual requirement, applicable techniques for developing these estimates are given in MIL-STD-756A, MIL-HDBK-217A, or the RADC Reliability Notebook, Volume I.

The results of the reliability prediction can be summarized as shown in SN 2.2.2 (1). Three indenture levels are used to describe major subsystems, next level items as required, and finally LRU level (the level at which the maintenance and this analysis is conducted). Entries for quantity per system and total system failure rate are made at the LRU level and the total system failure rate λ_T is the sum of the LRU failure rates.

SUB-NOTE 2.2.2 (1) Reliability Prediction Summary

Unit	Quantity per System	System Failure Rate (failure/10^6 hours)
Subsystem A		
Group sub 1		
LRU(a)	10	λ_a
LRU(b)	10	λ_b
LRU(c)	5	λ_c
Group sub 2		
LRU(c)	10	λ_d
LRU(d)	6	λ_e
Subsystem B		
LRU(e)	5	λ_f
LRU(f)	5	λ_g
LRU(g)	5	λ_h
		Total λ_T

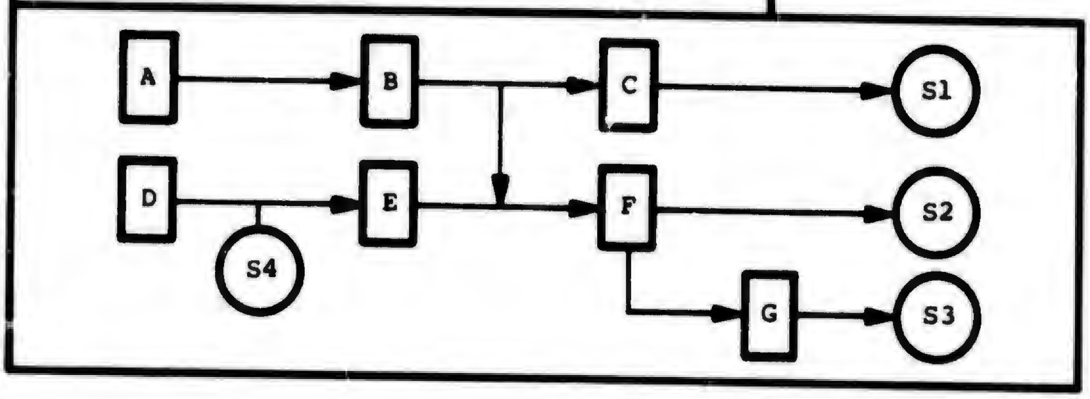
2.2.3 Determine Effect of LRU Failures on System Operation

System failure symptoms are now established. A symptom is defined as a loss or degradation of a major operational function or output of the system. Symptoms are described in terms of the manner in which system signals or outputs are displayed operationally or are provided to another system. A systematic review of the functional block diagram can be used to generate a list of symptoms by examining the following:

- External system outputs - signals provided to other systems.
- System outputs - signals output to operators.
- Status and monitor panels - these often display important internal system signals.
- Other built-in test equipment (BITE) information.

When the system failure symptoms are defined, the analyst will then complete a symptom-fault matrix. To illustrate this process, SN 2.2.3 (1) shows a theoretical system with seven LRU's (A through G) with failure rates λ_A through λ_G.

SUB-NOTE 2.2.3(1) System Functional Diagram



SUB-NOTE 2.2.3 (2) Initial Symptom-Fault Matrix

LRU	Failure Rate	S1	S2	S3	S4
A	λ_A	$\lambda_A/2$	$\lambda_A/2$		
B	λ_B	$\lambda_B/2$	$\lambda_B/2$		
C	λ_C	λ_C			
D	λ_D				λ_D
E	λ_E		λ_E		
F	λ_F		λ_F		
G	λ_G			λ_G	
Total	λ_T				

Arrows indicate the direction of signal flow. Signals S1, S2, and S3 are system outputs, and signal S4 is an internally measured signal which is displayed. SN 2.2.3 (2) shows the initial form of the symptom-fault matrix for this system. It was developed as follows:

a. Enter each LRU and its failure rate on successive lines of the table.

b. Determine the dominant failure symptoms for each LRU. To do this, determine the system failure symptoms that are the most significant in determining that this LRU failed. Even though several symptoms may be present, ordinarily a smaller number provides specific clues that the LRU in question may be at fault.

c. Apportion each LRU's failure rate among the dominant symptoms. The apportionment is based on system configuration, equipment description data, if available, or engineering judgment. In the absence of specific information, the failure rate is divided equally among the dominant symptoms.

d. When this initial allocation is complete, a reduction in the total number of entries may be made by defining compound symptoms. A compound symptom is the simultaneous occurrence of two symptoms. When a compound symptom is identified, the LRU failure rates which were previously assigned to the individual symptoms are assigned to the compound symptom column and deleted from the contributing columns. Compound symptoms containing three or more simple systems should be avoided unless they can be used to describe a catastrophic symptom such as "no cabinet outputs", "display blank", etc.

SN 2.2.3 (2) shows the symptom-fault matrix when the dominant symptoms have been determined for each LRU. For LRU's A and B, the failure symptoms are S1, S2, and S3. In each case, S2 dominates S3 since the same LRU's that produce S2 are those that produce S3. The reverse is not true since G contributes to S3 but not to S2. The analysis of E and F is similar since both cause symptoms S2 and S3, but S2 dominates S3. In studying D, it is clear that symptom S4 dominates S2 and S3.

In looking for compound symptoms, note that all LRU's except A and B exhibit a single dominant symptom. However, both A and B exhibit S1 and S2. A check of the functional diagram shows that a new symptom S5, which is "S1 and S2", may be added to the list to consolidate the entries for A and B. The result of this addition is shown in SN 2.2.3 (3). Note that once the dominant symptoms are identified, the analyst is in a position to answer the question, if symptom S_i occurs and in the absence of other information, which LRU's have most likely failed? This should be the basic philosophy in establishing a symptom-fault matrix.

When the symptom-fault matrix is complete, H(s,f), which is one of the prediction parameters used in the early prediction, is calculated. Let the symptom-fault matrix have symptoms S_i $i=1,2,\ldots,m$

and

LRU's f_j $j=1,2,\ldots n$,

and λ_{ij} is that part of the jth LRU's failure rate apportioned to S_i.

The $\sum_i \lambda_{ij} = \lambda_j$ the failure rate of f_j, and $\sum_j \sum_i \lambda_{ij} = \sum_j \lambda_j = \lambda_T$ the total system failure rate. Define $p_{ij} = \lambda_{ij}/\lambda_T$ as the probability of the joint occurrence of symptom S_i and LRU failure f_j. Then

$$H(s,f) = -\sum p_{ij} \log_2 p_{ij} \qquad \begin{matrix} i=1,2,\ldots,m \\ j=1,2\ldots,n \end{matrix} \qquad (1)$$

SUB-NOTE 2.2.3 (3) Symptom-Fault Matrix After S5 Is Added

LRU	Failure Rate	S1	S2	S3	S4	S5 = S1 and S2
A	λ_A					λ_A
B	λ_B					λ_B
C	λ_C	λ_C				
D	λ_D				λ_D	
E	λ_E		λ_E			
F	λ_F		λ_F			
G	λ_G			λ_G		
Total	λ_T					

H(s,f) is the average information associated with the occurrence of a symptom and a failure. SN 2.2.3 (4) is a convenient worksheet for performing this calculation. A brief example, corresponding to the matrix in SN 2.2.3 (3), is shown. All the failure rates (λ_{ij}) in a symptom-fault matrix are entered in the first column and the total (λ_T) is entered at the bottom.

In the second column, each failure rate is converted to a decimal ($p_{ij} = \lambda_{ij}/\lambda_T$). The third column contains $L(ij) = -\log_2 p_{ij}$. To simplify the computation, note that logarithms to the base 2 are related to logarithms to base 10 by the formula

$$-\log_2 X = -\log_{10} X/0.3010$$

Finally, the product of the second and third columns is entered in the fourth column and these entries are summed to obtain H(s,f).

SUB-NOTE 2.2.3 (4) Worksheet for Computing H(s,f)

λ_{ij}	P_{ij}	$L(ij) = -\log_2 P_{ij}$	$P_{ij}L(ij)$
$\lambda_A = 30$	0.15	2.74	0.41
$\lambda_B = 50$	0.25	2.00	0.50
$\lambda_C = 40$	0.20	2.32	0.46
$\lambda_D = 20$	0.10	3.32	0.33
$\lambda_E = 15$	0.075	3.73	0.28
$\lambda_F = 10$	0.05	4.31	0.21
$\lambda_G = 35$	0.175	2.51	0.44
$\lambda_T = 200$	1.00		H(s,f) = 2.63

2.3 Determine Maintenance Design Characteristics of LRU's

The design for maintenance is assessed by evaluating the four design checklists (factors X_1 through X_4) for each replaceable item (LRU). The functional block diagram is used to identify the outputs and their characteristics for each LRU on which the checklist scores are based.

Each checklist score reflects the manner in which the output is displayed or, if it is not displayed, the manner in which it can be tested. When outputs cannot be measured (module substitution required), the first three checklists are scored on the basis of how the measurement could be made if access were available. In such cases, the last item on checklist X_4 applies.

SN 2.3 (1) is the checklist to measure the complexity of the test characteristics to be measured during fault diagnosis and location. As the signals to be measured become more complex, more information is required to evaluate a test result. The increase in test complexity is accounted for by increasing the weight assigned to the test characteristic. The characteristics listed cover the range encountered in electronic system maintenance from built-in go/no-go tests to complex digital pulse trains.

SN 2.3 (2) is a checklist to measure the ease with which needed tests can be made. The rationale for developing this checklist was that test rapidity is a function of the type of device required to make the test; i.e., the more complex the test device and the more difficult to comprehend the displayed result, the longer a test will take.

SN 2.3 (3) is the checklist to measure the ease with which test results can be interpreted. The first test characteristic is selected when the results of a test can be related to a single replaceable item. The second test characteristic is selected when an output is determined to be incorrect but could be caused by two or more replaceable items. When a test result cannot be directly interpreted as incorrect output, and also cannot be related to a single replaceable item, the third test characteristic is selected.

SN 2.3 (4) is the checklist to measure the availability and identification of circuit points for test. Here, it was decided that the need for a physical test point and the ease with which a hookup could be made would affect the speed of diagnosis. If no connection is necessary to perform a test, very little time will be consumed. However, if test points need to be located and obstructions removed, the test time becomes progressively greater. If the item cannot be tested as installed, this characteristic is assigned the greatest weight because it makes the operational status extremely difficult to determine.

SUB-NOTE 2.3 (1) Checklist for Test Complexity (Factor X_1)

System ____________ LRU ____________

Test Characteristic	A Ident. No.	B Weight	C Number of Tests	D Total
Magnitude (voltage, current)	1	1	____	____
Polarity (voltage, current)	2	1	____	____
Frequency	3	1	____	____
Rise time	4	3	____	____
Fall time	5	3	____	____
Pulse duration	6	1	____	____
Phase	7	3	____	____
Wave shape	8	5	____	____
Distortion	9	5	____	____
Bandwidth	10	5	____	____
Gain	11	5	____	____
Modulation percentage	12	5	____	____
Impedance	13	3	____	____
Resistance	14	1	____	____
Standing wave ratio	15	5	____	____
Signal/noise	16	3	____	____
Noise figure	17	3	____	____
Noise intensity	18	3	____	____
Intermodulation	19	5	____	____
Go/no-go	20	1	____	____
Multistate pulse train	21	10	____	____
Total				

SUB-NOTE 2.3 (2) Checklist for Test Instrumentation (Factor X_2)

System ______________________ LRU ______________________

Test Device	A Ident. No.	B Weight	C Number of Tests	D Total
Multimeter	1	2	____	____
VTVM	2	2	____	____
Oscilloscope	3	10	____	____
Distortion meter	4	7	____	____
Phase meter	5	5	____	____
Impedance meter	6	7	____	____
Bridge	7	7	____	____
Power meter	8	5	____	____
Echo box	9	5	____	____
Counter	10	5	____	____
Digital voltmeter	11	3	____	____
Differential voltmeter	12	3	____	____
Audio signal generator	13	5	____	____
Tape tester	14	10	____	____
Modulation meter	15	7	____	____
Audio output meter	16	2	____	____
Audio indicator	17	1	____	____
RF signal generator	18	7	____	____
Pulse generator	19	10	____	____
Power supply	20	5	____	____
Dummy load	21	3	____	____
Frequency meter	22	7	____	____
Built-in display	23	1	____	____
Automatic test	24	1	____	____
Total				

SUB-NOTE 2.3 (3) Checklist for Test Evaluation (Factor X_3)

System________________ LRU________________

Test Characteristic	A Ident No.	B Weight	C Number of Tests	D Total
Test result interprets measured value and identifies defective unit	1	1	____	____
Test result interprets measured value but technician must associate test with defective unit	2	3	____	____
Test result must be both interpreted and associated	3	5	____	____
Total				

SUB-NOTE 2.3 (4) Checklist for Test Availability (Factor X_4)

System________________ LRU________________

Test Characteristic	A Ident. No.	B Weight	C Number of Tests	D Total
No connection need be made	1	1	____	____
Only initial hookup need be made for a sequence of tests	2	3	____	____
Hookup must be made to identified test points	3	5	____	____
Hookup must be made to unmarked test locations	4	7	____	____
Obstruction must be removed to gain access to test points	5	10	____	____
LRU must be removed to gain access to test points	6	15	____	____
Total				

For each LRU, the checklist evaluation is accomplished by determining how each particular output can best be tested within the specified maintenance philosophy and assigned category. The test characteristic relating to the selected type of test is assigned for each checklist, and the test is noted in the "Number of Tests" column. After all outputs have been evaluated, the number of tests is multiplied by the weight for each test characteristic and the product is recorded in the "Total" column. The sum of the values in the "Total" column is the checklist score for a particular LRU and is denoted X_{Ti}. The procedure is repeated for each replaceable item. Checklist scores are then combined to obtain an average system checklist value. This is done by multiplying each LRU's total checklist score by the failure rate for that item, summing these products, and then dividing by the total failure rate value for the system. That is:

$$\bar{X}_t = \Sigma\lambda_i \, X_{Ti} / \Sigma\lambda_i \qquad (2)$$

To facilitate the presentation of the results of this analysis, the use of a summary form as shown in SN 2.3 (5) is recommended. Here, the scores for several LRU are contained on a single sheet, along with the number of tests made and the weight for each. It is also suggested that the characteristics in each checklist be coded (i.e., for factor X_1, test characteristics 1 through 21) and the code be noted next to the weight on the summary form. This will facilitate review of the checklist scores to determine areas for improvement.

2.4 Compute Expected Total Active Downtime

When the values of $\bar{X}_t$ and H(s,f) are determined from equations (1) and (2), estimates of the fault location/checkout and fault correction/adjustment times are obtained by inserting these values in the following equation:

$$\ln (\bar{T}_d+\bar{T}_c) = 0.325 \ln \bar{X}_t + 0.805 \ln H(s,f) + 1.293 \qquad (3)$$

SUB-NOTE 2.3 (5) Checklist Summary Form

		Failure Rate	Complexity - X_1				Instrumentation - X_2				Evaluation - X_3				Availability - X_4				Total	
LRU	Qty	(Total) λ_i	Test No.	No. of Tests	Wt	Total	Test No.	No. of Tests	Wt	Total	Test No.	No. of Tests	Wt	Total	Test No.	No. of Tests	Wt	Total	X_{Ti}	λX_{Ti}

Preparation time is given by:

$$\overline{T}_p \text{ (airborne)} = 0.093\ (\overline{T}_d + \overline{T}_c) \quad (4a)$$

$$\overline{T}_p \text{ (ground)} = 0.048\ (\overline{T}_d + \overline{T}_c) \quad (4b)$$

Item obtainment time is given by:

$$\overline{T}_i = 2.15 \text{ (ground)}$$
$$= 16.13 \text{ (air)} \quad (5a)$$

(See SN 13A2, Paragraph 7 for further explanation of this item.)

Summing (3), (4), and (5) yields an average total active downtime as given by:

$$\overline{T} = \overline{T}_d + \overline{T}_c + \overline{T}_p + \overline{T}_i \quad (6)$$

This value can be adjusted to estimate the average ($\overline{T}'$) when the effect of "no trouble found" tasks is included.

Then $\overline{T}' = 0.718\ \overline{T} + 8.963$ (7)

Finally, the average man-minutes ($\overline{M.M.}$) to perform a task is given by:

$$\overline{M.M.} = 2.104\overline{T}' - 14.20 \quad (8)$$

3. DETAILED DESIGN PREDICTION

The detailed design prediction technique is appropriate once detailed functional block diagrams and a complete packaging philosophy are established for an equipment. The method of performing the detailed prediction is similar to that of the early prediction technique, and together they provide a continuous medium for establishing and updating maintainability predictions for a developing equipment. The following information is required to implement the technique:

- Maintenance concept, including status panels and/or operator control panel layouts and built-in test equipment operation and interface data
- Functional block diagrams
- Equipment theory of operation
- Detailed parts lists and schematics or circuit diagrams for LRU's
- Reliability estimates at the LRU level
- LRU sketches and/or drawings.

The information in the first five items is similar to that required for the early prediction. However, at this point, engineering judgments and assumptions will have given way to program decisions. Some of the equipment will be past the sketch phase and into a formal drawing cycle (last item). Decisions will have been made on suppliers and subcontractors, and, in many cases, individual LRU's will have been breadboarded and tested.

There are five steps associated with this prediction effort. Each is described below:

- Establish maintenance concept.
- Develop symptom-fault matrix.
- Determine maintenance design characteristics of the LRU's.
- Complete maintenance task time study for LRU's.
- Compute expected total active downtime.

3.1 Establish Maintenance Concept

Establishment of a maintenance concept requires that the analyst determine certain facts, including the following:

- Level of maintenance (flight line, shop, depot, etc.)
- Level of replacement (black box, assembly, module or part)
- Test concept (manual, automatic, or combination)

When an early design prediction has been previously made, this step requires a check on the validity of previous assumptions and the incorporation of any changes in philosophy or implementation of maintenance.

3.2 Develop Symptom-Fault Matrix

In developing the detailed design prediction, three steps precede the development of the symptom-fault matrix.

- Prepare functional block diagram.
- Perform reliability analysis.
- Conduct failure modes and effects analysis on each LRU.

3.2.1 Prepare Functional Block Diagram

The functional block diagram is a refinement of that developed for early design predictions. The guidelines for developing it are presented in Paragraph 2.2.1 and are applicable in this case also.

3.2.2 Perform Reliability Analysis

Consistent with the equipment maintenance philosophy, the functional block diagram will identify the system's LRU's. A reliability estimate is now developed for each LRU. These estimates are normally generated as a part of the reliability program. At this stage of design, the estimates should be based on the following:

- Designer generated parts lists and schematics used to develop breadboard models for formal and/or submitted drawings
- Subcontractor submission of parts lists and predictions
- Vendor and supplier reliability data
- Calculated and/or actual stress measurements which verify adherence to program derating requirements.

If the required estimates are not available as an output of the reliability program or other contractual requirement, applicable techniques for developing these estimates are given in references listed in Paragraph 2.2.2.

3.2.3 Conduct Failure Modes and Effects Analysis

To develop a symptom-fault matrix for the detailed prediction techniques, the analyst first completes a failure modes and effects analysis for the LRU's. System failure symptoms are established first. A symptom is defined as a loss or degradation of a major operational function or output of the system. Symptoms are described in terms of the manner in which system signals or outputs are displayed operationally or are provided to another system. A systematic review of the functional block diagram can be used to generate a list of symptoms by examining the following:

- External system outputs - signals provided to other systems.
- System outputs - signals output to operators.
- Status and monitor panels - these often display important internal system signals.
- Other built-in test equipment (BITE) information.

A failure modes and effects analysis (FMEA) sheet (SN 3.2.3(1)) is developed to facilitate analysis and concisely present the results of the FMEA. The method used to perform an FMEA using this sheet is as follows:

a. Each LRU (replaceable item) to be subjected to on-equipment maintenance is identified and listed in the "LRU Identification" column.

b. The major subgroups of each LRU are identified in the "Major Subgroup" column. If the LRU performs only one basic function, no subgroups need be listed and a dash may be entered in this column.

c. Assuming normal inputs to each subgroup listed in the "Major Subgroup" column. postulate the important failure modes of the outputs (signal, power, or controls out of specification, etc.). All significant failure modes must be identified, although those which have no effect on system operation or a small probability of occurrence may be disregarded.

d. The sum of the failure rates of parts or modules contributing to each failure mode are recorded in the "Failure Rate" column.

SUB-NOTE 3.2.3 (1) Failure Modes and Effects Analysis (FMEA) Data Sheet

LRU Identification	Major Subgroups	Failure Mode	Failure Rate	Symptoms	Dominant Symptoms

e. The effect of each postulated failure mode (no or incorrect output) is traced through the functional block diagram to determine its effect on system operation. This effect is described in the "Symptom" column and is coded in terms of previously identified symptoms.

f. Once the system symptoms are determined, the dominant symptoms for each failure mode are identified and entered in the "Dominant Symptoms" column. The dominant symptoms are identified by determining which, of all the system failure symptoms, are the most significant in determining that this LRU failed. For example, in comparing two symptoms A and B, symptom A dominates symptom B if all the LRU's that contribute to A also contribute to B, but not the reverse.

The information derived from the FMEA is combined into a symptom-fault matrix of replaceable units versus malfunctions symptoms as shown in SN 2.2.3 (1). The failure rates corresponding to a particular symptom resulting from failure modes within each replaceable unit are summed, and the result is entered in the matrix at the point of intersection of the replaceable item and symptom which that failure mode produced. Thus the matrix entries are the failure rates for each replaceable item attributable to particular dominant symptoms. When more than one symptom is associated with a given failure mode, the failure rate is divided equally among the indicated symptoms.

When this initial allocation is complete, a reduction in the total number of entries may be made by defining compound symptoms. A compound symptom is the simultaneous occurrence of two symptoms. When a compound symptom is identified, the LRU failure rates which were previously assigned to the individual symptoms are assigned to the compound symptom column and deleted from the contributing columns. Compound symptoms containing three or more simple systems should be avoided unless they can be used to describe a catastrophic symptom such as "no cabinet outputs", "displays blank", etc.

Paragraph 2.2.3 provides an example in which compound symptoms are introduced to simplify a symptom-fault matrix.

When the symptom-fault matrix is completed, H(s,f) is computed, using equation (1) and SN 2.2.3 (4).

3.3 Determine Maintenance Design Characteristics of Each LRU

This activity is identical to that performed for the early design prediction and described in paragraph 2.3. The instructions in paragraph 2.3 are applicable here also. The parameter $\overline{X}_t$ is computed using equation (2).

3.4 Complete Maintenance Task Time Study for LRU's

A task time study for the LRU's is required to predict fault correction/adjustment time. It entails the following steps:

- Definition of the range of fault correction/adjustment tasks that must be performed.
- Analysis of a representative sample of fault correction/adjustment tasks to determine the subtasks involved and application of time standards.
- Summary of the results of the second step to establish the average fault correction/adjustment time ($\bar{T}_c$) for the system.

Task analysis requires that each LRU be examined in detail to determine the subtasks that are involved in removing or repairing the item. The subtasks include actions such as removing screws, soldering wires, removing modules, etc. This time is estimated by applying the basic time standards applicable to the removal, replacement, and interchange of commonly used devices. These time standards are based on the assumption that subtasks will be performed under ideal (unimpeded) conditions. Impediment correction factors (SN 3.4 (1)) are used to adjust the time standards to allow for less-than-ideal maintenance conditions. If an obstruction, poor accessibility, excessive size or weight of an equipment, cramped working space, or other conditions impede a maintenance action, the appropriate impediment correction factor should be applied. A sample worksheet to be used in performing a task analysis is shown in SN 3.4 (2). The average fault correction/adjustment time for the system is calculated by:

$$\bar{T}_c = \frac{\sum_{i=1} \lambda_i \, t_{ci}}{\lambda_T} \qquad (9)$$

Where λ_i = failure rate of the ith LRU

λ_T = total system failure rate

t_{ci} = estimated task time for ith LRU.

SUB-NOTE 3.4 (1) Impediment Correction Factors

Device Category	Tool or Device	Impediment Correction Factor
Fastening parts	Noncaptive screws	1.5
	Captive fasteners	1.2
Connecting elements	Soldered devices	3.4
	Nonsoldered devices	---*
	Connecting devices	1.4
Plug-in components, assemblies, and subassemblies	Discrete parts	3.4
	Plug-in assemblies and subassemblies	1.6
External access	Covers, panels, enclosures, doors, etc.	---*
Adjustable items	Knob, screwdriver, wrench, etc.	1.2

*No data available.

SUB-NOTE 3.4 (2) Sample Fault Correction/Adjustment Time Worksheet

Task Description:

Subtask Description	Time Standard (minutes)	Impediment Correction Factor	Number of Devices	Time Required (minutes)

Total Unit Fault Correction Time

3.5 Compute Expected Total Active Downtime

When the values of $\bar{X}_t$ and H(s,f) are determined from equations (1) and (2), an estimate of the fault location time is obtained by inserting the parameter values in the following equation:

$$\ln \bar{T}_d = 0.420 \ln \bar{X}_t + 0.802 \ln H(s,f) + 0.625 \qquad (10)$$

Preparation time is given by:

$$\bar{T}_p \text{ (airborne)} = 0.093\ \bar{T}_d \qquad (11a)$$

$$\bar{T}_p \text{ (ground)} = 0.048\ \bar{T}_d \qquad (11b)$$

Item obtainment time is given by:

$$\bar{T}_i = 2.15 \text{ (ground)} \qquad (12a)$$

$$= 16.13 \text{ (air)} \qquad (12b)$$

(See paragraph 7 for further explanation of this item.)

As in equation (9), the average fault correction/adjustment time is given by:

$$\bar{T}_c = \frac{\Sigma \lambda_i t_{ci}}{\lambda_T} \qquad (13)$$

Then, the average total active downtime is given by summing equations (10), (11), (12), and (13).

$$\bar{T} = \bar{T}_d + \bar{T}_p + \bar{T}_i + \bar{T}_c \qquad (14)$$

This value can be adjusted to estimate the average when the effect of "no trouble found" tasks is included. Then,

$$\bar{T}' = 0.718\ \bar{T} + 8.963 \qquad (15)$$

The average man-minutes expended on a maintenance task is given by:

$$\overline{M.M.} = 2.104T - 14.200 \qquad (16)$$

SECTION 13B

EXAMPLES OF MULTIPLEXER SET MAINTAINABILITY PREDICTIONS

This section contains examples of applying the maintainability prediction procedures described in Section 13A, DN 13A3 to the Multiplexer Set.

SECTION 13B MULTIPLEXER SET MAINTAINABILITY PREDICTION

DESIGN NOTE 13B1 **MULTIPLEXER SET EARLY DESIGN PREDICTION**

1. INTRODUCTION

This design note contains step-by-step procedures of the early design predictions for the Multiplexer Set. The procedures used are described in Section 13A, DN 13A3. The steps to be performed are outlined below.

Step 1 - Establish maintenance concept

Step 2 - Develop symptom-fault matrix

- a. Prepare functional block diagram
- b. Perform reliability analysis
- c. Determine failure symptom based on failed item
  - 1 Hardware Level, Failure Rate, Symptom Matrix
  - 2 Computation of H(s,f)

Step 3 - Determine Maintenance Design Characteristics of the LRU's

Step 4 - Compute Expected Total Active Downtime

- a. Calculation of $\bar{T}_d + \bar{T}_c$
- b. Calculation of $\bar{T}_p$
- c. Calculation of $\bar{T}_i$
- d. Calculation of $\bar{T}$ and $\bar{T}'$

2. EARLY DESIGN PREDICTION

2.1 Establish Maintenance Concept (Step 1)

The combination of allowable maintenance downtime and Multiplexer Set complexity precludes conventional "scope and schematic" troubleshooting techniques. Integral to the design, therefore, are maintenance aids enabling effective, organizational level correction of essentially all system failures.

Built-in performance monitoring provisions signal the existence of system degradation or failure. As an integral supplement to the performance monitoring provisions, there are fault isolation circuits, controls, and displays. The monitoring provisions enable maintenance personnel to fault isolate to the replaceable module or printed circuit card level. Front panel displays, in the form of illuminating indicators and numerical readout devices, relate failure location to the repairman.

The Multiplexer Set is housed in two dip-brazed aluminum drawers, one for the multiplexer and another for the demultiplexer. The drawers measure approximately 21 inches high for a total height of about 42 inches. The 17-1/4-inch width makes the equipment suitable for standard relay rack mounting. Chassis slides are mounted on each side of the drawers. When the drawers are pulled out, the drawers may be tilted ±45° and ±90°.

All operator controls and indicators are mounted on the front panel. Wires from the front panel components are routed to the internal electronics through connectors which are mounted in a secondary panel directly behind the front panel.

The electronic circuits are mounted on edge-loaded cards which, in turn, are mounted in a wiring plane. The multiplexer rate comparison buffer card may be replaced by a source rate to transmission rate converter card or a transition encoder card. The demultiplexer smoothing buffer card may be replaced by a transmission rate to source rate converter card or a transition decoder card. The wires carrying signals between the circuits contained in the wiring plane assembly and other circuits are attached to the interconnection cards. Access to the wiring plane is through a hinged cover on the drawer fastened with link-lock fasteners.

The line drivers and line receivers are assembled into enclosed, RFI sealed metallic modules. Each module contains two line receiver circuits or two line driver circuits. Thirty-two modules are mounted on the back of both the multiplexer and the demultiplexer drawers. On the multiplexer, 31 of the modules are line receiver modules (total of 62 line receiver circuits) and one is a line driver module (total of two line driver circuits). On the demultiplexer, 31 of the modules are line driver modules (total of 62 line driver circuits) and one is a line receiver module (total of two line receiver circuits). The wires from the modules are routed into the chassis through EMI filters.

The multiplexer and demultiplexer both contain redundant power supplies, each power supply being a separate case-enclosed assembly mounted directly to the drawer. Power distribution between power supplies, wiring plane, and modules is by means of laminated bus bars.

Two air blowers are mounted in both the multiplexer and the demultiplexer. One air blower controls the flow of cooling air inside the drawer, primarily over the circuit cards, and the other blower controls the flow of air over the receiver/driver modules.

The maintenance concept for the multiplexer and demultiplexer was determined by reviewing the user's operational and maintenance philosophy. The concept, based upon detection, isolation, and replacement of failed subassemblies in the field, was established in the Request for Quote (RFQ). This philosophy was in consonance with the basic Air Force maintenance philosophy for fixed ground installation type communications systems.

2.2 Develop Symptom-Fault Matrix (Step 2)

Development of a symptom fault matrix requires that the following information be developed or prepared for the system.

- Functional block diagram
- Reliability analysis
- Failure symptom based on failed item

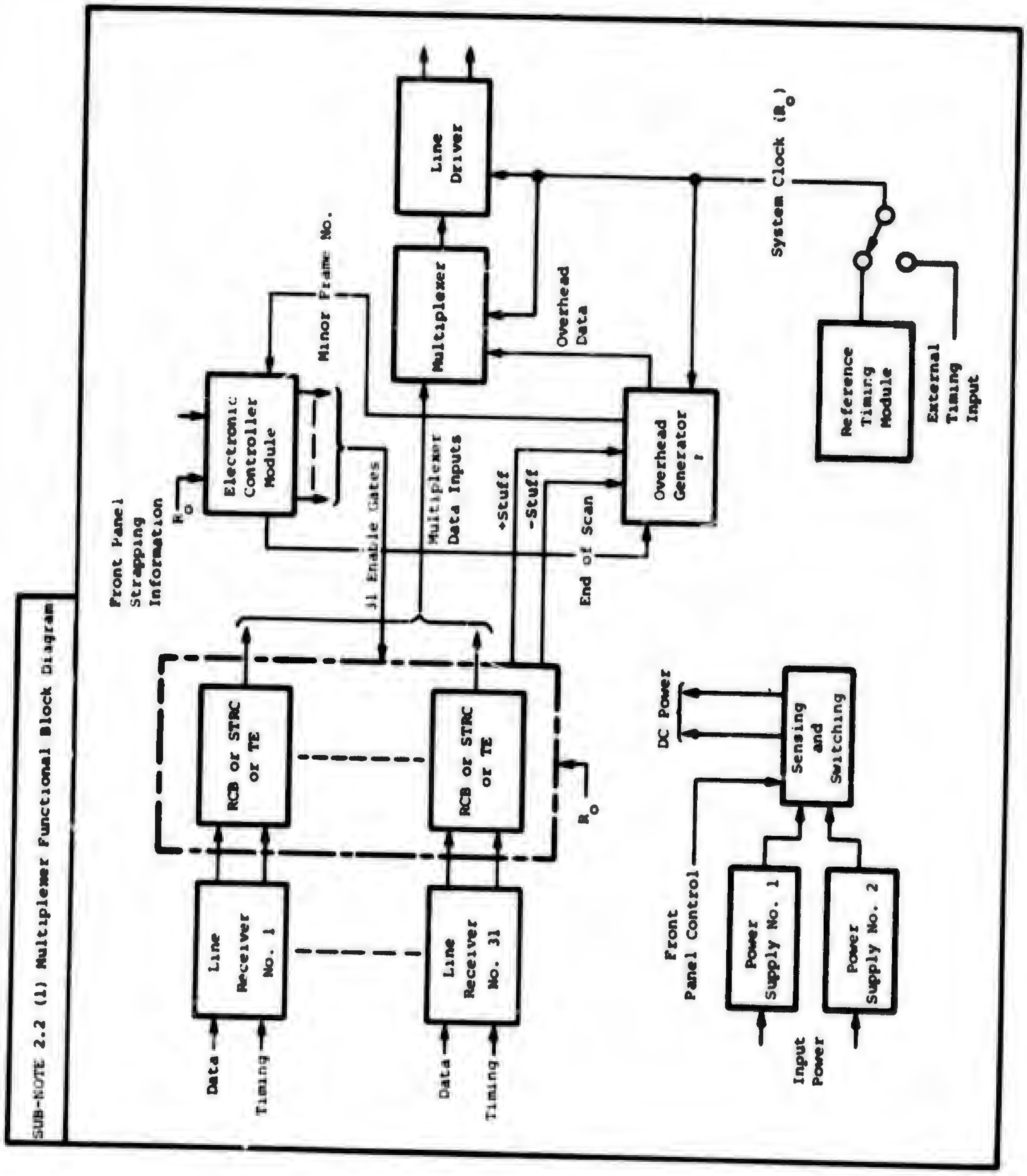
a. Prepare Functional Block Diagram

The Multiplexer Set is applied in the Defense Communications System (DCS) for combining digital channels into a single, time-division multiplexed, digital data signal. The first application of the Multiplexer Set is expected to be in the Phase II Defense Satellite Communications System (DSCS Phase II). Satellite access and short-haul, high-density applications also will involve TDM transmission over wideband ground links. The wide variety of data rates which must be accommodated to service the many DCS users properly results in a wide range of the number of channel inputs to a multiplexer; it further requires the capability to cascade multiplexer sets to reach high data rates for efficient link loading.

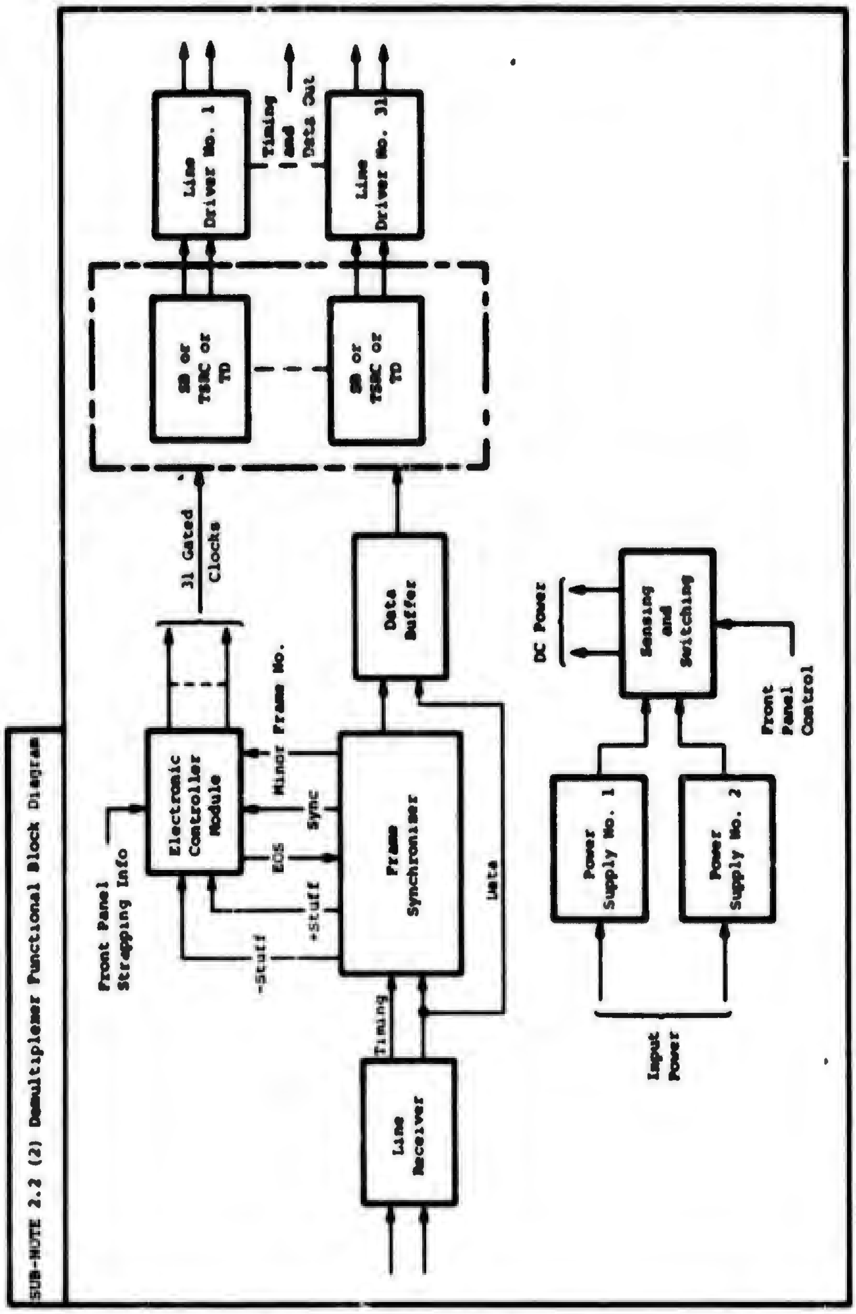
The Multiplexer Set provides asynchronous time division multiplexing and demultiplexing capabilities. The multiplexer portion (see SN 2.2(1)) accepts various lower rate digital input streams and interleaves them into a single higher speed digital stream. The demultiplexer portion (see SN 2.2(2)) accepts a high-speed digital stream, with associated timing, and disassembles it into a number of lower rate digital streams. The multiplexer set provides full duplex operation, performing independently and simultaneously the multiplexer and demultiplexer functions.

The Multiplexer Set acquires frame and maintains bit count integrity on all channels while accepting input data timing variations within prescribed limits. The multiplexer set automatically determines where an out-of-frame condition exists. Upon determination of this condition, the equipment automatically and continuously attempts to reacquire in-frame condition. When the cause for out-of-frame condition has been removed, the reacquisition of in-frame condition is automatically accomplished.

The multiplexer automatically generates and transmits, as part of the composite multiplexed output data stream, the overhead data required for proper operation of the demultiplexer. The multiplexer does not require information from the demultiplexer to perform the overhead data function. The demultiplexer receives and automatically detects and utilizes the overhead data for proper operation of the demultiplexer.



SUB-NOTE 2.2 (1) Multiplexer Functional Block Diagram


SUB-NOTE 2.2 (2) Demultiplexer Functional Block Diagram
Line Driver No. 1
Timing and Data Out
Line Driver No. 31
SB or TSRC or TD
SB or TSRC or TD
31 Gated Clocks
Data Buffer
DC Power
Sensing and Switching
Front Panel Control
Minor Frame No.
Electronic Controller Module
Sync
EOS
+Stuff
-Stuff
Front Panel Strapping Info
Frame Synchronizer
Data
Timing
Line Receiver
Power Supply No. 1
Power Supply No. 2
Input Power

b. Perform Reliability Analysis

A preliminary reliability prediction was performed on the Multiplexer Set. Failure rate was developed based on the following:

Primary Source - RADC-TR-67-108 and RADC-TR-69-350

Secondary Source - MIL-HDBK-217A

Other - RADC-TR-69-458

The predicted failure rate for the Multiplexer Set, consisting of the multiplexer and demultiplexer, is 510.04 failures/10^6 hours. SN 2.2(3) delineates the failure rate for the hardware items comprising the set.

c. Determine Failure Symptom Based on Failed Item

The system symptom matrix indicator, symptom, and type of display matrix are shown in SN 2.2(4) and SN 2.2(5) for the multiplexer and demultiplexer, respectively. The symptom matrix was prepared based on the analysis of the design concept for the item and the overall fault isolation features proposed for incorporation. Basically, these features are as follows:

(1) When unacceptable equipment performance is detected, front panel indicators show the equipment function involved. When repeated application of a given function is made within the design, the front panel readout also relates the specific iteration of the function affected. Opening the equipment drawer, the repairman finds replaceable subassemblies labeled to correspond with the front panel display. As an example, a failure in channel 23 rate conversion circuits causes the error monitoring circuits to illuminate the front panel RCB/STRC indicator. To determine which RCB channel is affected, the repairman depresses the CHANNEL NUMBER INITIATE pushbutton. The CHANNEL NUMBER indicator displays the number 23, completing the isolation process. Checkout following repair is an automatic function, performed by the on-line performance monitoring circuits.

(2) A self-test feature is provided for periodic confidence checking of built-in monitoring and isolation circuits.

SUB-NOTE 2.2(3) Reliability Prediction for the Multiplexer Set

Item	Base Failure Rate (Failures /10^6 hr)	Quantity per Set	Failure Rate (Failures /10^6 hr)
Multiplexer Set			510.04
Multiplexer			186.89
Front panel	5.04	1	5.04
Line receiver	0.67	62	41.54
Receiver circuit	0.29		
Diagnostics	0.38		
Rate comparison buffer	3.01	31	93.31
Common electronics	21.12	1	21.12
Timing	2.04	1	2.04
Line driver	2.17	2	4.34
Driver circuit	1.20		
Diagnostics	0.97		
Power supplies	11.00	---*	11.00
Air blower	3.40	2	6.80
Relay board	1.70	1	1.70
Demultiplexer			323.15
Front panel	5.11	1	5.11
Line driver	2.17	62	134.54
Driver circuit	1.20		
Diagnostics	0.97		
Smoothing buffer	3.56	31	110.36
Common electronics	36.00	1	36.00
Timing	10.00	1	10.00
Line receiver	0.67	2	1.34
Receiver circuit	0.29		
Diagnostics	0.38		
Power supplies	17.00	---*	17.00
Air blower	3.40	2	6.80
Relay board	2.00	1	2.00

*Redundant

SUB-NOTE 2.2(4) Symptom Matrix (Multiplexer)

Symptom No.	Symptom	Type of Display	
		Indicator Light	Digital Readout
1	Out of tolerance (Source data timing rate exceeds limit)	X	
2	Error channel card	X	X
3	Error channel module	X	X
4	Error combiner card	X	X
5	Error driver module	X	X
6	Error timing module	X	X
7	Error power supply		
-1	Power supply 1	X	
-2	Power supply 2	X	
8	Indicator lamps (Lamps fail to light during lamp test circuitry)	X	
9	Incorrect operation after corrective action	X	X
10	Inability to perform major functions (self-test, reset, etc.)	X	X

SUB-NOTE 2.2(5) Symptom Matrix (Demultiplexer)

Symptom No.	Symptom	Type of Display	
		Indicator Light	Digital Readout
1	Loss of frame	X	
-1	A - Loss of frame sync	X	
-2	B - Loss of frame (source generated)	X	
2	Error rate (Selected link error rate threshold is exceeded - source problem)	X	
3	Error channel card	X	X
4	Error channel module	X	X
5	Error combiner card	X	X
6	Receiver module	X	X
7	Power Supply		
-1	Power supply 1	X	
-2	Power supply 2	X	
8	Indicator lamps (Lamps fail to light during lamp test circuitry)	X	
9	Incorrect operation after corrective action	X	X
10	Inability to perform major functions (self-test, reset, etc.)	X	X

(3) On-line performance monitoring of numerous equipment functions is required. Because these functions vary widely, the monitoring circuit associated with a function tends to be function peculiar in itself. This factor is used heavily in the basic fault isolation approach. In essence, a discrete monitoring circuit arrangement is required for each equipment function. Detected improper operation of that function inherently isolates the failure location to a small electrical portion of the equipment.

(4) The proposed packaging design is totally given to a functional arrangement, with most circuit functions completely contained on one or two replaceable printed circuit cards.

(5) When a given function has multiple application within an equipment, a common monitoring circuit can evaluate function performance, but normally cannot distinguish which of the several iterations of the function is at fault. With the Multiplexer Set equipment, input and output conversion, buffering, and smoothing functions are incorporated in multiples consistent with input/output channel count. A common monitoring circuit sequentially evaluates these repetitive functions, stopping only when an out-of-tolerance condition is detected. Designation of the specific malfunctioning channel is provided at the equipment front panel by means of numerical readout. This readout is based on status of the monitor circuit sequencer at the time of fault detection. The use of this technique for diagnostic resolution is excellent, with a typical callout of two printed circuit cards.

(6) The design incorporates a unique technique for isolating power distribution failures. Each replaceable printed circuit card includes a fusable link at its power input. A miniature indicator is connected across this link. Abnormal current demands by card components cause the fuse link to open and the indicator to illuminate. The load sides of all fusable links are also sensed by a common circuit whose output drives a front panel CARD FUSE indicator when a power distribution failure occurs; this indicator is illuminated

while the power supply continues to drive unaffected functions. Advised that an overload situation has occurred, the repairman quickly locates the defective subassembly by opening the equipment and identifying the printed circuit card whose indicator is illuminated.

(7) Redundant power supplies permit replacement of defective units at failure occurrence or at a later time as dictated by operational requirements. Automatic monitoring and switching circuits are provided. Front panel indicators relate which supply is on line, and which supply has demonstrated on out-of-tolerance condition.

(8) The fault isolation provisions are effective for 94.7 percent of the total equipment failures. Of the remaining 5.3 percent, occurring primarily in connectors, interconnecting wiring, and discrete front panel components, the integral diagnostic provisions offer a substantial degree of fault localization. This occurs due to the functional arrangement of test and packaging designs. Improper operation of a function, when not corrected by replacement of its associated printed circuit cards, can generally be expected to lie within wiring or other such items associated with the function. Thus localized, the specific failure location can be determined by conventional continuity checking procedures.

(9) For use in those cases where continuity checking of automatically localized malfunctions does not yield the exact failure location, each replaceable printed circuit card is equipped with several test points to which key signals and voltages are routed. These test points are conveniently located along the outer edge of the card, thereby substantially reducing the need for use of an extender device.

The next step in the prediction process is to construct a symptom-fault matrix. This step is to determine the effects of failure of hardware item (see SN 2.2(6) on the symptom (see SN 2.2(4) and SN 2.2(5)) occurrence. Basically defined, it is the allocation of the failure rate of each hardware item in

SUB-NOTE 2.2(6) Symptom-Fault Matrix (Multiplexer Set)

	Failure Rate Failures/ 10^6 Hr	Symptom																						
		Multiplexer (Ref. SN 2.2 (4))											Demultiplexer (Ref. SN 2.2 (5))											
		1	2	3	4	5	6	7-1	7-2	8	9	10	1-1	1-2	2	3	4	5	6	7-1	7-2	8	9	10
Multiplexer	186.89																							
Front Panel	5.04											5.04												
Line Receiver	41.54			40.146			1.394																	
Receiver Circuit	-																							
Diagnostics	-																							
Rate Comparison Buffer	93.31		93.31																					
Common Electronics	21.12				19.12					2.0														
Timing	2.04						2.04																	
Line Driver	4.34					4.34																		
Driver Circuit	-																							
Diagnostics	-																							
Power Supplies	11.00							5.2	5.2		0.6													
Air Blower	6.80										6.8													
Relay Board	1.70				1.0							1.0												
Demultiplexer	323.15																							
Front Panel	5.11																							5.11
Line Driver	134.54																134.54							
Driver Circuit	-																							
Diagnostics	-																							
Smoothing Buffer	110.36															110.36								
Common Electronics	36.00																	34.00				2.0		
Timing	10.00																						10.0	
Line Receiver	1.34																		1.34					
Receiver Circuit	-																							
Diagnostics	-																							
Power Supplies	17.00																			8.2	8.2		0.6	
Air Blower	6.80																						6.8	
Relay Board	2.00																	1.0						1.0
Multiplexer Set	510.04																							

relation to the percent contribution to each symptom identified in the symptom matrix. The steps in development of the symptom-fault matrix are as follows:

a. Hardware Level, Failure Rate, Symptom Matrix

The combined information from SN 2.2(3), SN 2.2(4), and SN 2.2(5) forms the basis for development of the symptom-fault matrix delineated in SN 2.2(6).

b. Computation of H(s,f)

The average information associated with the occurrence of a symptom and failure, H(s,f), is calculated from the matrix in SN 2.2(6), using the following equation:

$$H(s,f) = -\Sigma P_{ij} \log_2 P_{ij}$$

Where:

H(s,f) the average information associated with the occurrence of a symptom (s) and a failure (f)

$$P_{ij} = \frac{\lambda_{ij}}{\lambda_T}$$

Each matrix entry appears in SN 2.2(7) as a failure rate (λ_{ij}). The total failure rate λ_T is shown at the bottom. Each failure rate is converted to a fraction $P_{ij} = \lambda_{ij}/\lambda_T$ and scaled by a factor of 10^3 in the second column. Columns three and four contain $L(ij) = -\log_2 P_{ij}$ and $P_{ij}\ L(ij)$, respectively, the latter being scaled by a factor of 10^3. The last column is summed to obtain H(s,f) and is 2.958.

The third column, which is L(ij), is determined based on the following change in base formulae:

$$\text{Log}_a X = \frac{\log_b X}{\log_b a}$$

thus $$\log_2 X = \frac{\log_{10} X}{\log_{10} 2} \quad \text{where } X = P_{ij}$$

SUB-NOTE 2.2(7) Worksheet for Computing H(s,f) (Multiplexer Set)			
λ_{ij}	$P_{ij} = \frac{\lambda_{ij}}{\lambda_T}$ (X 10^3)	L (ij) $= -\log_2 P_{ij}$	P_{ij} L (ij) (X 10^3)
5.04	9.8814	6.6616	65.8259
40.146	78.7102	3.6676	288.6775
1.394	2.733	8.5160	23.2742
93.31	182.9435	2.4509	448.3762
19.12	37.4866	4.7382	117.6190
2.0	3.9212	7.9953	31.3511
2.04	3.9996	7.9671	31.8652
4.34	8.509	6.8775	58.5206
5.2	10.1951	6.6173	67.4640
5.2	10.1951	6.6173	67.4640
0.6	1.1763	9.7331	11.4490
6.8	13.332	6.2961	83.9396
1.0	1.9606	8.9956	17.6367
1.0	1.9606	8.9956	17.6367
5.11	10.0186	6.6430	66.5535
134.54	263.779	1.9228	507.1942
110.36	216.3718	2.2085	477.8571
34.0	14.4234	6.1162	88.2163
2.0	3.9212	7.9956	31.3523
10.0	19.606	5.6734	111.2326
1.34	2.6272	8.5770	22.5334
8.2	16.0769	5.9601	95.8199
8.2	16.0769	5.9601	95.8199
0.6	1.1763	9.7328	11.4486
6.8	13.332	6.2961	83.9396
1.0	1.9606	8.9956	17.6367
1.0	1.9606	8.9956	17.6367
$\Sigma 510.04/10^6$			$\Sigma 2958.3405$
P_{ij} L (ij) X 10^{-3} = H(s,f) = 2.958			

Example:

$$\log_2 0.256 = \frac{\log_{10} 0.256}{\log_{10} 2} = \frac{\log (2.56 \times 10^{-1})}{0.3010}$$

$$= \frac{\log_{10} 2.56 + \log_{10} 0.1}{0.3010}$$

$$= \frac{0.4082 + (-1)}{0.3010} = \frac{0.5918}{0.3010}$$

$$= -1.96$$

2.3 Determine Maintenance Design Characteristics of the LRU's (Step 3)

The design for maintenance is assessed by completing four design checklists relating to testing of each lowest replaceable unit (LRU). Each checklist score reflects the manner in which the outputs of the LRU's are displayed or measured within the scope of the established maintenance concept. The checklists are delineated in SN 2.3(1). The results of this effort are delineated in SN 2.3(2). The LRU's in each functional block are scored in relation to the checklist factors for complexity, instrumentation, evaluation, and availability. Upon completion of the summary matrix $\bar{X}_t$, the average maintenance checklist score is calculated based on the following:

$$\bar{X}_t = \frac{\Sigma \lambda_i X_{Ti}}{\Sigma \lambda_i}$$

Where:

$$X_{Ti} = X_1 + X_2 + X_3 + X_4$$

The solution of $\bar{X}_t$ from results in SN 2.3 (2) yields:

$$\bar{X}_t = \frac{3949.28}{510.04} = 7.743$$

SUB-NOTE 2.3(1) (Sheet 1 of 4 sheets) Checklist Summary

Test Complexity (Factor X_1)

System________________ LRU________________

Test Characteristic	A Ident. No.	B Weight	C Number of Tests	D Total
Magnitude (voltage, current)	1	1	____	____
Polarity (voltage, current)	2	1	____	____
Frequency	3	1	____	____
Rise time	4	3	____	____
Fall time	5	3	____	____
Pulse duration	6	1	____	____
Phase	7	3	____	____
Wave shape	8	5	____	____
Distortion	9	5	____	____
Bandwidth	10	5	____	____
Gain	11	5	____	____
Modulation percentage	12	5	____	____
Impedance	13	3	____	____
Resistance	14	1	____	____
Standing wave ratio	15	5	____	____
Signal/noise	16	3	____	____
Noise figure	17	3	____	____
Noise intensity	18	3	____	____
Intermodulation	19	5	____	____
Go/no-go	20	1	____	____
Multistate pulse train	21	10	____	____
Total				

SUB-NOTE 7.3(1) (Sheet 2 of 4 sheets) Checklist Summary

Test Instrumentation (Factor X_2)

System ________________ LRU ________________

Test Device	A Ident. No.	B Weight	C Number of Tests	D Total
Multimeter	1	2	____	____
VTVM	2	2	____	____
Oscilloscope	3	10	____	____
Distortion meter	4	7	____	____
Phase meter	5	5	____	____
Impedance meter	6	7	____	____
Bridge	7	7	____	____
Power meter	8	5	____	____
Echo box	9	5	____	____
Counter	10	5	____	____
Digital voltmeter	11	3	____	____
Differential voltmeter	12	3	____	____
Audio signal generator	13	5	____	____
Tape tester	14	10	____	____
Modulation meter	15	7	____	____
Audio output meter	16	2	____	____
Audio indicator	17	1	____	____
RF signal generator	18	7	____	____
Pulse generator	19	10	____	____
Power supply	20	5	____	____
Dummy load	21	3	____	____
Frequency meter	22	7	____	____
Built-in display	23	1	____	____
Automatic test	24	1	____	____
Total				

SUB-NOTE 2.3(1) (Sheet 3 of 4 sheets) Checklist Summary

Test Evaluation (Factor X_3)

System__________ LRU__________

Test Characteristic	A Ident. No.	B Weight	C Number of Tests	D Total
Test result interprets measured value and identifies defective unit	1	1	____	____
Test result interprets measured value but technician must associate test with defective unit	2	3	____	____
Test result must be both interpreted and associated	3	5	____	____
Total				

SUB-NOTE 2.3(1) (Sheet 4 of 4 sheets) Checklist Summary

Test Availability (Factor X_4)

System__________ LRU__________

Test Characteristic	A Ident. No.	B Weight	C Number of Tests	D Total
No connection need be made	1	1	____	____
Only initial hookup need be made for a sequence of tests	2	3	____	____
Hookup must be made to identified test points	3	5	____	____
Hookup must be made to unmarked test locations	4	7	____	____
Obstruction must be removed to gain access to test points	5	10	____	____
LRU must be removed to gain access to test points	6	15	____	____
Total				

SUB-NOTE 2.3(2) Checklist Scores for Early Prediction

LRU	Total λ	Complexity-X_1				Instrumentation-X_2				Evaluation-X_3				Availability-X_4				Total	
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	ΣD	λD
Front panel	5.04	20 14	1 1	1 5	1 5	24 1	1 2	1 5	1 10	3 2	5 3	1 5	5 15	1 5	1 10	1 5	1 50	88	443.52
Line receiver	41.54	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	166.16
Rate comparison bit	93.31	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	373.24
Common electronics	21.12	20 20	1 1	1 1	1 1	23 23	1 1	1 1	1 1	1 2	1 3	1 1	1 3	1 1	1 1	1 1	1 1	10	211.20
Timing	2.04	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	8.16
Line driver	4.34	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	17.36
Power supplies	11.0	20 20	1 1	1 1	1 1	23 23	1 1	1 1	1 1	1 2	1 3	1 1	1 3	1 1	1 1	1 1	1 1	10	110.0
Air blower	6.80	20	1	1	1	1	2	1	2	3	5	4	20	3	5	4	20	43	292.40
Relay board	1.70	20 20	1 1	1 1	1 1	23 23	1 1	1 1	1 1	1 2	1 3	1 1	1 3	1 1	1 1	1 1	1 1	10	17.0
Front panel	5.11	20 14	1 1	1 5	1 5	24 1	1 2	1 5	1 10	3 2	5 3	1 5	5 15	1 5	1 10	1 5	1 50	88	449.68
Line driver	134.51	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	538.16
Smoothing buffer	110.36	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	441.44
Common electronics	36.00	20 20	1 1	1 1	1 1	23 23	1 1	1 1	1 1	1 2	1 3	1 1	1 3	1 1	1 1	1 1	1 1	10	360.00
Timing	10.00	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	40.0
Line receiver	1.34	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	5.36
Power supplies	17.00	20 20	1 1	1 1	1 1	23 23	1 1	1 1	1 1	1 2	1 3	1 1	1 3	1 1	1 1	1 1	1 1	10	170.0
Air blower	6.80	20	1	1	1	1	2	1	1	3	5	4	20	3	5	4	20	42	285.6
Relay board	2.00	20 20	1 1	1 1	1 1	23 23	1 1	1 1	1 1	1 2	1 3	1 1	1 3	1 1	1 1	1 1	1 1	10	20.00
Σ	510.04																		3949.28

2.4 Computation of Expected Total Active Downtime (Step 4)

a. Calculation of $\bar{T}_d + \bar{T}_c$

Estimations of the fault location/checkout time and fault correction/adjustment time are obtained by injecting the parameter values for H(s,f) and $\bar{X}_t$ determined in step 2 (Paragraph 2.2) and step 3 (Paragraph 2.3) into the following equation:

$$\ln(\bar{T}_d + \bar{T}_c) = 0.325 \ln \bar{X}_t + 0.805 \ln H(s,f) + 1.293$$

$$\ln(\bar{T}_d + \bar{T}_c) = 0.325 \ln(7.743) + 0.805 \ln(2.958) + 1.293$$

$$= 0.325\,(2.04678) + 0.805\,(1.08451) + 1.293$$

$$= 0.6652 + 0.87303 + 1.293 = 2.8312$$

$$\ln(\bar{T}_d + \bar{T}_c) = 2.8312$$

then $\bar{T}_d + \bar{T}_c = 16.97$ minutes

b. Calculation of $\bar{T}_p$

Since the Multiplexer Set is a ground system, preparation time is given by the equation:

$$T_p = 0.048\,(\bar{T}_d + T_c) = 0.048\,(16.97) = 0.8145 \text{ minutes}$$

c. Calculation of $\bar{T}_i$

Item obtainment time for ground equipment is:

$$\bar{T}_i = 2.15 \text{ minutes}$$

d. Calculation of $\bar{T}$ and $\bar{T}'$

The average total active downtime is given by:

$$\bar{T} = (T_d + \bar{T}_c) + \bar{T}_p + \bar{T}_i$$

$$\bar{T} = (16.97) + 0.8145 + 2.15 = 19.93 \text{ minutes}$$

Adjustment to estimate the average ($\bar{T}'$) when the effect of "no trouble found" tasks is included yields:

$$\bar{T}' = 0.718\bar{T} + 8.963$$

$$= 14.309 + 8.963 = 23.272 \text{ minutes}$$

The prediction $\bar{M}_{ct}$ for the multiplexer set based on MIL-HDBK-472 Method II and III procedures was 9.44 minutes. This value did not include item obtainment time (2.15 minutes) or adjustment to include "no trouble found" tasks.

DESIGN NOTE 13B2 MULTIPLEXER SET DETAILED DESIGN PREDICTION

1. INTRODUCTION

The major changes in design or concept between the early design and the final design of the Multiplexer Set were that the early design features had no thermal alarm, access to printed circuit cards was by extending and rotating the chassis 45° to 90°, the display was an electromechanical type, and the blower was a conventional type with leads attached to a terminal strip. In the final design, configuration and access are as shown in SN 1(1) through SN 1(4), the display is digital readout, and the blower is a plug-in unit.

2. DETAILED DESIGN PREDICTION

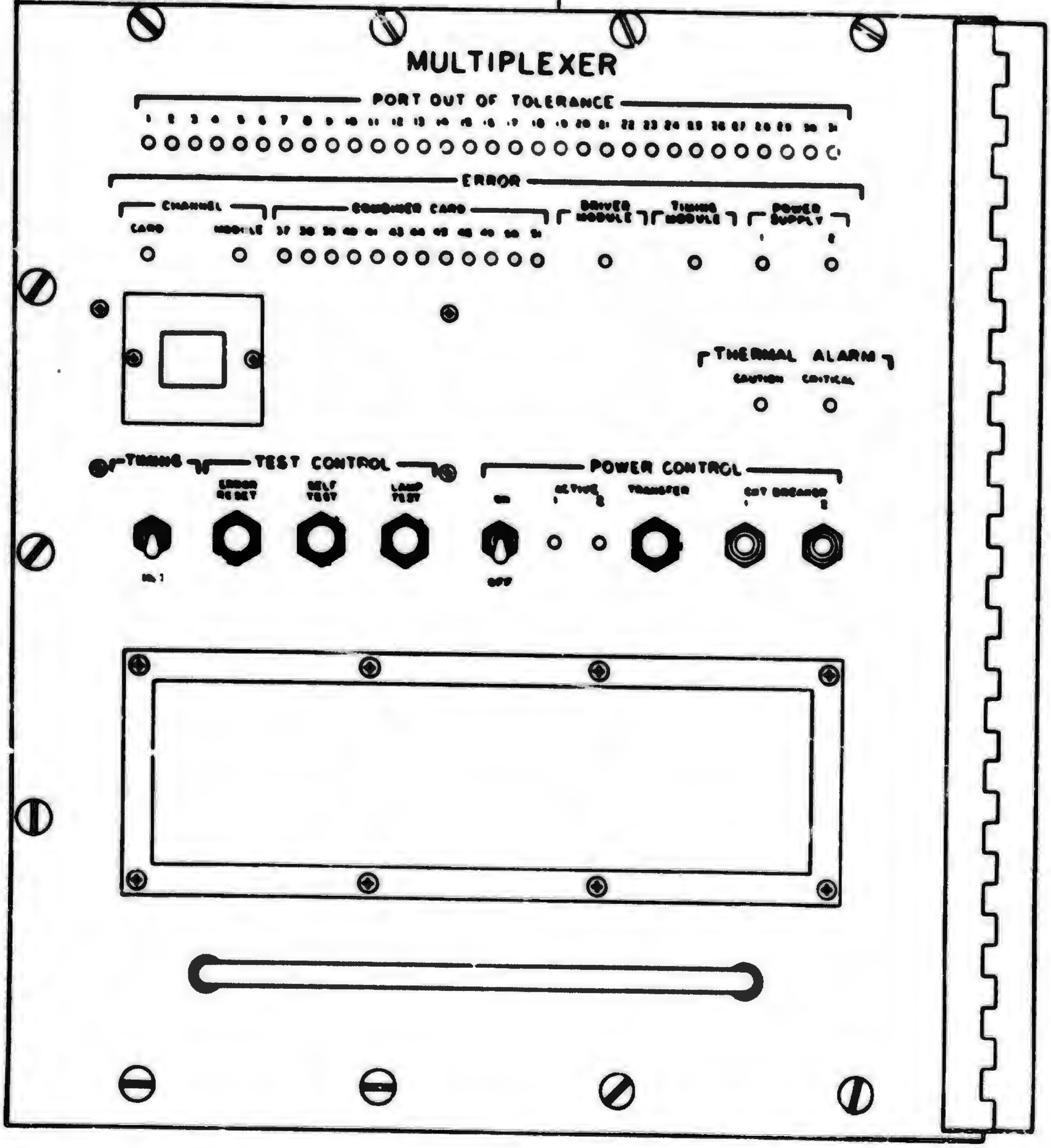
2.1 Establish Maintenance Concept (Step 1)

The Multiplexer Set consists of two rack-mounted units: the multiplexer and the demultiplexer. The set provides a data terminal capable of full duplex operation. The multiplexer provides asynchronous time-division multiplexing by accepting up to 31 data and timing inputs at various rates and overhead information and interleaving them to form a single digital data plus timing output at a correspondingly higher rate. The demultiplexer accepts the single data plus timing input and reconstitutes the original data rates and timing inputs originally supplied to the multiplexer.

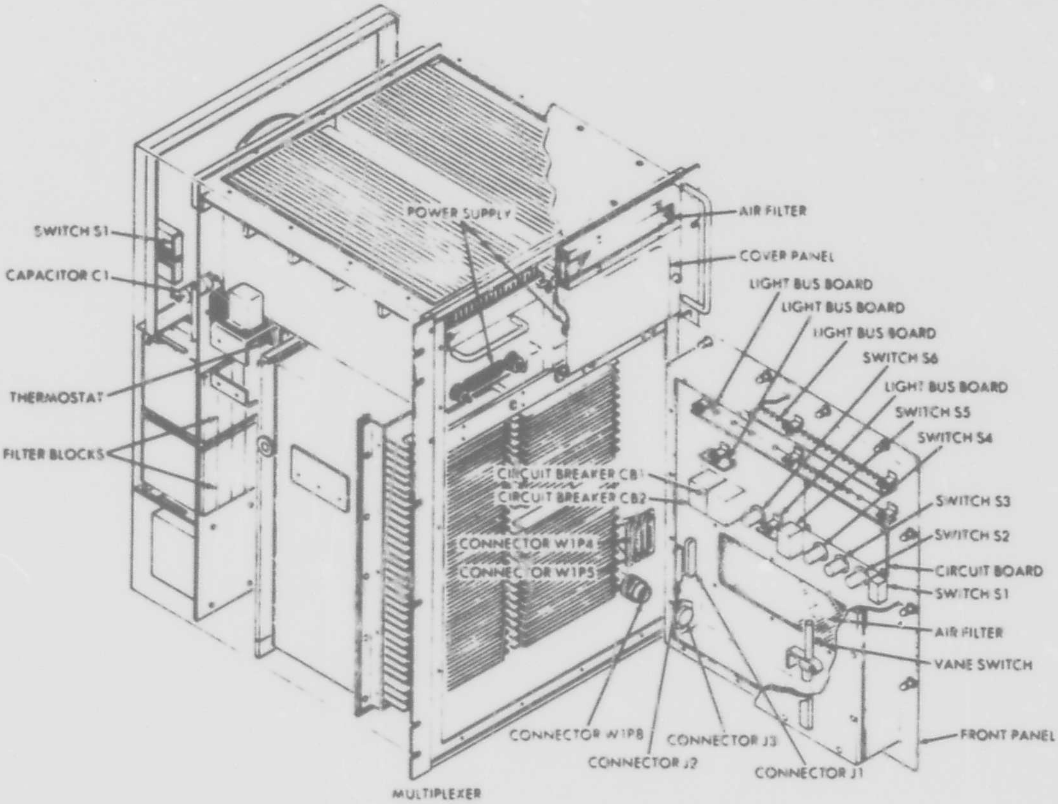
The front status panel for the multiplexer is shown in SN 1 (1) and for the demultiplexer is shown in SN 1 (3). The physical arrangement of components in the multiplexer is shown in SN 1 (2), and in the demultiplexer is shown in SN 1 (4).

The multiplexer set incorporates built-in diagnostic circuits that detect and isolate malfunctions within the equipment. These circuits operate in three modes: automatic, diagnostic self-test, and lamp test.

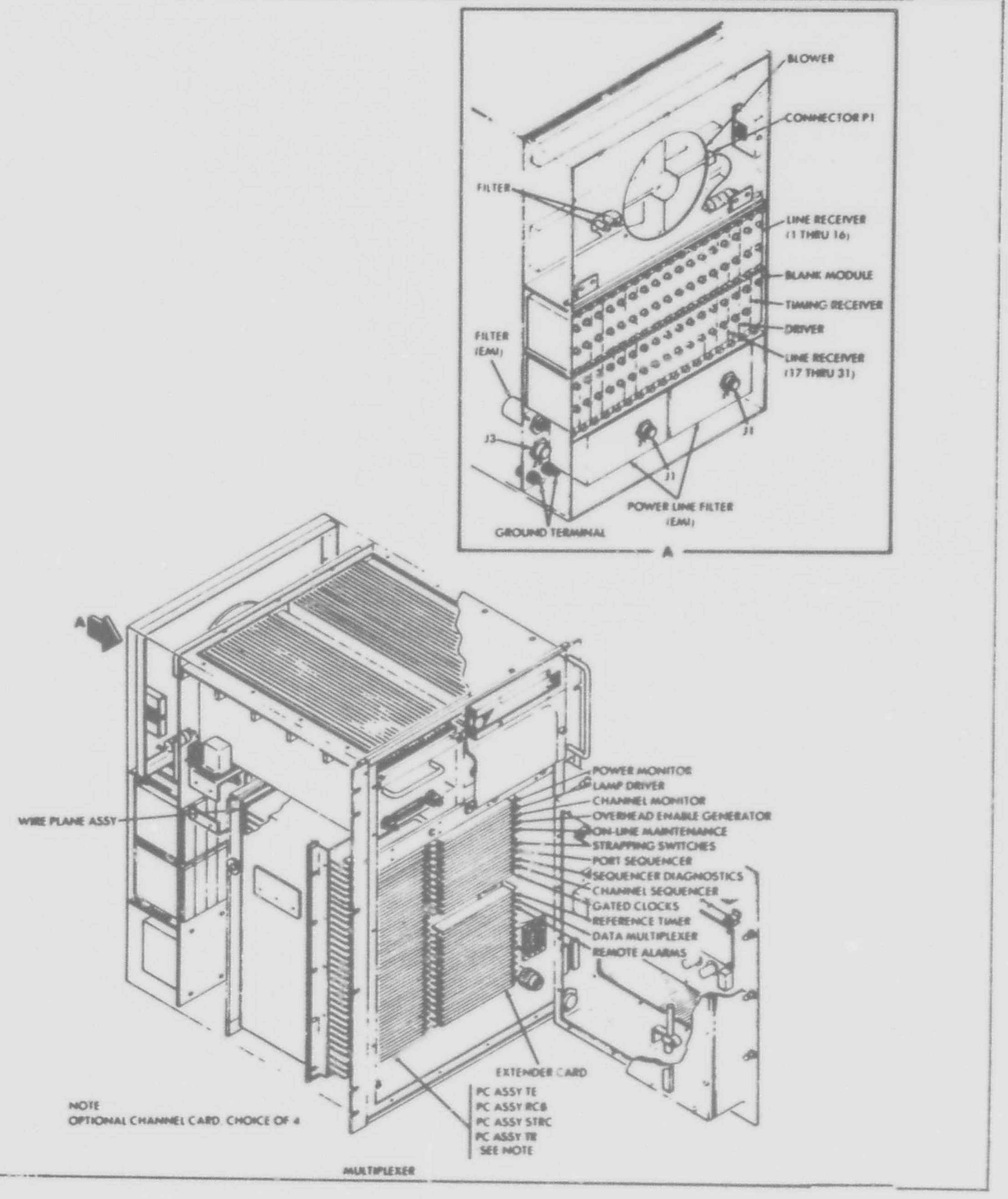
SUB-NOTE 1 (1) Multiplexer Front Panel



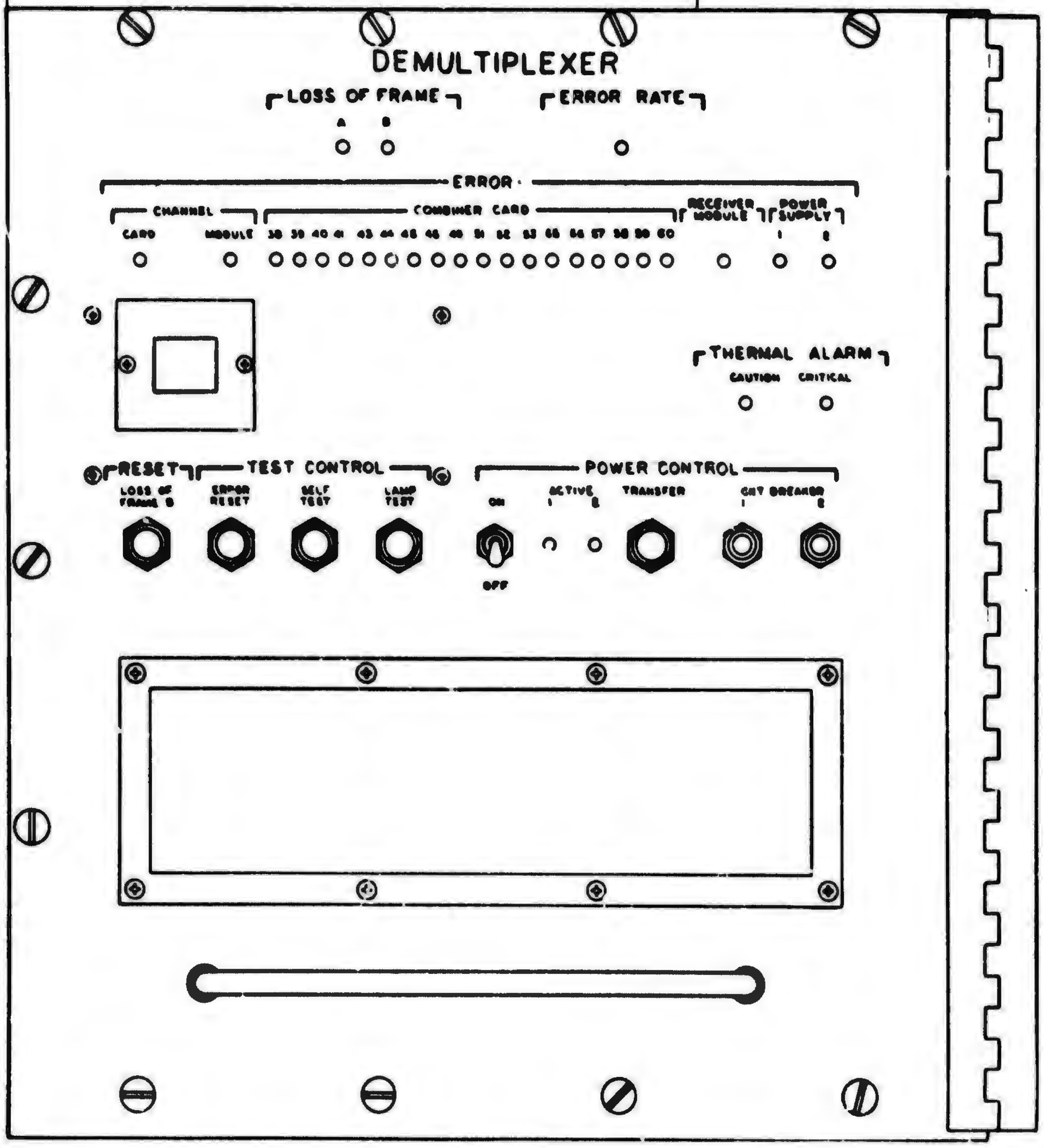
SUB-NOTE 1 (2) (Sheet 1 of 2 sheets) Multiplexer Component Locations



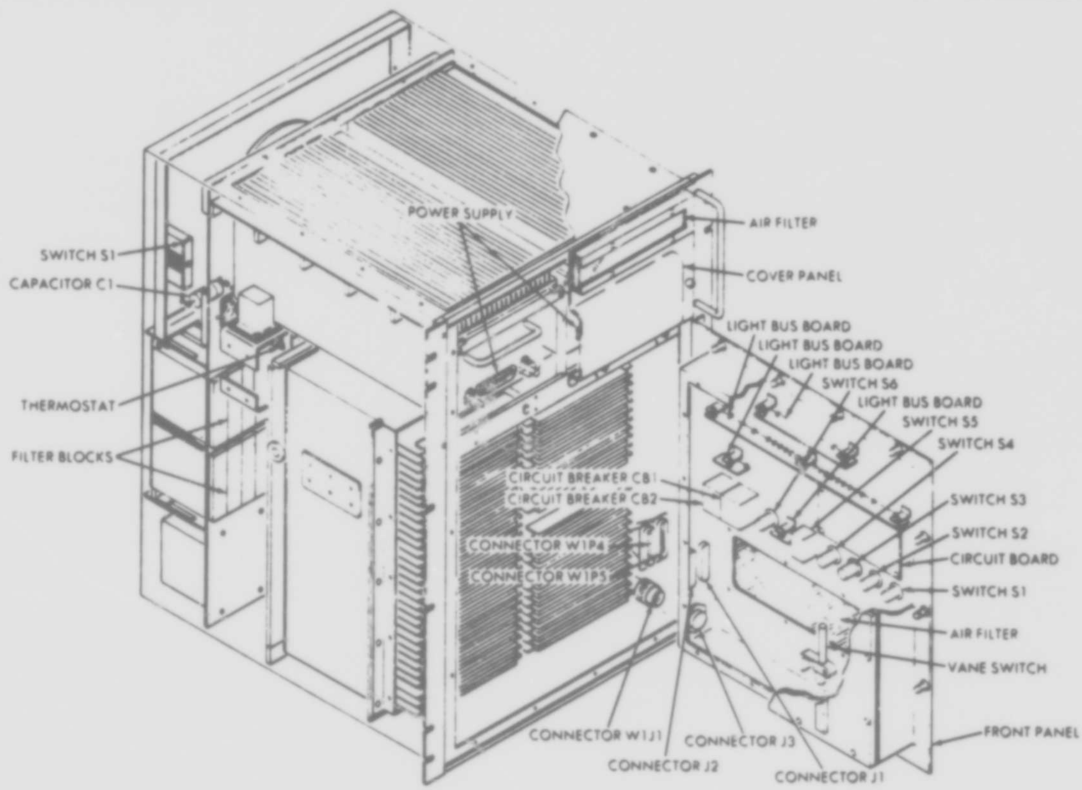
SUB-NOTE 1 (2) (Sheet 2 of 2 sheets) Multiplexer Component Locations



SUB-NOTE 1 (3) Demultiplexer Front Panel

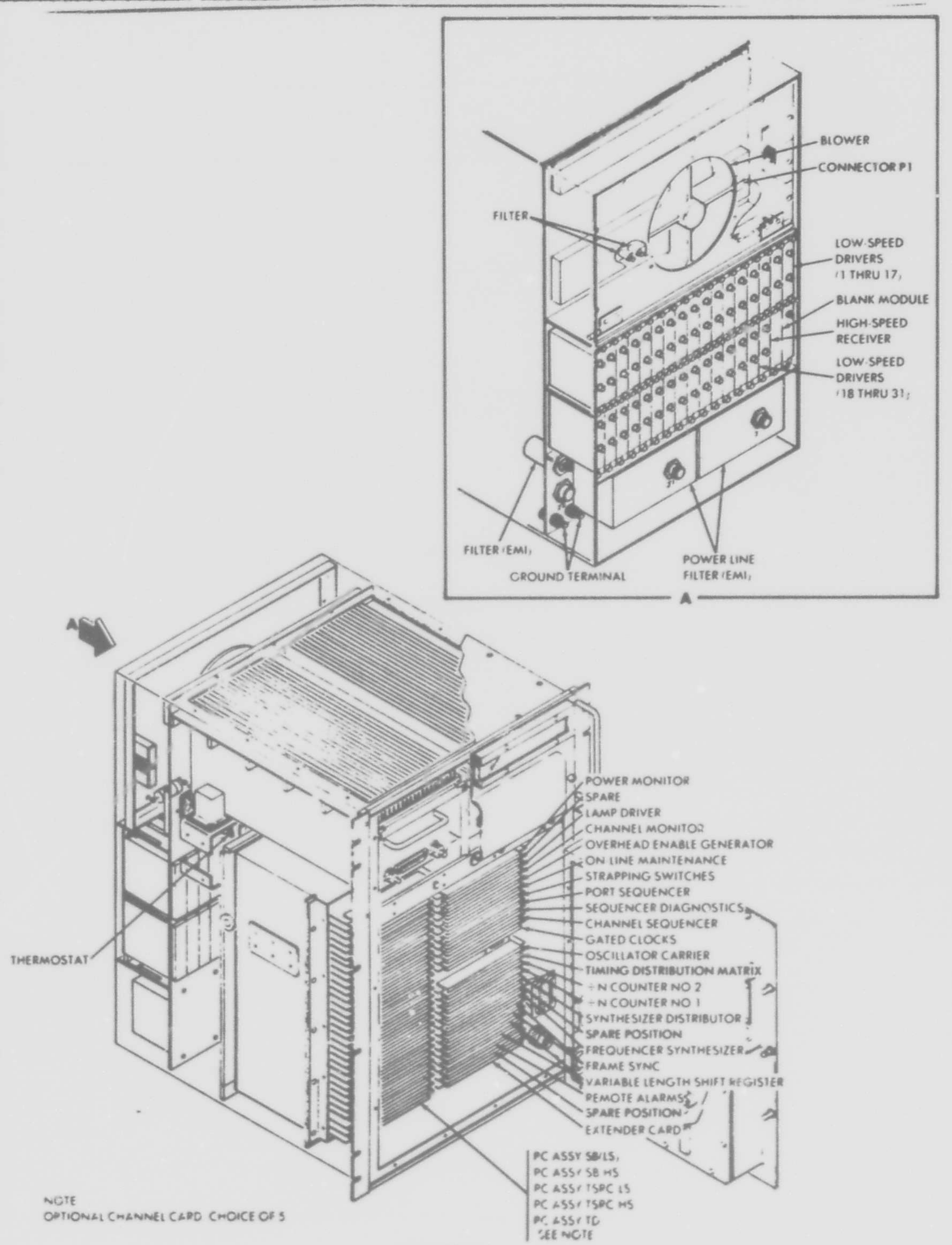


SUB-NOTE 1 (4) (Sheet 1 of 2 sheets) Demultiplexer Component Locations



DEMULTIPLEXER

SUB-NOTE 1 (4) (Sheet 2 of 2 sheets) Demultiplexer Component Locations



DEMULTIPLEXER

a. Automatic Mode

Diagnostic circuits within the equipment automatically detect and display the source of a majority of malfunctions to a single replaceable subassembly, such as a printed circuit CMP, power supply, or line driver/receiver module, but in selected cases to two or more of these items.

b. Self-Test Mode

Periodic confidence testing of the automatic diagnostic circuits is provided by the diagnostic self-test mode for both the multiplexer and demultiplexer. Simulated errors are introduced into all operating circuits monitored by the automatic diagnostic function.

c. Lamp-Test Mode

Activation of the LAMP TEST switches permits check of the lamp circuits. All individual operating and error indicators light and a numerical display appears in the digital readout.

The maintenance concept for the multiplexer and demultiplexer was determined by receiving the user's operational and maintenance philosophy. The concept, based upon the detection, isolation, and replacement of failed subassemblies in the field, was established in the Request for Quote (RFQ). This philosophy was in consonance with the basic Air Force maintenance philosophy for fixed ground installation type communications systems. To complement the concept, the equipment incorporates automated and semiautomated diagnostic circuits and a higher modular packaging arrangement. These characteristics enable correction of most failures by subassembly exchange. The remaining failures will occur in discrete chassis-mounted components and replaceable subassemblies. Conventional troubleshooting and repair techniques are used for correction of these failures.

The maintenance concept, hardware level for maintenance, and type and level of diagnostics were also based on the specified design requirement at 10.0 minutes mean corrective time ($\bar{M}_{ct}$) and 30.0 minutes maximum (95th percentile) corrective maintenance time ($M_{max\ ct}$).

2.2 Develop Symptom-Fault Matrix (Step 2)

Development of a symptom-fault matrix requires that the following information be developed or prepared for the system:

- Functional block diagram
- Reliability analysis
- Failure symptom based on failed item

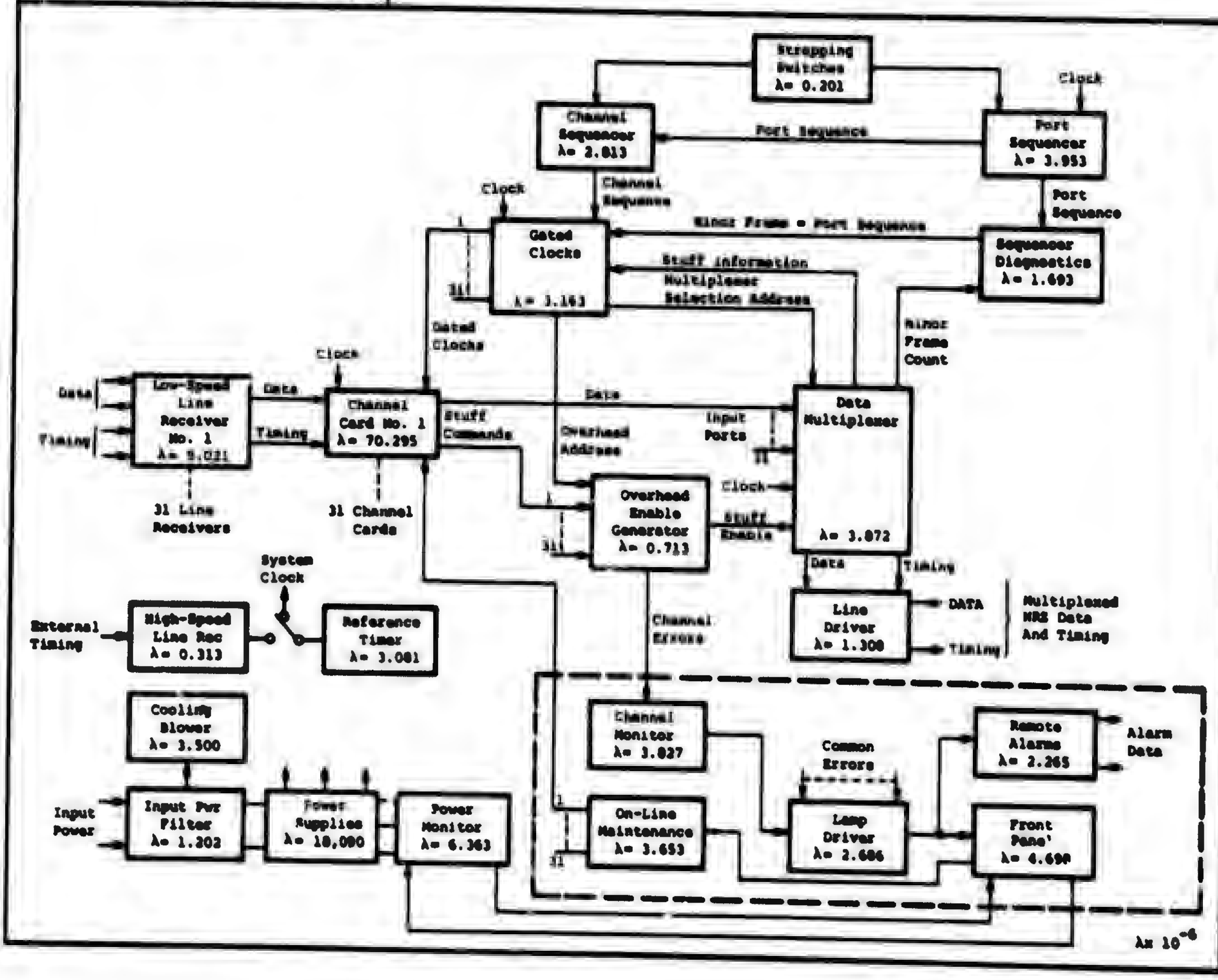
a. Preparing Functional Block Diagram

A functional block diagram of the Multiplexer Set is shown in SN 2.2(1). The area enclosed by dotted lines is the diagnostic block diagram.

(1) Multiplexer

The multiplexer is normally provided with inputs of data plus timing, but alternate inputs may be provided. Each input may be connected to one port or to several ports strapped together. The data and timing inputs to each channel are passed through two identical line receiver circuit cards in the low-speed line receiver module to the appropriate channel card. The channel card may be any one of the option cards available. Available option cards include rate comparison buffer (RCB), source to transmission rate converter (STRC), transition encoder (TE), or timing recover (TR) card. Whichever option is installed, the function of the channel card is to accept data into an elastic store at the data rate and to clock data out of the store at the multiplexer system rate. Provided that the incoming data is within tolerance, the channel card will generate a positive stuff, negative stuff, or no-action command to the overhead enable generator. Data from the channel cards (up to 31 in operation) and the overhead information are multiplexed into an interleaved data stream. The multiplexer system clock is derived either from the internal reference timer or from an external timing source whose output is fed through a high-speed line receiver. The system clock is the source of all multiplexer internal timing and is used as the basis of the many gating and address code outputs of the gated clocks card.

SUB-NOTE 2.2 (1) Multiplexer Block Diagram



The switch positions on the strapping switch card indicate to the channel sequencer and port sequencer cards which channels are active, which are strapped, and which are not used. The port sequencer counts the number of ports in use, and the channel sequencer informs the gated clocks which channels are in use and which are the active and strapped channels. The sequencer diagnostics card contains the circuits that compare the port sequence with minor frame counts and notify the gated clock when the two are equal. The gated clocks card acts as a central control and provides gating signals and/or address codes to the channel cards, the overhead enable generator, and the data multiplexer. These functions ensure that the correct channel and port sequences are observed, word count and minor frame count are observed, and the overhead bits are properly interleaved and the overhead channel identification code coincides with the correct minor frame.

Multiplexed data and overhead information plus timing are passed to two identical line driver circuit cards in the line driver module. The line driver output of bipolar NRZ data plus timing is also the multiplexer output.

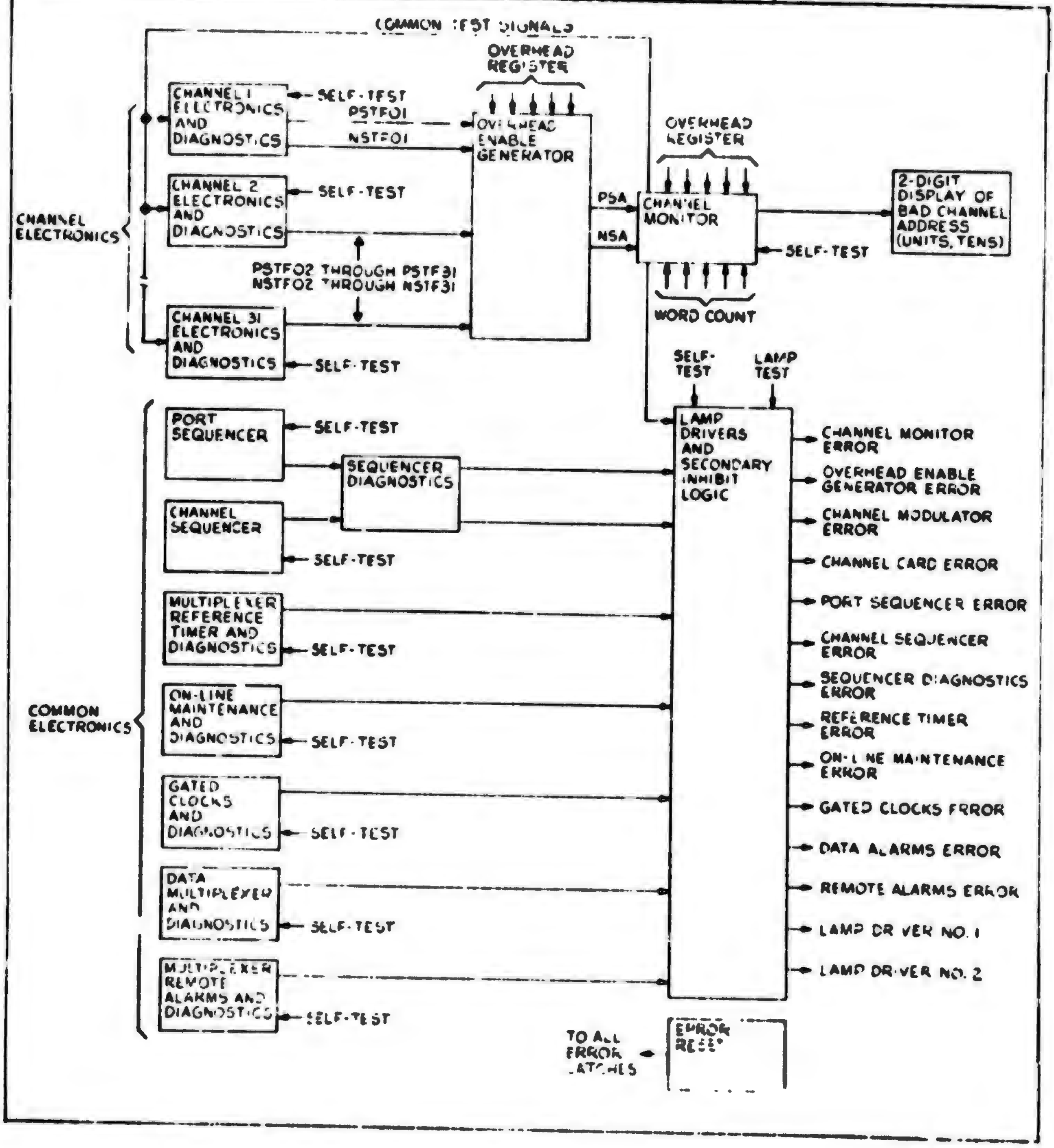
(2) Multiplexer Diagnostics

The functional block diagram of the multiplexer diagnostics is shown in SN 2.2(2).

The multiplexer diagnostics system is divided into two major parts: the first part consists of the diagnostic circuits for all of the channel electronics; the second part consists of the diagnostic circuits for the common electronics. This division is shown in SN 2.2(2).

In the channel electronics, channel cards stuff signals PSTFXX and NSTFXX are inspected for stuff commands only at W29 so that the lines OSTF and NSTF are used for diagnostic signals from W1 to W24. Common test signals are provided to all channel cards from the channel monitor to exercise portions of the channel card circuits so that predictable stuffing signals appear on the PSTF and NSTF lines for each channel during the W1 and W22 time period. During

SUB-NOTE 2.2 (2) Multiplexer Diagnostics Block Diagram



W23, an out-of-tolerance condition is imposed, and during W24, the contents of the error latches for the channel card receiving overhead service are transferred to the channel monitor. The PSTF and NSTF lines all feed to the overhead enable generator, where the channels are multiplexed by the overhead register binary number so that two output lines PSA and NSA transmit the diagnostic data to the channel monitor. Each channel has its diagnostic data presented during its minor frame for overhead service. The channel monitor inspects the incoming diagnostic data, and if an error indication is received, the two-digit display on the front panel indicates the number of the defective channel card or module. In addition, the lamp driver circuits are activated to light either the CARD or MODULE error indicator.

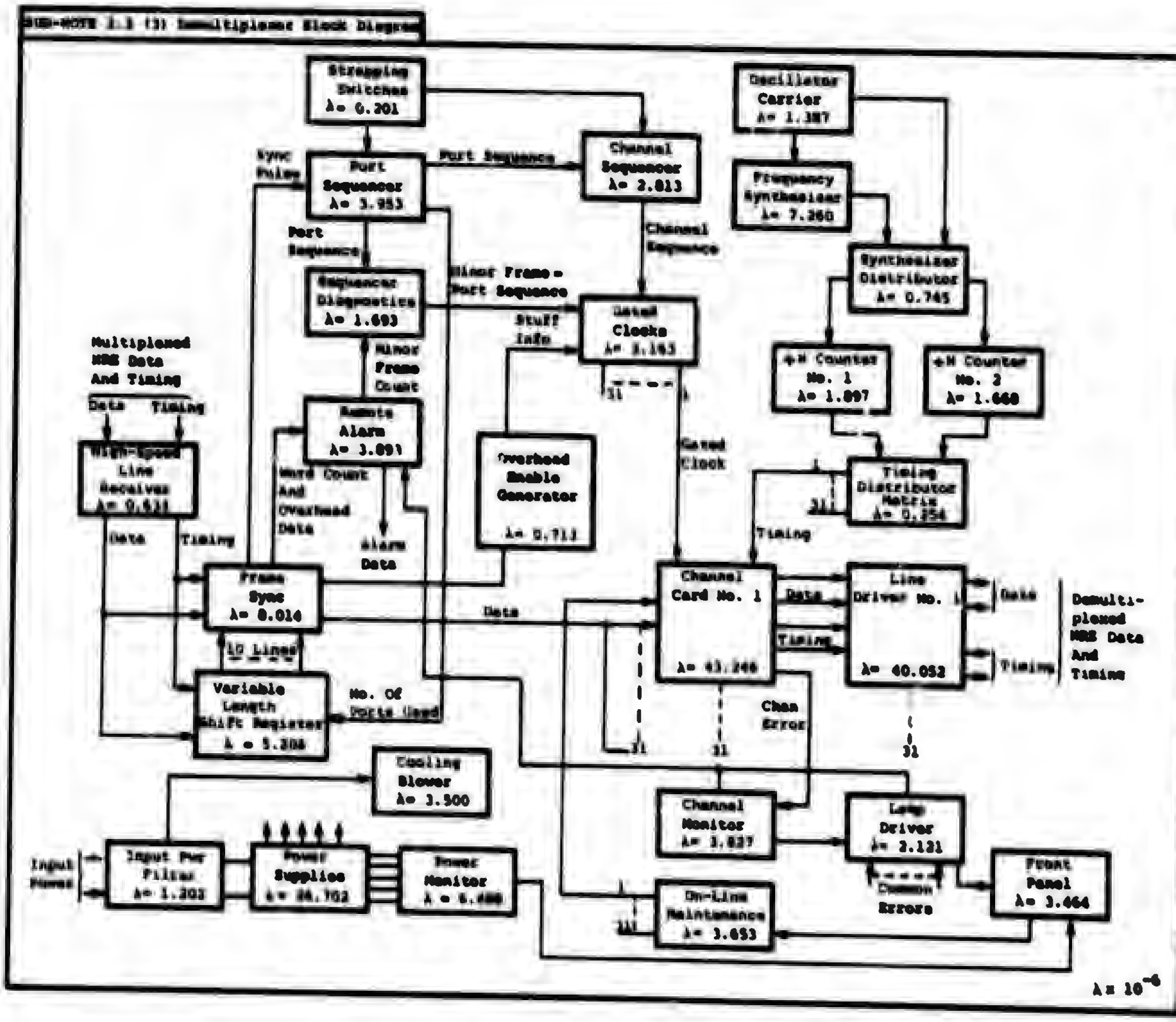
The common electronics cards are not exercised as the channel cards are, since dead time is not available in the common electronics circuits. In these cards, the diagnostic circuitry checks the circuit functions and provides an output, held in an error latch, when an incorrect function is detected. The malfunction signals, including the port sequencer and channel sequencer malfunction signals, which are generated on the sequencer diagnostics card, are supplied to the lamp driver cards to light the appropriate front panel indicator.

The three front panel switches associated with the diagnostic circuitry perform the following functions: the ERROR RESET switch, when actuated, resets all error latches in the multiplexer; the SELF TEST switch, when actuated, applies a known malfunction to all circuits so that all error latches are set and all error indicators light; and the LAMP TEST switch, when actuated, applies inputs to all lamp drivers to light all front panel indicators.

(3) Demultiplexer

A functional block diagram of the demultiplexer is shown in SN 2.2(3).

The demultiplexer inputs are the multiplexer outputs, one of which is data plus overhead information, and the other is timing. The two inputs are fed


Stropping Switches λ= 0.201
Port Sequencer λ= 3.953
Sync Pulses
Port Sequence
Channel Sequencer λ= 2.813
Channel Sequence
Oscillator Carrier λ= 1.387
Frequency Synthesizer λ= 7.260
Synthesizer Distributor λ= 0.745
÷N Counter No. 1 λ= 1.897
÷N Counter No. 2 λ= 1.668
Sequencer Diagnostics λ= 1.693
Minor Frame = Port Sequence
Stuff Info
Clocks
Minor Frame Count
Alarm λ= 3.891
Multiplexed NRZ Data And Timing
Data
Timing
High-Speed Line Receiver λ= 0.631
Word Count And Overhead Data
Alarm Data
Overhead Enable Generator λ= 0.711
Gated Clock
Timing Distributor Matrix λ= 0.254
Frame Sync λ= 8.014
10 Lines
Variable Length Shift Register
No. Of Ports Used
Channel Card No. 1
Line Driver No. 1 λ= 40.052
Demulti-plexed NRZ Data And Timing
Chan Error
31
Cooling Blower λ= 3.300
Channel Monitor λ= 3.827
Driver λ= 2.121
Common Errors
Front Panel λ= 3.464
Input Power
Input Pwr Filter λ= 1.202
Power Supplies
Power Monitor
On-Line Maintenance λ= 3.653
λ x 10^-6

through two identical circuit cards in the high-speed line receiver module to the frame sync and variable-length shift register cards. The frame sync card performs a bit-by-bit scan of the incoming data until the first 11 bits of one of the three overhead sync codes are recognized. When this occurs the next 12 overhead bits are inspected, and if the complete 23-bit sync code is correct (i.e., it conforms to one of the three sync codes with an error of two bits or less), the frame sync card locks into sync. A sync pulse is sent to the port sequencer to initialize port sequence, word count and overhead data is supplied to the remote alarms card, and stuff information is provided to the gated clocks card. The remote alarms card uses word count and overhead information to produce a minor frame count output to the sequencer diagnostics.

The switch positions on the strapping switch card indicate to the channel sequencer and port sequencer cards which channels are active, which are strapped, and which are not used. The port sequencer counts the number of ports in use, and the channel sequencer informs the gated clocks which channels are in use and which are the active and strapped channels. An output representing the number of ports used is provided by the port sequencer to the variable-length shift register. This information enables the variable-length shift register and frame sync cards to scan incoming data for the first 11 bits of the overhead sync code by knowing the number of bits in the incoming data words, as the number of bits equals the number of ports used plus one.

The data output from the frame sync card is identical to its input. The frame sync card does not process the data, but provides an output data bus that is connected to all 31 channel cards. The gated clocks card provides the gating signals to all channel cards to perform the demultiplexing process. Each channel card clocks in a data bit from the data bus at the time it is enabled by the gated clock input. The data bit is passed into an elastic store similar to that in the multiplexer input channel. Data is clocked out of the store at the rate set by the timing distribution matrix output. Data into the store is at an unsmooth rate, as the gated clock enables the input of data bits plus positive stuff bits, or inhibits data bits for the negative stuffing action. The elastic store output is at a smooth rate proportional to the output timing, which is monitored by a digital phase-lock-loop comparison of clock in to clock out. As the data clocked in increases or decreases in rate, the output timing compensates smoothly, over a relatively long time period, until input and output rates are identical and the output is smooth. The data output is now transparent to the multiplexer data input. Output data and timing signals are passed through two identical circuit cards in the line driver module.

Output timing is independently derived in the demultiplexer by an oscillator carrier card and frequency synthesizer card producing many high frequency clock signals. The synthesizer distributor card provides a matrix for manual preselection of the clock range required, according to the demultiplexer channel output rates. The two divide by N counters are also manually preset to count down the high frequency preselected clock signals to a frequency that is 24 times the channel output rate. The timing distribution matrix provides a manual preselection for each output channel from the counted down clock frequencies. Thus the demultiplexer clock ranges, frequency division rates, and applicable output channels are preset to give a timing output at 24 times the channel rate. Divide by 24 action to provide the actual channel timing is provided in the channel card under control of the digital phase-lock-loop circuit. If the input rate is greater than 518.4 Kbps, a divide by 12 (instead of a divide by 24) action is initiated to provide the actual channel timing.

b. Perform Reliability Analysis

A preliminary reliability prediction was performed for the major items identified. This was based on identification of the LRU, parts count, items per set, and failure rate. Failure rate information was derived from various sources as follows:

- MIL-HDBK-217A
- MIL-STD-756A
- RADC TR's
  - RADC-TR-67-108
  - RADC-TR-67-307
  - RADC-TR-68-114
  - RADC-TR-68-280
- FARADA
- IDEP
- Other Government sources
- Contractor data

SN 2.2(4) summarizes the results of the prediction effort for the multiplexer and the demultiplexer. The total failure rate has been identified in the functional block diagrams (SN 2.2(1) and SN 2.2(3)).

c. Determine Failure Symptom Based on Failed Item

The system symptom indicator, symptom, and type of display matrix are shown in SN 2.2(5) and SN 2.2(6) for the multiplexer and demultiplexer, respectively. The next step in the prediction process is to construct a symptom-fault matrix. This step is to determine the effects of failed hardware items on symptom operation. Basically defined, it is the allocation of the failure rate of each hardware item in relation to the percent contribution to each symptom identified in the symptom matrix. The steps in the development of the symptom-fault matrix are as follows:

(1) Hardware Level, Failure Rate, Symptom Matrix

The combined information from SN 2.2(4), SN 2.2(5), and SN 2.2(6) is entered on the symptom-fault matrix for the multiplexer and demultiplexer, respectively. This is illustrated in SN 2.2(7) and SN 2.2(8). The first column delineates the hardware breakdown, the second column the total failure rate, and the third column the symptom number.

SUB-NOTE 2.2 (4) (Sheet 1 of 3 sheets) Summary of Failure Rate Data for the Multiplexer Set

Item	Total/per Item		No. Items per set	Total/per Set	
	No. of Parts	Failure Rate**		No. of Parts	Failure Rate**
Multiplexer Set				9904	374.458
Multiplexer				4573	146.710
Front Panel	85	4.698	1	85	4.698
Line Driver, High Speed	26	1.308	1	26	1.308
Receiver, Low Speed	38	0.291	31	1178	9.021
Receiver, High Speed	42	0.313	1	42	0.313
Rate Comparison Buffer	43	2.132	24	1032	51.168
Source-Transmission Rate Converter	45	2.396	4	180	9.584
Transition Encoder	57	3.181	3	171	9.543
Reference Timer	54	3.081	1	54	3.081
Port Sequencer	63	3.953	1	63	3.953
Channel Sequencer	44	2.813	1	44	2.813
Gated Clocks	49	3.163	1	49	3.163
Sequencer Diagnostics	28	1.693	1	28	1.693
Overhead Enable Generator	14	0.713	1	14	0.713
Power Monitor	167	6.363	1	167	6.363
Strapping Switches	51	0.201	1	51	0.201
Channel Monitor	70	3.827	1	70	3.827
On-Line Maintenance	56	3.653	1	56	3.653
Data Multiplexer	62	3.872	1	62	3.872
Remote Alarm	78	2.265	1	78	2.265
Lamp Driver	23	1.343	2	46	2.686
Air Blower	1	3.500	1	1	3.500
Input Power Filter	28	1.202	1	28	1.202
Power Supply	524	25.494	2*	1048	18.090

*Two power supplies in redundant configuration.
**Failures/10^6 hours.

SUB-NOTE 2.2 (4) (Sheet 2 of 3 sheets) Summary of Failure Rate Data for the Multiplexer Set

Item	Total/per Item		No. Items per set	Total/per Set	
	No. of Parts	Failure Rate**		No. of Parts	Failure Rate**
Multiplexer Set					
Demultiplexer				5331	227.748
Front Panel	64	3.464	1	64	3.464
Line Driver, Low Speed	24	1.292	31	744	40.052
Transition Decoder	66	3.668	3	198	11.004
Receiver, High Speed	42	0.633	1	42	0.633
Smoothing Buffer, High Speed	55	3.187	3	165	9.561
Smoothing Buffer, Low Speed	54	2.828	21	1134	59.388
Transmission-Source Rate Converter, Low Speed	62	3.388	3	186	10.164
Transmission-Source Rate Converter, High Speed	57	3.129	1	57	3.129
Lamp Driver	36	2.121	1	36	2.121
Port Sequencer	63	3.953	1	63	3.953
Variable Length Shift Register	41	2.603	2	82	5.206
Channel Sequencer	44	2.813	1	44	2.813
Frame Sync	63	4.007	2	126	8.014
Gated Clocks	49	3.163	1	49	3.163
Sequencer Diagnostics	28	1.693	1	28	1.693
Overhead Enable Generator	14	0.713	1	14	0.713
Power Monitor	167	6.488	1	167	6.488
Strapping Switch	51	0.201	1	51	0.201
Channel Monitor	70	3.827	1	70	3.827
On-Line Maintenance	56	3.653	1	56	3.653
Timing Distribution Matrix	62	0.254	1	62	0.254
Remote Alarms	93	3.893	1	93	3.893
Divide By N Counter #1	46	1.897	1	46	1.897
Divide By N Counter #2	54	1.668	1	54	1.668

**Failures/10^6 hours.

SUB-NOTE 2.2 (4) (Sheet 3 of 3 sheets) Summary of Failure Rate Data for the Multiplexer Set

Item	Total/per Item		No. Items per set	Total/per Set	
	No. of Parts	Failure Rate**		No. of Parts	Failure Rate**
Multiplexer Set					
Demultiplexer					
Frequency Synthesizer	258	7.260	1	258	7.260
Synthesizer Distributor	28	0.745	1	28	0.745
Oscillator Carrier	17	1.387	1	17	1.387
Air Blower	1	3.500	1	1	3.500
Input Power Filter	28	1.202	1	28	1.202
Power Supply	684	37.604	2*	1368	26.702

*Two power supplies in redundant configuration.
**Failures/10^6 hours.

NOTE: Channel Module Configuration is in accordance with prototype set 1.

SUB-NOTE 2.2 (5) (Sheet 1 of 3 sheets) Symptom Matrix (Multiplexer)

Symptom No.	Symptom	Type of Display		Malfunction Item
		Indicator Light	Digital Readouts	
	Multiplexer			
1	Port out of tolerance (Data timing rate exceeds limit (source))	X		
2	Error channel card (Channel card malfunction)	X	X	
3	Error channel module (Channel module malfunction)	X	X	
4	Error combiner card	X (37-41, 43-46, 49-51)	X	
5	Error driver module (Multiplexer output driver module malfunction)	X	X	
6	Error timing module (Timing input module malfunction)	X		
7	Error power supply			
-1	Power supply 1 malfunction	X		
-2	Power supply 2 malfunction	X		
8	Thermal alarm			
-1	CAUTION lit CRITICAL out	X		Blower, vane switch, relays, filter interlock switch

SUB-NOTE 2.2 (5) (Sheet 2 of 3 sheets) Symptom Matrix (Multiplexer)

Symptom No.	Symptom	Type of Display		Malfunction Item
		Indicator Light	Digital Readouts	
-2	CAUTION and CRITICAL lit	X		Blower, vane switch, relays, filter, interlock switch
-3	CRITICAL lit; CAUTION out	X		Thermostat
9	Power Supply			
-1	ACTIVE indicators 1 and 2 out	X		Lamp
-2	Improper transfer; no error indicators lit	X		Power monitor card, transfer switch
-3	Error display for supply in use; equipment operates normally	X		Power monitor card
-4	Error display after supply replaced	X		Power monitor card, power switch, input filter, circuit breaker
10	Out of Tolerance			
-1	One PORT OUT OF TOLERANCE lit; no error display	X		Source strapping switch card
-2	All PORT OUT OF TOLERANCE displayed; no error display	X		Strapping switch card, reference timer card

SUB-NOTE 2.2 (5) (Sheet 3 of 3 sheets) Symptom Matrix (Multiplexer)

Symptom No.	Symptom	Type of Display		Malfunction Item
		Indicator Light	Digital Readouts	
10	Out of Tolerance (Cont)			
-3	Two active channels indicate PORT OUT OF TOLERANCE; no error display	X		Strapping switch card
-4	One PORT OUT OF TOLERANCE indicator lit. Card or module error remains after card and/or module is replaced.	X	X	Strapping switch card
11	Card/Module Errors			
-1	Card error for 49 remains after card is replaced (operating external timing)	X	X	Source
-2	Card error for 49 remains after card is replaced (operating from internal)	X	X	Timing switch
-3	Card error for card XX remains after card is replaced; multiplexer operating normally	X	X	Source
-4	Any card or module error remains after indicated item has been replaced (except for -1 and -2 above)	X	X	Connector pin, card, or chassis wiring

SUB-NOTE 2.2 (6) (Sheet 1 of 3 sheets) Symptom Matrix (Demultiplexer)

Symptom No.	Symptom	Type of Display		
		Indicator Light	Digital Readouts	Malfunction Item
	Demultiplexer			
1	Loss of frame	X		
-1	A - Loss of frame sync	X		
-2	B - Loss of frame (source generated)	X		
2	Error rate (Selected link error rate threshold is exceeded (source))	X		
3	Error channel card (Channel card malfunction)	X	X	
4	Error channel module (Channel module malfunction)	X	X	
5	Error combiner card	X (38-41, 43-46, 49, 51-53, 55-60)	X	
6	Receiver module (Line receiver malfunction)	X	X	
7	Power Supply	X		
-1	Power supply 1 malfunction	X		
-2	Power supply 2 malfunction	X		
8	Thermal Alarm			
-1	CAUTION lit CRITICAL out	X		Blower, vane switch, relays filter, interlock switch

SUB-NOTE 2.2 (6) (Sheet 2 of 3 sheets) Symptom Matrix (Demultiplexer)

Symptom No.	Symptom	Type of Display		
		Indicator Light	Digital Readouts	Malfunction Item
8	Thermal Alarm (Cont)			
-2	CAUTION and CRITICAL lit	X		Blower, vane switch, relays, filter, interlock switch
-3	CRITICAL lit; CAUTION out	X		Thermostat
9	Power Supply			
-1	ACTIVE Indicators 1 and 2 out	X		Lamp
-2	Improper transfer; no error indicators lit	X		Power monitor card, trasnfer switch
-3	Error display for supply in use; equipment operates normally	X		Power monitor card
-4	Error display after supply replaced	X		Power monitor card, power switch, input filter, circuit breaker
10	Loss of frame			
-1	LOSS OF FRAME A indicator lit continuously; no error displayed	X		Source, strapping switch
-2	Card error remains after indicator card is replaced	X	X	Strapping switch card, multiplexer

SUB-NOTE 2.2 (6) (Sheet 3 of 3 sheets) Symptom Matrix (Demultiplexer)

Symptom No.	Symptom	Type of Display		
		Indicator Light	Digital Readouts	Malfunction Item
11	Card/module errors			
-1	Card error for 49 remains after card is replaced (operating external timing)	X	X	Source
-2	Card error for 49 remains after card is replaced (operating from internal)	X	X	Timing switch
-3	Card error for card XX remains after card is replaced; multiplexer operating normally	X	X	Source
-4	Any card or module error remains after indicator item has been replaced (except for -1 and -2 above)	X	X	Connector pin, card or chassis wiring

SUB-NOTE 2.2 [illegible] Symptom-Fault Matrix (Multiplexer)

Hardware Item	Failure Rate	1	2	3	4	5	6	7-1	7-2	8-1	8-2	8-3	9-1	9-2	9-3	9-4	10-1	10-2	10-3	10-4	11-1	11-2	11-3	11-4
Front Panel	4.690	No Generated Failure																			[illegible]		[illegible]	
Line Driver, High-Speed	1.308					1.308							0.9396	0.9396		1.0792								
Receiver, Low-Speed	4.021			4.021																		0.9396		
Receiver, High-Speed	0.313						0.313																	
Rate Comparison Buffer	5.166		5.166																					
Multiplex-Transmission Rate Converter	9.500		9.500																					
Transition Encoder	4.581		4.581																					
Reference Timer	1.081				0.77[illegible]													[illegible]						
Post Sequencer	1.451				1.451																			
Channel Sequencer	4.011				4.011																			
Gated Clocks	3.163				3.163																			
Sequencer [illegible]	1.441				1.441																			
Overhead Enable Generator	0.719				0.719																			
Power Monitor	6.363													2.121	2.121	2.121								
Strapping Switches	[illegible]																0.25[illegible]	0.25[illegible]	0.25[illegible]	0.25[illegible]				
Channel Monitor	3.827				3.827																			
Module Maintenance	4.453				4.453																			
Data Multiplexer	1.872				1.872																			
Remote Alarm	[illegible]				[illegible]																			
Lamp Driver	2.606				2.606																			
Air Blower	[illegible]																							
Input Power Filter	1.232									1.166	1.166	1.166												
Power Supply	18.[illegible]90									0.6006	0.6006					0.8006								
Wiring & Other								9.085	9.085															
Multiplexer	146.710																							

SUB-SYSTEM [illegible] Symptom-Fault Matrix (Demultiplexer)

Hardware Item	Failure Rate	Symptom 1-1	1-2	2	3	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9-1	[illegible]	9-3	9-4	[illegible]	[illegible]	[illegible]	11-2	[illegible]	[illegible]
Front Panel	1.4[illegible]	[illegible] Multiplexer [illegible]									[illegible]	[illegible]		[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	
Line Driver, Low-Speed	40.052					[illegible]																	
Transition Decoder	11.[illegible]4				11.[illegible]4																		
Receiver, High-speed	[illegible]							[illegible]															
Smoothing Buffer, High-speed	[illegible]				[illegible]																		
Smoothing Buffer, Low-speed	50.[illegible]				[illegible]																		
Transmission-source Rate Converter, Low-speed	10.[illegible]4				[illegible]4																		
Transmission-source Rate Converter, High-speed	[illegible]				[illegible]																		
Lamp Driver	[illegible]						[illegible]																
Port Sequencer	[illegible]						[illegible]																
Variable Length Shift Register	[illegible]						[illegible]																
Channel Sequencer	2.01[illegible]						[illegible]																
Frame Sync	[illegible]14						[illegible]14																
Gated Clocks	[illegible]						[illegible]																
Sequencer Diagnostics	[illegible]						[illegible]																
Overhead Enable Generator	[illegible]						[illegible]71																
Power Monitor	[illegible]																						
Strapping Switch	0.2[illegible]													[illegible]	[illegible]	[illegible]							
Channel Monitor	[illegible]						[illegible]											[illegible]	[illegible]				
On-Line Maintenance	[illegible]						[illegible]																
Timing Distribution Matrix	[illegible]						[illegible]																
Remote Alarms	[illegible]						[illegible]																
Divide By [illegible] Counter No. 1	[illegible]						[illegible]																
Divide By [illegible] Counter No. 2	[illegible]						[illegible]																
Frequency Synthesizer	7.2[illegible]						[illegible]																
Synthesizer Distributor	[illegible]						[illegible]																
Oscillator [illegible]	[illegible]						[illegible]																
Air Blower	[illegible]										[illegible]	[illegible]	[illegible]										
Input Power Filter	[illegible]										[illegible]	[illegible]					[illegible]						
Power Supply	26.[illegible]								[illegible]	[illegible]													
Wiring & Other																							
Demultiplexer:	227.[illegible]																						

(2) Compute H(s,f)

The information from SN 2.2(7) and SN 2.2(8) is used to develop the information in SN 2.2(9), which is the worksheet for computing H(s,f). The results of the worksheet developed similar to that of early design (see DN 13B1, SN 2.2(7)) yields:

$$H(s,f) = 5.389$$

2.3 Determine Maintenance Design Characteristics of the LRU's (Step 3)

This step is identical to that performed in the early design prediction (see DN 13B1, Para 2.3). In this case, based on further design definition, each individual LRU was scored instead of functional blocks. The individual checkout score results are shown in SN 2.3(1). The checklists for test complexity (X_1), test instrumentation (X_2), test evaluation (X_3), and test availability (X_4) are as depicted in DN 13B1, SN 2.3(1).

Upon completion of SN 2.3(1), $\bar{X}_t$ (the average maintenance checklist score) is calculated based on the following:

$$\bar{X}_t = \frac{\Sigma\lambda_i X_{Ti}}{\Sigma\lambda_i}$$

where: $X_{Ti} = X_1 + X_2 + X_3 + X_4$

and is the summation of column D in SN 2.3(1) for each LRU.

The solution of $\bar{X}_t$ from the results in SN 2.3(1) yields:

$$\bar{X}_t = 19.338$$

2.4 Perform Maintenance Task Time Study (Step 4)

The method for predicting fault correction/adjustment time entails three steps as follows:

- Definition of the range of fault correction/adjustment tasks that must be performed.
- Analysis of a representative sample of fault correction tasks to determine the subtasks involved and application of time standards.
- Summarization of the results of the second step to establish the average fault correction time ($\bar{T}_i$) for the system.

Task analysis requires that a representative set of LRU's be examined in detail to determine the subtasks involved in the interchange of actions.

Review of the multiplexer and demultiplexer comprising the Multiplexer Set reveals the following representative subtasks for both the multiplexer and demultiplexer units:

- Front panel
  - Switches
  - Air filter
  - Circuit breaker
  - Lamps
- Printed circuit cards
- Blower
- Line driver and receivers
- Power supply
- Power line filters

Task analyses for these items are delineated in SN 2.4(1).

The time standards presented in SN 2.4(1) are based on the assumption that subtasks are performed under ideal (unimpeded) conditions. If a task is performed under other than ideal conditions, an impediment correction factor (the ratio of the mean time to perform subtasks under impeded conditions to the mean time under ideal conditions) must be applied. In the case of the Multiplexer Set, no "less-than-ideal" maintenance conditions exist which would impede the technician in performing the corrective action. The impediment correction factor is thus 1 for the Multiplexer Set.

SN 2.4(2) summarizes the fault correction time predictions. Each LRU identified in SN 2.4(1) is listed for the multiplexer and demultiplexer, together with the total T_c value computed and the total failure rate for that LRU grouping.

SUB-NOTE 2.2 (9) (Sheet 1 of 3 sheets) Worksheet for Computing H(s,f)

λ_{ij}	$P_{ij} = \lambda_{ij}/\lambda_T$ (X 10^3)	L (ij) $= -\log_2 P_{ij}$	P_{ij} L (ij) (X 10^3)
0.9396	2.50	8.6448	21.6120
0.9396	2.50	8.6448	21.6120
1.8792	5.01	7.6418	38.2854
0.9396	2.50	8.6448	21.6120
1.308	3.49	8.1634	28.4902
9.021	24.09	5.3760	129.5078
0.313	0.83	10.2352	8.4952
51.168	136.64	2.872	392.4300
9.584	25.59	5.289	135.3455
9.534	25.46	5.289	134.6579
2.7729	7.40	7.079	52.3846
0.3081	0.82	6.9308	5.6832
3.953	10.55	6.5672	69.2839
2.813	7.51	7.0578	53.0040
3.163	8.44	6.8893	58.1456
1.693	4.52	7.7903	35.2121
0.713	1.90	9.0255	17.1484
2.121	5.66	7.4657	42.2558
2.121	5.66	7.4657	42.2558
2.121	5.66	7.4657	42.2558
0.0515	0.13	12.9106	1.6783
0.0515	0.13	12.9106	1.6783
0.0515	0.13	12.9106	1.6783
0.0515	0.13	12.9106	1.6783
3.827	10.22	6.6131	67.5858
3.653	9.75	6.6810	65.1397
3.827	10.22	6.6131	67.5858
2.265	6.04	7.3720	44.5268
2.686	7.17	7.1245	51.0826
1.166	3.11	8.3295	25.9047
1.166	3.11	8.3295	25.9047
1.166	3.11	8.3295	25.9047
0.4006	1.06	9.8827	10.4756
0.4006	1.06	9.8827	10.4756
0.4006	1.06	9.8827	10.4756
9.045	24.15	5.3724	129.7434
9.045	24.15	5.3724	129.7434

SUB-NOTE 2.2 (9) (Sheet 2 of 3 sheets) Worksheet for Computing H(s,f)

λ_{ij}	$P_{ij} = \lambda_{ij}/\lambda_T$ (X 10^3)	L (ij) $= -\log_2 P_{ij}$	P_{ij} L (ij) (X 10^3)
0.4949	1.32	9.5661	12.6272
0.4949	1.32	9.5661	12.6272
0.4949	1.32	9.5661	12.6272
0.9898	2.64	8.5661	22.6145
0.4949	1.32	9.5661	12.6272
40.052	106.95	3.2252	344.935
11.004	29.38	5.0897	149.5353
0.663	1.77	9.1428	16.1827
9.561	25.53	5.2923	135.1124
59.388	158.59	2.6571	421.3894
10.164	27.14	5.2039	141.2338
3.129	8.35	6.9046	57.6534
2.121	5.66	7.4657	42.2558
3.953	10.55	6.5672	69.2839
5.206	13.90	6.1694	85.7546
2.813	7.51	7.0578	53.0040
8.014	21.40	5.5468	118.7015
3.163	8.44	6.8893	58.1456
1.693	4.52	7.7903	35.2121
0.713	1.90	9.0405	17.1769
2.1626	5.66	7.4657	42.2558
2.1626	5.66	7.4657	42.2558
2.1626	5.66	7.4657	42.2558
0.1005	0.26	8.5880	2.2328
0.1005	0.26	8.5880	2.2328
3.827	10.22	6.6132	67.5869
3.653	9.75	6.6810	65.1397
0.254	0.67	7.2222	4.8388
3.893	10.39	6.5894	68.4638
1.897	5.06	7.6272	38.5936
1.668	4.45	7.8245	34.8190
7.260	19.38	5.6900	110.272
0.745	1.98	8.9810	17.782
1.387	3.67	8.0906	29.6925
1.166	3.11	8.3295	25.9047
1.166	3.11	8.3295	25.9047
1.166	3.11	8.3295	25.9047

SUB-NOTE 2.2 (9) (Sheet 3 of 3 sheets) Worksheet for Computing $H(s,f)$

λ_{ij}	$P_{ij} = \lambda_{ij}/\lambda_T$ (X 10^3)	$L(ij) = -\log_2 P_{ij}$	P_{ij} $L(ij)$ (X 10^3)
0.4006	1.06	9.8827	10.4756
0.4006	1.06	9.8827	10.4756
0.4006	1.06	9.8827	10.4756
13.356	35.66	4.8100	171.5246
13.356	35.66	4.8100	171.5246
Σ 374.458			$\Sigma P_{ij} L(ij) \times 10^{-3} = 4.8602409 = H(s,f)$

The fault correction/adjustment time for the system is calculated by

$$\bar{T}_c = \frac{\Sigma \lambda_i T_{ci}}{\lambda_T}$$

where

λ_i = failure rate of the ith LRU

T_{ci} = estimated task time for ith LRU

λ_T = Total system failure rate

from SN 2.4(2)

$$\bar{T}_c = \frac{716.165}{374.458} = 1.91 \text{ minutes}$$

2.5 Compute Expected Total Active Downtime (Step 5)

a. Calculation of $\bar{T}_d$

The estimate for the fault location checkout time ($\bar{T}_d$) is calculated, using the following equation:

$$\ln \bar{T}_d = 0.420 \ln \bar{X}_t + 0.802 \ln H(s,f) + 0.625$$

The values for H(s,f) and $\bar{X}_t$ have been calculated in steps 2 and 3, respectively. Using these results and substituting in the equation above yields

$$\ln \bar{T}_d = 0.420 \ln (19.338) + 0.802 \ln (4.868) + 0.625$$
$$= 0.420 (2.96207) + 0.802 (1.58104) + 0.625$$
$$= 1.244 + 1.2679 + 0.625 = 3.1369$$
$$\bar{T}_d = 23.03 \text{ minutes}$$

b. Calculation of $\bar{T}_p$

The Multiplexer Set is a ground system, and thus preparation time is given by the following equation:

$$\bar{T}_p = 0.048 \bar{T}_p$$
$$= 0.048 (23.03)$$
$$= 1.1 \text{ minutes}$$

SUB-NOTE 2.3 (1) (Sheet 1 of 5 sheets) Checklist Scores for Detailed Design Prediction

LRU	Total λ	Complexity X_1				Instrumentation X_2				Evaluation X_3				Availability X_4				Total	
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	ΣD	λD
Front panel	0.9396 0.9396 1.8792 0.9396	20 20 14 20 14 20 14	1 1 1 1 1 1 1	1 1 4 1 4 1 4	1 1 4 1 4 1 4	23 23 1 23 1 20 1	1 1 2 1 2 1 2	1 1 4 1 4 1 4	1 1 8 1 8 1 8	1 1 3 1 3 1 3	1 1 5 1 5 1 5	1 1 4 1 4 1 4	1 1 20 1 20 1 20	1 1 3 1 3 1 3	1 1 5 1 5 1 5	1 1 4 1 4 1 4	1 1 20 1 20 1 20	4 4, 52} 56 4, 52} 56 4, 52} 56	3.7584 52.6176 105.2352 52.6176
Line driver, high-speed	1.306	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	5.232
Receiver, low-speed	9.021	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	36.084
Receiver, high-speed	0.313	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	1.252
Rate comparison buffer	51.168	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	204.672
Source transmission rate converter	9.584	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	38.336
Transition encoder	9.543	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	38.172
Reference timer	2.7729 0.306	20 20 20	1 1 1	1 1 1	1 1 1	23 23 23	1 1 1	1 1 1	1 1 1	1 1 3	1 1 5	1 1 1	1 1 5	1 1 1	1 1 1	1 1 1	1 1 1	4 4, 8} 12	11.0916 3.6972
Port sequencer	3.953	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	15.812
Channel sequencer	2.813	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	11.252
Gated clocks	3.163	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	12.652
Sequencer diagnostic	1.693	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	6.772
Overhead generator	0.713	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	2.852

SUB-NOTE 2.3 (1) (Sheet 2 of 5 sheets) Checklist Scores for Detailed Design Prediction

LRU	Total λ	Complexity X_1				Instrumentation X_2				Evaluation X_3				Availability X_4				Total	
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	ΣD	λD
Power monitor	2.121	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 12	25.452
		20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	
	2.121	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 12	25.452
		20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	
		20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 12	25.452
		20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	
Strapping Switches	0.05025	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	0.402
	0.05025	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	0.402
	0.05025	20	1	1	1	23	1	1	1	2	3	1	3	1	1	1	1	6	0.3015
	0.05025	20	1	1	1	23	1	1	1	2	3	1	3	1	1	1	1	6	0.3015
Channel monitor	3.827	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	15.308
On-line maintenance	3.653	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	14.612
Data Multiplexer	3.872	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	15.488
Remote Alarm	2.265	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	9.060
Lamp driver	2.686	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	10.744
Air blower	1.166	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	9.328
	1.166	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	9.328
	1.166	20	1	1	1	23	1	1	1	2	3	1	3	1	1	1	1	6	6.996
Input power filter	0.4006	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	3.2048
	0.4006	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	3.2048
	0.4006	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	3.2048
Power supply	18.090	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	72.36
Front Panel	0.4949	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 56	27.7144
		14	1	4	4	1	2	4	8	3	5	4	20	3	5	4	20	52	
	0.4949	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 56	27.7144
		14	1	4	4	1	2	4	8	3	5	4	20	3	5	4	20	52	
	0.4949	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	1.9796
	0.9898	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 56	55.4288
		14	1	4	4	1	2	4	8	3	5	4	20	3	5	4	20	52	
	0.4949	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 10	4.949
		20	1	1	1	23	1	1	1	2	3	1	3	1	1	1	1	6	

SUB-NOTE 2.3 (1) (Sheet 3 of 5 sheets) Checklist Scores for Detailed Design Prediction

LRU	Total λ	Complexity X_1				Instrumentation X_2				Evaluation X_3				Availability X_4				Total	
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	ΣD	λ_D
Line driver, low-speed	40.052	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	160.208
Transition decoder	11.004	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	44.016
Receiver, high-speed	0.663	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	2.652
Smoothing buffer, high-speed	9.561	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	38.244
Smoothing buffer, low-speed	59.388	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	237.552
Transmission source rate converter, low-speed	10.164	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	40.656
Transmission source rate converter, high-speed	3.129	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	12.516
Lamp driver	2.121	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	8.484
Port sequencer	3.953	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	15.812
Variable length shift register	5.206	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	20.824
Channel sequencer	2.813	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	11.252
Frame sync	8.014	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	32.056
Gated clocks	3.163	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	12.652
Sequencer diagnostic	1.693	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	6.772
Overhead enable generator	0.713	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	2.856

SUB-NOTE 2.3 (1) (Sheet 4 of 5 sheets) Checklist Scores for Detailed Design Prediction

LRU	Total λ	Complexity X_1				Instrumentation X_2				Evaluation X_3				Availability X_4				Total	
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	ΣD	λD
Power monitor	2.1626	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 12	25.9512
		20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	
	2.1626	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 12	25.9512
		20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	
	2.1626	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4 } 12	25.9512
		20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	
Strapping switch	0.1[illegible]	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	0.804
	0.1[illegible]05	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	0.804
Channel monitor	3.827	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	15.308
On-line maintenance	3.653	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	14.612
Timing distribution matrix	[illegible]	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	1.016
Remote alarms	3.893	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	15.572
Divide by N counter No. 1	1.897	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	7.588
Divide by N counter No. 2	1.668	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	6.672
Freq synthesizer	[illegible].745	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	2.980
Oscillator carrier	1.387	20	1	1	1	23	1	1	1	1	1	1	1	1	1	1	1	4	5.548
Air blower	1.166	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	9.328
	1.166	20	1	1	1	23	1	1	1	2	3	1	3	1	1	1	1	6	6.996
	1.166	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	9.328

SUB-NOTE 2.3 (1) (Sheet 5 of 5 sheets) Checklist Scores for Detailed Design Prediction

LRU	Total λ	Complexity X_1				Instrumentation X_2				Evaluation X_3				Availability X_4				Total	
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	ΣD	λD
Input power filter	0.4006	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	3.2048
	0.4006	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	3.2048
	0.4006	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	3.2048
Power supply	13.356	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	106.848
	13.356	20	1	1	1	23	1	1	1	3	5	1	5	1	1	1	1	8	106.848
	Σ 374.458																		7241.5292

$$\bar{X}_t = \frac{\Sigma \lambda_i \, X_{Ti}}{\Sigma \lambda_i} = \frac{\Sigma \lambda_i \, D_{Ti}}{\Sigma \lambda_i} = \frac{7241.5292}{374.458} = 19.338$$

where

$$D_{Ti} = D_1 + D_2 + D_3 + D_4$$

c. Calculation of $\bar{T}_i$

The average item obtainment time ($\bar{T}_i$) for ground equipment is

$$\bar{T}_i = 2.15 \text{ minutes}$$

d. Calculation of $\bar{T}$ and $\bar{T}'$.

The average total active downtime is given by:

$$\bar{T} = \bar{T}_c + \bar{T}_d + \bar{T}_p + \bar{T}_i$$

Substituting the values obtained in steps 4 and 5 yields:

$$\bar{T} = 1.91 + 23.03 + 1.1 + 2.15$$

$$\bar{T} = 28.19 \text{ minutes}$$

Adjustment to estimate the average ($\bar{T}'$) when the effect of "no trouble found" tasks are included yield:

$$\bar{T}' = 0.718\bar{T} = 8.963$$

$$= 0.718 \ (28.19) + 8.963 = 20.240 + 8.963$$

$$= 29.203$$

Although man-hours were not a stipulated requirement for the Multiplexer Set, man-hours are predicted below based on the relationship between downtime and man-hours. The equation relating these factors is:

$$\text{Maintenance man-minutes } (\overline{MM}) \text{ per task} = 2.104\ \bar{T} - 14.200$$

Substituting the predicted value of $\bar{T}$ for the Multiplexer Set yields:

$$\overline{MM} \text{ per task} = 2.104\ (29.203) - 14.200 = 61.443 - 14.200$$

$$= 47.243$$

The conversion factor for $\overline{MM}$ to man-hours ($\overline{MH}$) is:

$$\overline{MH} \text{ per task} = \frac{\overline{MM} \text{ per task}}{60}$$

For the Multiplexer Set, the maintenance man-hour per task is 0.787. The Maintainability demonstration, based on conduct of 54 samples selected in accordance with MIL-STD-471, yielded data which demonstrated an $\bar{M}_{ct}$ of 7.62 minutes. The demonstration did not consider item obtainment ($\bar{T}_i$) time for ground support equipment.

Comparison of the demonstrated data of 7.62 minutes with the predicted data minus item obtainment time ($\bar{T} - \bar{T}_i$) demonstrates that the prediction technique yields 27.053 minutes compared to the demonstrated 7.62 minutes.

SUB-NOTE 2.4(1) (Sheet 1 of 5 sheets) Multiplexer Set Task Analysis

Task Description	Time Standard (minutes)	Impediment Correction Factor	Number of Devices	Time Required (minutes)
Front Panel Switches				
Release front panel	0.55	1	11	0.605
Open panel	0.018	1	--	0.018
Remove securing nut from switch	0.7	1	1	0.7
Unsolder connections	0.005	1	4	0.020
Position switch and attach securing nut to switch	0.497	1	1	0.497
Locate/position wires and solder wires to switch	0.483	1	4	1.932
Close panel	0.021	1	--	0.021
Secure hardware	0.069	1	11	0.759
Total				4.552
Front Panel Air Filter				
Remove front panel filter mounting hardware	0.132	1	8	1.056
Remove filter	0.05	1	--	0.05
Replace filter	0.05	1	--	0.05
Secure front panel filter mounting hardware	0.132	1	8	1.056
Total				2.212

SUB-NOTE 2.4(1) (Sheet 2 of 5 sheets) Multiplexer Set Task Analysis

Task Description	Time Standard (minutes)	Impediment Correction Factor	Number of Devices	Time Required (minutes)
Front Panel Circuit Breakers				
Release front panel	0.055	1	11	0.605
Open panel	0.018	1	1	0.018
Remove securing nut from circuit breaker	0.7	1	1	0.7
Unsolder connections	0.005	1	4	0.020
Position circuit breaker and attach securing hardware	0.497	1	1	0.497
Locate/position wires and solder wires to circuit breaker	0.483	1	1	1.932
Close panel	0.021	1	1	0.021
Secure hardware	0.069	1	11	0.759
Total				5.242
Front Panel Lamp				
Pull out plastic lamp cover	0.028	1	1	0.028
Remove bulb	0.02	1	1	0.02
Position bulb	0.08	1	1	0.08
Replace plastic cover	0.081	1	1	0.081
Total				0.209
Front Panel LED Digital Display				
Remove display bezel	0.132	1	2	0.264
Remove plug from LED	0.028	1	1	0.028
Replace LED	0.081	1	1	0.081
Replace bezel and tighten screws	0.132	1	2	0.264
Total				0.637
Front Panel Lamp and LED (Average)		$\frac{209+0.637}{2} = \frac{0.846}{2} = 0.423$		

SUB-NOTE 2.4(1) (Sheet 3 of 5 sheets) Multiplexer Set Task Analysis

Task Description	Time Standard (minutes)	Impediment Correction Factor	Number of Devices	Time Required (minutes)
Printed Circuit Cards				
Release front panel	0.055	1	11	0.605
Open panel	0.018	1	1	0.018
Locate printed circuit card	0.004	1	1	0.004
Remove printed circuit card	0.028	1	1	0.028
Replace printed circuit card	0.081	1	1	0.081
Close panel	0.021	1	1	0.021
Secure hardware	0.069	1	11	0.759
Total				1.516
Blowers				
Release back panel	0.055	1	8	0.440
Disconnect connector P1	0.334	1	1	0.334
Remove mounting hardware from blower	0.132	1	4	0.528
Remove blower	0.05	1	1	0.05
Position blower	0.05	1	1	0.05
Attach securing hardware	0.132	1	4	0.528
Connect connector P1	0.238	1	1	0.238
Close back panel	0.021	1	1	0.021
Secure hardware	0.069	1	8	0.562
Total				2.751

SUB-NOTE 2.4(1) (Sheet 4 of 5 sheets) Multiplexer Set Task Analysis

Task Description	Time Standard (minutes)	Impediment Correction Factor	Number of Devices	Time Required (minutes)
Line Driver/Receiver				
Remove mounting screw	0.132	1	1	0.132
Remove line connectors	0.334	1	2	0.668
Remove line driver/receiver	0.028	1	1	0.028
Position line driver/receiver	0.081	1	1	0.081
Secure mounting screw	0.132	1	1	0.132
Connect line cables	0.238	1	2	0.476
Total				1.517
Power Supplies				
Set power control PWR ON-OFF switch to OFF	0.007	1	1	0.007
Set circuit breakers to OFF	0.007	1	1	0.007
Remove power supply front cover, including air filter	0.132	1	8	1.056
Remove retaining screws	0.132	1	2	0.264
Disconnect multipin plug	0.334	1	1	0.334
Disconnect connector lugs	0.081	1	2	0.162
Remove power supply retaining screws fitted to heat sink	0.132	1	2	0.264
Remove power supply	0.05	1	1	0.05
Insert power supply	0.05	1	1	0.05
Secure with retaining screws	0.132	1	2	0.264
Connect connector lugs	0.081	1	2	0.162
Connect multipin plug and secure retaining screws	0.238 0.132	1 1	1 2	0.238 0.264
Install front cover, including air filter	0.132	1	8	1.056
Total				4.178

SUB-NOTE 2.4(1) (Sheet 5 of 5 sheets) Multiplexer Set Task Analysis

Task Description	Time Standard (minutes)	Impediment Correction Factor	Number of Devices	Time Required (minutes)
<u>Power Line Filters</u>				
Disconnect power cable	0.195	1	1	0.195
Release securing hardware	0.132	1	6	0.792
Remove power line filter	0.028	1	1	0.028
Unsolder power connectors	0.005	1	3	0.015
Position power line filter	0.081	1	1	0.081
Solder power connectors	0.483	1	3	1.449
Position power line filter	0.081	1	1	0.081
Secure mounting hardware	0.132	1	6	0.792
Connect power cable	0.238	1	1	0.238
Total				3.671

SUB-NOTE 2.4(2) Fault Correction Time Summary

LRU	λ		T_c	λ_{T_c}
Front panel switches	1.76175		4.552	8.0194
Front panel air filter	0.58725,	4.698	2.212	1.2989
Front panel circuit breaker	1.1745		5.242	6.1567
Front panel lamps and LED	1.1745		0.423	0.4968
Printed circuit cards		108.578	1.516	164.604
Blower		3.5	2.751	9.6285
Line driver/receivers		10.642	1.517	16.1439
Power supplies		18.090	4.178	75.5800
Power line filters		1.202	3.671	4.4125
Front panel switches	1.299		4.552	5.9130
Front panel air filter	0.433	3.464	2.212	0.9577
Front panel circuit breaker	0.866		5.242	4.5395
Front panel lamps and LED	0.866		0.423	0.3663
Printed circuit cards		152.165	1.516	230.6821
Blower		3.50	2.751	9.6285
Line driver/receiver		40.715	1.517	61.7646
Power supplies		26.702	4.178	111.5609
Power line filters		1.202	3.671	4.4125
Σ		374.458		716.165

$$T_c = \frac{\Sigma \lambda_i \bar{T}_{ci}}{\lambda_T} = 1.91$$

CHAPTER 14

MAINTAINABILITY DESIGN AUDIT

This chapter contains a description of the maintainability design audit activity.

CHAPTER 14 MAINTAINABILITY DESIGN AUDIT

SECTION 14A - DESCRIPTION

Design Note 14A1 - Design Audit

SECTION 14A

DESCRIPTION

This section contains a description of the maintainability design audit activity.

SECTION 14A

DESCRIPTION

DESIGN NOTE 14A1 - DESIGN AUDIT

1. GENERAL

DESIGN NOTE 14A1 — DESIGN AUDIT

1. GENERAL

This effort encompasses the day-to-day activity of the maintainability engineer to enable him to tie all his other tasks together and to determine the status of and influence on the maintainability program. In determining the status, there are two primary areas of interest: the design concept and the maintenance concept.

The best way to describe the day-to-day monitoring activity is to show the types of data that are considered to determine status.

a. Design Concept

- Engineering drawings
- Reliability allocations/predictions
- Mock-ups
- Test programs
- Hardware

b. Maintenance Concept

- Spares plans and lists
- Technical orders plans
- Technical orders
- Training plans
- AGERD's
- CRS's

Following the initial allocation and specification effort, maintainability design audit should continue throughout the development and testing interval. Such effort provides a basis for assessment of the evolving design in terms of specified maintainability constraints and recognized maintainability design principles. When analysis findings indicate the deviation or potential deviation of ultimate design performance from such acceptable limitations, supplemental design guidance should be initiated by the maintainability engineer. This guidance will take two basic forms: personal liaison and coordination between design and maintainability personnel, and guidance documentation to responsible program management. The latter form should be used where the former does not yield acceptable design alteration. The contractor's data collection system should include a separate file of such documented guidance. This coordination and documentation effort, based upon results of the repetitive maintainability design audit represents the generation of design criteria and guidance supplemental to that contained in the end item specifications.

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