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VALIDATION OF DISCARD-AT-FAILURE MAINTENANCE MATHEMATICAL MODEL

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Techniques Branch
Rome Air Development Center
Research and Technology Division
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R. E. Purvis
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AFLC, GAFB, N.Y., 30 Mar 66-93

FOREWORD

This report was prepared by the Radio Corporation of America of Camden, New Jersey, for Rome Air Development Center, Reliability Branch, Engineering Division. Mr. Russell E. Purvis was the principal investigator. Other project personnel were J.E. Stuart, J. Tartar, and R. L. McLaughlin. This report was prepared by R.L. McLaughlin and R.E. Purvis. This study was made under Contract No. AF30(602)-3336 and was performed during the period 20 February 1964 and 15 June 1965. The work was performed under Project 5519, Task 551901.

The authors express their appreciation to Mr. E. Simshauser (EMERR), USAF Project Engineer, and acknowledge their indebtedness to him for his invaluable guidance, critical evaluation, constructive criticism, and continued enthusiastic support during this contract.

Additionally, the authors express their sincere appreciation to Mr. F. Mazzola of RADC for his constructive criticism and to the many personnel visited at field and depot locations who willingly provided necessary information.

This technical report has been reviewed and is approved.

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ABSTRACT

The decision to discard or repair at failure, and development of a design guide to best implement the decision, has received considerable attention from military support planners over the years. The impetus behind this general investigation is the recognized need to realize several goals: potential cost and skill reduction and increased system performance. This study reports on a validation program for a mathematical model directed to the establishment of economic decision criteria for determining the optimum discard, or repair, at failure maintenance policy. Design guidelines are provided in the form of design/support alternatives available to the designer.

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Evaluation Memo

"Criteria for Discard-at-Failure Maintenance"

The objective of the study was to evaluate and empirically validate a repair-at-failure maintenance (RAFM) versus a discard-at-failure maintenance (DAFM) mathematical model previously developed by RADC under Contract AF30(602)-2681. The objective was met; however, complete and rigid statistical testing of the prediction accuracy of the model, which was significantly revised and expanded, was limited by the type and quantity of cost data available on the study equipments. In order to realize the full benefit of this study the technique must be placed at the immediate disposal of and be accepted by design/support planners. Since its application would have a definite impact on current maintenance philosophies it would be necessary to demonstrate to appropriate AF personnel that the technique would have a decided and favorable influence on minimizing product life cycle acquisition and maintenance/support costs and would improve system/equipment operational readiness. Equally important would be the implementation of the technique as a contractual requirement. As future work it would be desirable to consider (1) additional model application to build up a statistically significant cost data sample and achieve a higher level of confidence in technique validity and (2) investigate the advantages of computerizing the model to simplify the mechanics of application and minimize calculation errors.

Ernest P. Simshauser
ERNEST P. SIMSHAUSER
Project Engineer

VALIDATION OF A DISCARD-AT-FAILURE MAINTENANCE MATHEMATICAL MODEL

1. INTRODUCTION

1.1 Purpose

The purpose of this report is to present the findings resulting from a validation of a mathematical model which permits an economic decision necessary for establishment of discard-at-failure maintenance (DAFM) or repair-at-failure maintenance (RAFM). Additionally, the modified and validated model is presented along with design guidelines and procedures for the application of the model.

1.2 Scope

The scope of this program was as follows:

a. To substantiate the predictive capability of the mathematical model reported in RADC-TDR-63-140.
b. To render the model valid, if found inadequate, i.e., revise the model to allow prediction of cost pertinent to the required decisions.
c. To illustrate the mode of application of the model rendered valid and confirm the economic advantages/disadvantages offered by use of the discard-at-failure maintenance concept.
d. To revise and/or update the applicable model constants using most recent Air Force information.

A major effort in this program consisted of field trips to sites and depots supporting certain equipments to determine if the model actually described what it purported to measure and to collect the information necessary for the model application and validation.

1.3 Contents of This Report

This report contains a quantitative, systematic procedure enabling the determination of an optimum RAFM/DAFM decision, in the least total expected cost sense. Additionally, information requirements are established along with suggested responsibilities. Applicable constants for technique application are provided. The procedure is applicable to equipment with multiple assembly levels, in addition to both ground and airborne environments.

The contents of this report have been arranged to facilitate its use as both a design tool and a procedure for the model application. Section 2 contains the general reasons for changing the mathematical model given in RADC-TDR-63-140.[1] Section 3 contains the revised mathematical model. Section 4 contains an evaluation of the model applied to existing systems with particular emphasis on an air-borne subsystem. Section 5 contains an evaluation of potential re-design considerations for the subsystem investigation in section 4. Section 6 presents potential impact on maintenance from the advent of integrated circuitry. Section 7 presents a summary of the results, conclusions, and recommendations from this study.

An explanation of terms is followed by a list of the major symbols used in development of the mathematical model. The appendixes are designed to supplement the information given in the text. They are: appendix 1 gives data on the field trips - sites, depots, and airbase; appendix 2 gives detailed reason for the change from the model descrived in RADC-TDR-63-140; appendix 3 gives a detailed provisioning procedure; appendix 4 presents the background data on the reliability and maintainability predictions on the AN/ASG-19; appendix 5 presents production data from a division of RCA; and appendix 6 shows details of how the cost constants were derived.

2. JUSTIFICATION FOR REVISION OF RADC-TDR-63-140 MODEL

2.1 General

The following comments concerning the validity of the mathematical model developed in RADC-TDR-63-140 constitute the major reasons making revision to the model necessary. (For detailed reasons, see appendix II).

2.2 Comments on Findings

2.2.1 General Comment - The RADC-TDR-63-140 model is basically a linear prediction model, having two independent variables, viz., failure and repair rates (this over-simplification leads to a number of serious sources of error).

2.2.2 Specifics - The following are the major sources of error:

2.2.2.1 Model Sources of Error -

a. The model assumes that changes in the independent variables produce demonstrable differences in resource cost, e.g., more work requires more manpower, or less work requires less test equipment.

b. The model neglects acquisition costs which vary significantly with design alternatives.

c. The model does not possess common dimensions; i.e., spares procurement is based on confidence against outage, whereas manpower procurement is based on direct labor. (The revised model treats alternate means of resource cost investment in terms of operational readiness return). The model does not differentiate between fixed and nonchargeable costs and variable costs.

2.2.2.2 Model Application Sources of Error - Determination of Optimum Module size is established by selecting, from the various size alternatives, that size showing the greatest cost difference between discard and repair; however, two high total cost alternatives may show smaller differences than two low total cost alternatives.

The model application presumes that module cost is linearly related to parts per module. Thus, the application procedures neglect the significant cost trades that exist between standardization of module type and size; with the cost effect of back plane wiring as related to these tradeoffs.

The application of the model assumes that a maintenance philosophy is established independent of support cost.

3. PROPOSED MATHEMATICAL MODEL

3.1 General Procedure

A general procedure was developed for reducing the number of design-support configurations to be technically and economically feasible. This procedure permits elimination of those design-support configurations that cannot meet operational constraints. Design-support configurations that have economic advantage over others are used to further eliminate feasible alternatives. The remaining alternative design-support configuration is the least cost alternative.

3.2 Program Phasing

The model is intended for application in two phases of equipment life cycle.

a. Proposal phase
b. Program definition and development phase

The primary intent of the model and associated method of analysis is to provide a tool for explicitly attacking the modular design problem during the program definition, design, and development cycle in terms of total resource cost implications. Additionally, the technique is applicable for analysis and evaluation of existing equipment in field operation for the purpose of potential support performance improvement and or cost reduction. Section 3.7 of the report contains a discussion of potential application of the technique to contractor proposal development.

For each phase, appropriate modifications to information requirements can be considered along with the costs appropriate to decision making.

3.2.1 Cost Analysis Method - The cost method used for general analysis avoids consideration of interest. This position has been taken for the following reasons:

a. Interest is charged on all commodities at the same rate. Thus, individual commodity interest need not be computed.

b. The minimum cost point is unaffected by the application of interest costs.

c. The goal of the analysis is the establishment of total expected variable cost incurred by the government, and the establishment of the best possible difference of RAFM/DAFM support and acquisition policy.

It is immaterial to the source of the funds, and the interest paid on the funds, how the funds are spent, e.g., additional DAFM spares versus additional RAFM personnel. The value of the funds, as measured by an alternate means of investment, e.g., reduction of national debt, has already been established by the requirement for a system having specified performance requirements.

The cost analysis method developed does not use proration as a device to assign costs, but instead is predicated on demonstrable difference in cost as a result of choosing a design/support alternative.

The problem which the model permits solving is the allocation of specific levels of assembly to specific maintenance echelons such that a least cost repair/discard philosophy can be established.

3.2.2 <u>Support Alternatives</u> - The relation between the system hardware and support alternatives is shown in figure 1 and table 1. Figure 1 provides a generalized breakdown of a system into its various levels of assembly. In general, a repair/discard decision is required at each level of assembly.

Table 1 indicates the possible alternatives for discard and/or repair location that are used in further development of the mathematical model.

3.3 Basic Mathematical Model

The total cost (T) of a system, equipment, etc., can be represented by

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

where

A = the cost of acquisition

S = the cost of operation and support

The cost S is the lifetime cost, where lifetime is usually assumed to be 10 years. Figure 2 shows the basic mathematical model which has to be evaluated. Each element would ordinarily be evaluated to obtain the total cost. For purposes of reaching a decision on whether to employ throwaway maintenance (DAFM) or repair maintenance (RAFM), and optimum location to do either, differences in total cost are employed. Thus it is unnecessary to evaluate equivalent elements of the two models when considering which one of two possible decisions to choose. It is necessary only to evaluate the elements that are pertinent to a particular decision. (See table 1 and figure 1 for the range of decisions that have to be made.)

Let

T_1 = total cost (design, operation, and support) of the first alternative

T_2 = total cost (design, operation, and support) of the second alternative

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

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

where elements of cost common to the first and second alternatives need not be considered if they are equal. If the quantity $\Delta T_{2,1}$

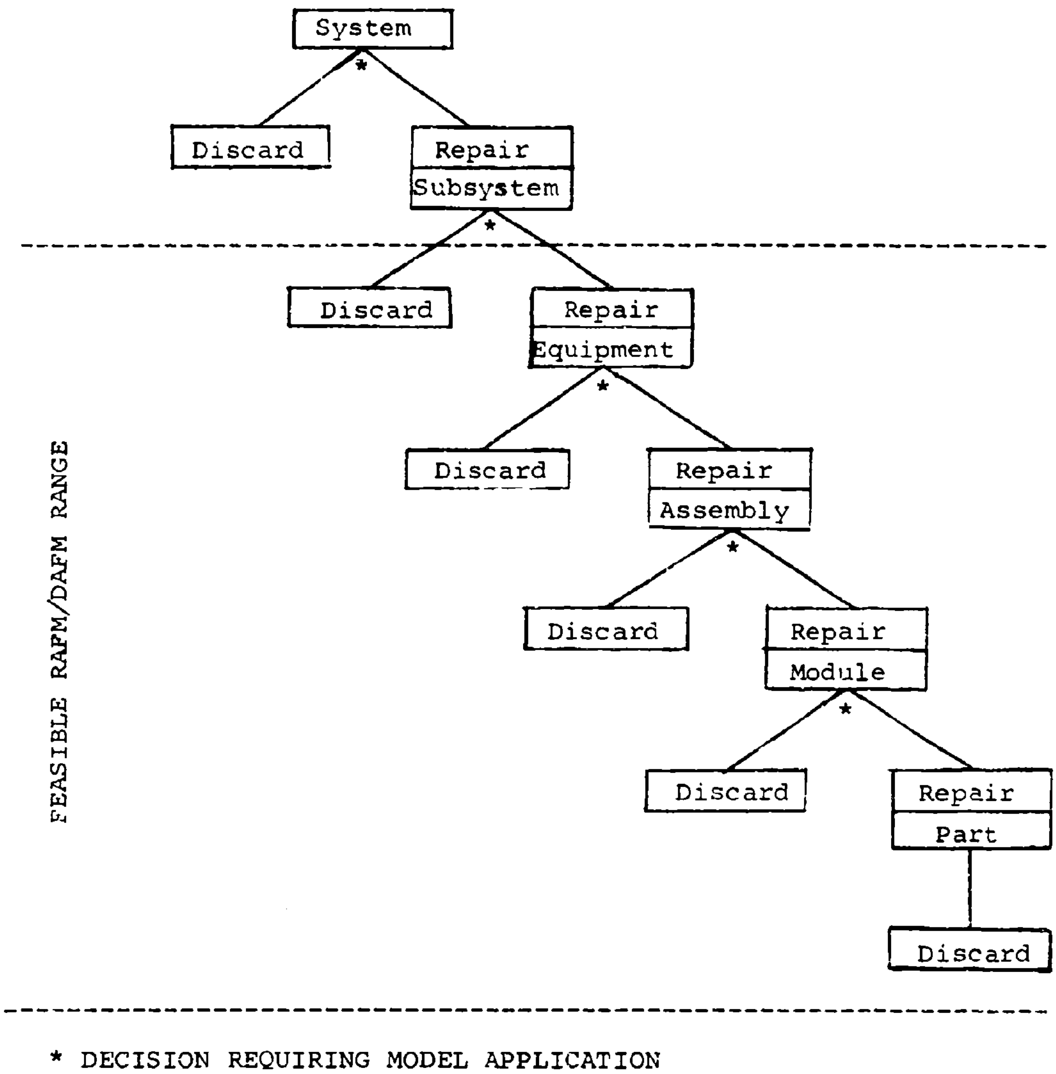
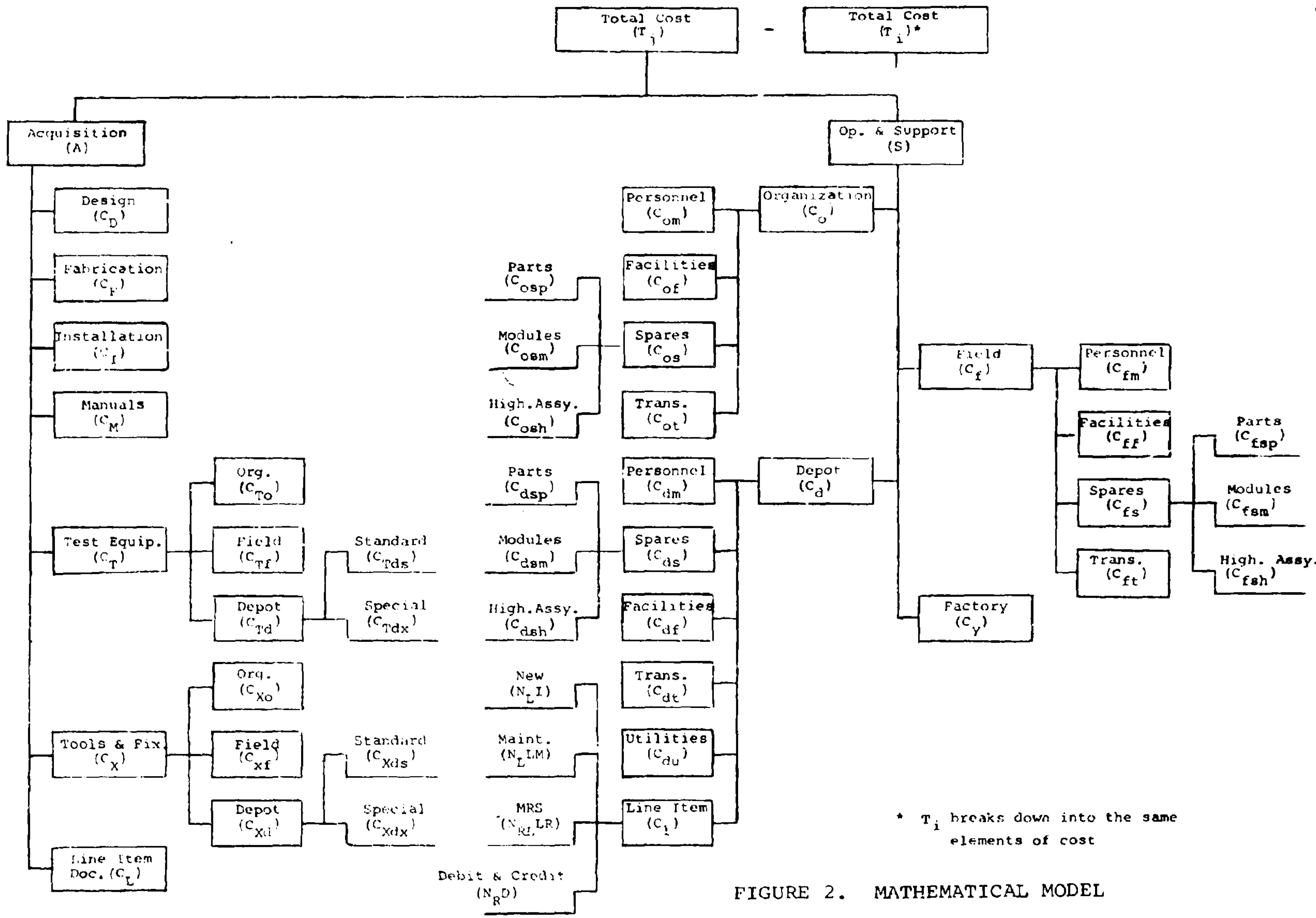


FIGURE 1. REPAIR/DISCARD ALTERNATIVES (END ITEM BREAKDOWN)

TABLE 1
POSSIBLE SUPPORT ALTERNATIVES

No.	Units Involved	Organization	Field	Depot	Factory
1	Organization	Part repair HMA*			
2		Discard Module			
3		Discard HMA			
4	Organization-Field	R and R Module	Discard Module		
5		R and R Module	Module repair		
6		R and R** HMA	Discard HMA		
7		R and R HMA	Discard Module		
8		R and R HMA	Part repair HMA		
9	Organization-Depot	R and R Module		Discard Module	
10		R and R Module		Module repair	
11		R and R HMA		Discard HMA	
12		R and R HMA		Discard Module	
13		R and R HMA		Part repair HMA	
14	Organization-Factory	R and R Module			Discard Module
15		R and R Module			Module repair
16		R and R HMA			Discard HMA
17		R and R HMA			Discard Module
18		R and R HMA			Part repair HMA
19	Organization-Field-Depot	R and R HMA	R and R Module	Discard Module	
20		R and R HMA	R and R Module	Module repair	
21	Organization-Field-Factory	R and R HMA	R and R Module		Discard Module
22		R and R HMA	R and R Module		Module repair
23	Organization-Depot-Factory	R and R HMA		R and R Module	Discard Module
24		R and R HMA		R and R Module	Module repair

*HMA = higher modular assembly
**R and R = remove and replace



* T_i breaks down into the same elements of cost

FIGURE 2. MATHEMATICAL MODEL

is negative, it means that the second alternative is less costly. If positive, it means that the first alternative is the correct choice, viz., less costly.

Once two alternatives have been compared, the one yielding the lesser cost advantage is dropped from further consideration. Successive alternatives are devised and watched against the current alternative that has greater cost advantage.

3.4 Development of Elements of the Basic Model

3.4.1 Cost of Acquisition - Acquisition costs (A) should be estimated by the contractor according to his normal practices and procedures, excluding costs already incurred. The elements to be considered include all charges to the government which may arise from the design, development, fabrication, and installation of the equipment. Particular attention should be paid to items which mark the differences between otherwise similar alternatives. Among these may be:

a. Built-in fault isolation features

b. Special test equipment

c. Special tools

d. Maintenance manuals

Differences in research, development, design, or hardware costs should be considered where they constitute a significant portion of total costs. Differences in requirements for government-furnished equipment (GFE) should also be established and costs obtained from the government. In any case, refined estimates of costs are justified only when the alternative, or group of alternatives, has cost or other advantages which make it a good candidate for selection.

Cost of acquisition (A) can be represented by

$$A = C_D + C_F + C_I + C_M + C_T + C_X + C_L \quad (3)$$

where

C_D = cost of design

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

The costs of test equipment can be further broken down as follows:

$$C_T = T_{To}+C_{Tf}+C_{Td} \quad (4)$$

and

$$C_{Td} = D_{Tds}+C_{Tdx} \quad (5)$$

where

C_{To} = cost of test equipment at organization

C_{Tf} = cost of test equipment at field

C_{Td} = cost of test equipment at depot

C_{Tds} = cost of standard test equipment at depot

C_{Tdx} = cost of special test equipment at depot

The cost of tools and fixtures can be further broken down in exactly the same way.

$$C_X = C_{Xo}+C_{Xf}+C_{Xd} \quad (6)$$

and

$$C_{Xd} = C_{Xds}+C_{Xdx} \quad (7)$$

3.4.2 <u>Cost of Operation and Support</u> - The cost of operation and support (S) is represented by

$$S = C_o+C_f+C_d+C_y \quad (8)$$

where

C_o = cost at organization

C_f = cost at field

C_d = cost at depot

C_y = cost at factory

3.4.2.1 Cost at Organization - The cost at organization (C_o) is represented by

$$C_o = C_{om}+C_{of}+C_{os}+C_{ot} \quad (9)$$

where

C_{om} = cost of personnel

C_{of} = cost of facilities

C_{os} = cost of spares

C_{ot} = cost of transportation

3.4.2.1.1 Cost of Personnel -

$$C_{om} = (\sum_{i}\sum_{j} G_{ij} X_{ij}) + F \tag{10}$$

where

G_{ij} = number of men with skill i in an operation and maintenance unit j.

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

F = the administrative and service costs normal to an operating and maintenance unit of size $\sum_{i}\sum_{j} G_{ij}$.

The values of these variables are found as follows:

a. G_{ij}, is a man with skill i in operations and maintenance unit j, and is determined by a manning analysis.[2,3,4].

b. X_{ij}, see table VI-1 in appendix VI.

c. F, cancels out when differential costs are considered.

3.4.2.1.2 Cost of Facilities - The cost of facilities (C_{of}), including utilities, is represented by

$$C_{of} = C_{ofu} + C_{ofm} + C_{oft} \tag{11}$$

where

C_{ofu} = cost of utilities (power)

C_{ofm} = cost of materials for maintenance of facilities

C_{oft} = cost of materials for maintenance of test equipment

Normally these are negligible and can be neglected; or, often, they will cancel out when differential costs are considered. Where they are neither, estimates should be made using the best available information. (The buildings, power generators, test equipment, and such, are acquisition costs if chargeable.)

a. C_{ofu}, 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.

b. C_{ofm}, estimate cost of material used in maintaining the facility.

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

3.4.2.1.3 Cost of Spares - The actual number of spare items, of all types, is established by using an optimizing technique. The principle of the technique is: choosing the one alternative from among many alternatives, returning maximum reduction in downtime per unit cost invested.

The general equation representing cost of spares at organization (C_{os}) is

$$C_{os} = C_{osp}+C_{osm}+C_{osh} \tag{12}$$

where

C_{osp} = cost of parts
C_{osm} = cost of modules
C_{osh} = cost of higher assemblies

3.4.2.1.3.1 Cost of Parts - Let the cost of parts (C_{osp}) be represented by the following equation:

$$C_{osp} = LE\sum_i c_{i-p} n_{i-p} \lambda_{i-p} \tag{13}$$

and

$$= N_{R-po}\bar{c}_p \tag{14}$$

where

L = life of equipment

E = number of equipments scheduled for operation

n_{i-p} = number of part i per equipment

c_{i-p} = cost of part i

λ_{i-p} = usage rate of part i

N_{R-po} = total parts repair demands (usage)-organization $= LE\Sigma n_{i-p}\lambda_{i-p}$ (15)

$\bar{c}_p$ = mean cost of part

When usage information is missing, λ_i is found by the following:

$$\lambda_{i-p} = 3\lambda_{i-pf} \quad (16)$$

[17]

where

λ_{i-pf} = predicted failure rate of the part i

3.4.2.1.3.2 Cost of Modules - The cost of modules at organization is represented by

$$C_{osm} = \sum_i S_{i-mo} c_i \quad (17)$$

where

S_{i-mo} = number of modules of type i, used and on-hand, at time of phase-out, at organization to obtain desired operational readiness [2,3,4] goal for the system

$$S_{i-mo} = S[\text{support alternative}, Q(\lambda, \mu)] \quad (18)$$

where

Q = unreadiness

c_i = cost of module of type i

The usage rate is approximately equal to the failure rate for the module case.

3.4.2.1.3.3 Cost of Higher Assemblies - The cost of higher assemblies, at organization, is

$$C_{osh} = \sum_i S_{i-ho} c_i \quad (19)$$

where

S_{i-ho} = number of higher assemblies, of type i, used and on hand, at time of phase-out, at organization to obtain desired operational readiness goal for the system.

$$S_{i-ho} = S[\text{support alternative, } Q(\mu,\lambda)] \quad (20)$$

C_i = cost higher assembly of type i.

3.4.2.1.4 Cost of Transportation - The transportation costs (C_{ot}) are determined in the following manner:

a. To field by routine methods - negligible

b. To field by rush means - (number of demands)(average length of round trip)(cost per trip).

c. To depot - included with other depot costs.

d. Vehicles on which equipment is mounted should be included in acquisition costs whether GFE or contractor supplied.

3.4.2.2 Cost at Field - The cost at field (C_f) is represented by

$$C_f = C_{fm}+C_{ff}+C_{fs}+C_{ft} \quad (21)$$

3.4.2.2.1 Cost of Personnel - The cost of personnel at field (C_{fm}) is

$$C_{fm} = (\sum_i\sum_j G_{ij}X_{ij})+F \quad (22)$$

where the symbols, on the right side of the equation, are defined in paragraph 3.4.2.1.1. Manning should be directed toward achieving an appropriate cycle time rather than operational readiness directly.[2,3,4]

3.4.2.2.2. Cost of Facilities at Field - Use, in determining cost of facilities at field (C_{ff}), procedures under paragraph 3.4.2.1.2.

3.4.2.2.3 Cost of Spares at Field - The cost of spares at field is expressed

$$C_{fs} = C_{fsp}+C_{fsm}+C_{fsh} \quad (23)$$

where

C_{fsp} = cost of parts

C_{fsm} = cost of modules

C_{fsh} = cost of higher assemblies

3.4.2.2.3.1 Cost of Parts - The cost of parts at field (C_{fsp}) is

$$C_{fsp} = LE\sum_i c_{i-p} n_{i-p} \lambda_{i-p} \quad (24)$$

where the symbols on the right side of the equation are as defined in paragraph 3.4.2.1.3.1. Also

$$C_{fsp} = N_{R-pf}\bar{c}_p \quad (25)$$

where

N_{R-pf} = total parts repair demands-field.

3.4.2.2.3.2 Cost of Modules - The cost of modules at field (C_{fsm}) is

$$C_{fsm} = \sum_i S_{i-mf} c_i \quad (26)$$

where

S_{i-mf} = number of modules, of type i, used and on hand, at the phase-out period, at field to obtain desired operational readiness goal for the equipment.[2,3,4]

$$S_{i-mf} = S[\text{support alternative}, Q(\mu,\lambda)] \quad (27)$$

3.4.2.2.3.3 Cost of Higher Assemblies - The cost of higher assemblies, at field, (C_{fsh}) is

$$C_{fsh} = \sum_i S_{i-hf} c_i \tag{28}$$

where

S_{i-hf} = num·.er of higher assemblies, of type i, used and on hand, at the phase out period, at field to obtain desired operational readiness for the equipment.

$$S_{i-hf} = S\ [\text{support alternative},\ Q(\mu,\lambda)] \tag{29}$$

3.4.2.2.4 Cost of Transportation - The cost of transportation (C_{ft}) is counted as part of organization or depot costs. (See paragraphs 3.4.1.4 and 3.4.2.3.4.)

3.4.2.3 Cost at Depot - The cost at depot (C_d) is represented by

$$C_d = C_{dm}+C_{df}+C_{ds}+C_{dt}+C_{du}+C_1 \tag{30}$$

where

C_{dm} = cost of personnel at depot
C_{df} = cost of facilities at depot
C_{ds} = cost of spares at depot
C_{dt} = cost of transportation at depot
C_{du} = cost of utilities at depot
C_1 = cost of line item at depot

3.4.2.3.1 Cost of Personnel at Depot - The cost of personnel at depot (C_{dm}) is represented as follows:

Let:

N_{R-md} = the module repair demand at depot

$$= LE\sum_i n_{i-m}\lambda_{i-m} \tag{31}$$

N_{R-hd} = the higher assembly repair demand at depot

$$= LE\sum_i n_{i-h}\lambda_{i-h} \tag{32}$$

Since there is essentially a constant workload at the depot, rather than the standby/work situation that exists at the field and organization, C_{dm} can be expressed as follows

$$C_{dm} = LE[(\sum_i n_{i-m}\lambda_{i-m}/\mu_{i-m}) + (\sum_i n_{i-h}\lambda/\mu_{i-h})]c_d \quad (33)$$

where

μ_{i-m} = mean repair rate of modules, of type i, at depot

μ_{i-h} = mean repair rate of higher assemblies, of type i, at depot

c_d = cost of labor - direct and indirect

3.4.2.3.2 Cost of Facilities at Depot - The cost of facilities (C_{df}) is represented by

$$C_{df} = C_{dfm}+C_{dft} \quad (34)$$

where

C_{dfm} = cost of material for maintenance of facilities at depot

C_{dft} = cost of material for maintenance of test equipment at depot

The statements in paragraph 3.4.2.1.2 are applicable in evaluation of these costs.

3.4.2.3.3 Cost of Spares in Depot - The general equation representing cost of spares in depot is

$$C_{ds} = C_{dsp}+C_{dsm}+C_{dsh} \quad (35)$$

where

C_{dsp} = cost of parts

C_{dsm} = cost of modules

C_{dsh} = cost of higher assemblies

3.4.2.3.3.1 Cost of Parts - The cost of parts at depot (C_{dsp}) can be expressed as

$$C_{dsp} = LE\sum_i c_{i-p}n_{i-p}\lambda_{i-p} \quad (36)$$

also

$$C_{dsp} = N_{R-pd}\bar{c}_p \qquad (37)$$

where

N_{R-pd} = total part repair demand-depot
(See paragraph 3.4.2.1.3.1)

3.4.2.3.3.2 Cost of Modules - The cost of modules at depot (C_{dsm}) is

$$C_{dsm} = \sum_i S_{i-md} c_i \qquad (38)$$

where

S_{i-md} = number of modules, of type i, used and on hand, at the phase-out period at depot to obtain desired operational readiness for the equipment.

$$S_{i-md} = S \text{ [support alternative, } Q(\mu,\lambda)] \qquad (39)$$

3.4.2.3.3.3 Cost of Higher Assemblies - The cost of higher assemblies, at depot, (C_{dsh}) is

$$C_{dsh} = \sum_i S_{i-hd} c_i \qquad (40)$$

where

S_{i-hd} = number of higher assemblies, of type i, used and on hand, at phase-out period at depot to obtain desired operational readiness for the equipment.

$$S_{i-hd} = S \text{ [support alternative, } Q(\mu,\lambda)] \qquad (41)$$

3.4.2.3.4 Cost of Transportation - Depot - The cost of transportation associated with depot (C_{dt}) can be expressed

$$C_{dt} = C_{dto} + C_{dtf} \qquad (42)$$

where

C_{dto} = total cost of round trip from organization to depot

C_{dtf} = total cost of round trip from field to depot.

This formula is evaluated by means of the following:

$$C_{dto} = [(N_{R-md})r_1+(N_{R-hd})r_2]\bar{c}_{dto} \quad (43)$$

and

$$C_{dtf} = [(N_{R-md})q_1+(N_{R-hd})q_2]\bar{c}_{dtf} \quad (44)$$

where

$1 = r_1+r_2+q_1+q_2$

$\bar{c}_{dto}$ = mean cost of round trip between organization and depot

$\bar{c}_{dtf}$ = mean cost of round trip between field and depot

(See paragraph 3.4.2.3.1)

3.4.2.3.5 Cost of Utilities at Depot - The cost of utilities (C_{du}) is

$$C_{du} = C_{due}+C_{dub} \quad (45)$$

where

C_{due} = cost of power

C_{dub} = cost of buildings

Normally this cost will cancel out when taking differentials corresponding to different alternatives. If it does not

$$C_{due} = C_{ofu} \text{ (section 3.4.2.1.2)} \quad (46)$$

and C_{dub} is as referenced in appendix VI.

3.4.2.3.6 Cost of Line Item - The cost of line item (C_1) can be represented by

$$C_1 = N_L[I+(L)(M)]+N_{RL}(L)(R)+(N_R)(D) \quad (47)$$

where

N_L = number of new line items introduced into the supply system

I = cost of introducing a line item into the supply system

M = cost per year of maintaining a line item in the supply system

N_{RL} = number of stock item repaired by depot

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

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

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

The values of M, R, and D are determined by RADC-TDR-63-140 and are constant; the value of I has changed. (For all these values, see appendix VI.) The values of the other parameters are variable with system type.

3.4.2.4 Cost at Factory - The total cost at factory (C_Y) will vary so much with the type of labor to be employed that no attempt will be made to estimate the cost. In general, if factory repair is one of the alternative plans, it will be part of all alternates.

Repair at factory is rare; however, special conditions may make it appropriate in some cases. Repairs may be made at the factory rather than at the depot for several reasons. Most instances are accounted for by one of the following:

a. Rare skills and/or expensive special test equipment are required to perform maintenance, e.g., gyroscopes and some other sealed assemblies.

b. 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.

In both of these instances, costs associated with performing the work at the factory generally should be about the same or less than would be incurred if the work were done at the depot. Otherwise, the work would be scheduled for performance at the depot.

In general, factory maintenance is not planned as an integral part of maintenance policy. Requirements for self-sufficiency of the military generally preclude planning on factory or other contractor maintenance of critical equipment. Where it might be planned (as in a above), experience and/or estimates from the probable contractor should provide adequate cost figures for use in comparisons. Detail costing becomes less important in fixed price contracts, favored type today, as contrasted to cost plus fixed fee and similar types common in the past. Consequently, no detail breakdown will be made for estimating costs of factory maintenance in the few situations where it is applicable.

3.5 General Evaluation Procedure

Figure 3 illustrates a tabular procedure for evaluating each element of the mathematical model. Provision is made, in figure 3, for the evaluation of two alternatives. Only the elements that change, from one alternative to the other, will be required. Once two alternatives have been evaluated, the one yielding a cost advantage is retained, and the other alternative is no longer considered.

3.5.1 Application Method - The method of model application is based on the recognition that "the where to perform maintenance" is as vitally important as "whether to perform maintenance." Thus an iterative procedure designed to capture both the "where to" and the "whether to" perform maintenance has been developed. The procedure provides for systematic evaluation of support alternatives for a given modular design configuration alternative. Where more than one feasible modular design configuration exists the procedure is repeated using cost differences between the alternatives to eliminate the more costly of any two alternatives. Iteration is carried out until only one (the optimum of the set of alternatives) modular design configuration remains.

In the application of the model it is imperative that the proper perspective be maintained; specifically, the evaluation is directed to real demonstrable differences. Thus, at all points the entire modular design configuration and support system is under evaluation. Additionally, selective application of the technique to specific assemblies of a given level or specific module types may be performed, it being only required, as above, to evaluate design-support alternatives with respect to real cost differences.

TABLE ( )
COST DECISION ELEMENTS

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step ( ) A( )	Step ( ) A( )
Design	D	3		(Column 1)	(Column 2)
Fabrication	F	3			
Installation	I	3			
Manuals	M	3			
Test Equipment	T	3,4			
Organization	To	4			
Field	Tf	4			
Depot	Td	4,5			
Standard	Tds	5			
Special	Tdx	5			
Tools and Fixtures	X	3,6			
Organization	Xo	6			
Field	Xf	6			
Depot	Xd	6,7			
Standard	Xds	7			
Special	Xdx	7			
Line Item Documentation	L	3			
				S( )	S( )
Organization	o	8,9			
Personnel	om	9,10			
Facilities	of	9,11			
Utilities	ofu	11	3.4.2.1.2		
Materials for Maintenance	ofm	11	3.4.2.1.2		
Materials for Test Equip.	oft	11	3.4.2.1.2		
Spares	os	9,12			
Parts	osp	12,13,14	3.4.2.1.3.1		
Modules	osm	12,17,18	3.4.2.1.3.2		
Higher Assemblies	osh	12,19,20	3.4.2.1.3.3		
Transportation	ot		3.4.2.1.4		
Field	f	8,21			
Personnel	fm	21,22			
Facilities	ff	21	3.4.2.2.2		
Utilities	fu	11	3.4.2.1.2		
Materials for Maintenance	ffm	11	3.4.2.1.2		
Materials for Test Equip.	fft	11	3.4.2.1.2		

FIGURE 3. COST DECISION ELEMENTS

TABLE ( ) (CONT.)
COST DECISION ELEMENTS

Cost Element (C)	Sub-script	Refer to Equation	Refer to Paragraph	Step ( ) S( ) (Column 1)	Step ( ) S( ) (Column 2)
Field (cont.)					
Spares	fs	21,23			
Parts	fsp	23,24,25	3.4.2.2.3.1		
Modules	fsm	23,26,27	3.4.2.2.3.2		
Higher Assemblies	fsh	23,28,29	3.4.2.2.3.3		
Depot	d	8,30			
Personnel	dm	30,31,32,33	3.4.2.3.1		
Facilities	df	30,34	3.4.2.3.2		
Materials for Maintenance	dfm	11	3.4.2.1.2		
Materials for Test Equip.	dft	11	3.4.2.1.2		
Spares	ds	30,35			
Parts	dsp	35,36,37	3.4.2.3.3.1		
Modules	dsm	35,38,39	3.4.2.3.3.2		
Higher Assemblies	dsh	35,40,41	3.4.2.3.3.3		
Transportation	dt	30,42			
Organization	dto	42,43			
Field	dtf	42,44			
Utilities	du	30,45			
Power	due	45,46	3.2.3.3.5		
Buildings	dub		3.5.3.3.5		
Line Item	l	30,47			
New	N_{LI}	47			
Maintenance	N_{LLM}	47			
MRS	N_{RLLR}	47			
Debit and Credit	N_{RD}	47			
Factory	v	8			
Total Cost ($T_{( )}$ and $T_{( )}$)		1			
Cost Difference ($\Delta T_{( ),( )}$)		2			

FIGURE 3. COST DECISION ELEMENTS (CONT.)

In the application of the model, it is desirable to perform no more computations than necessary. Table 2 presents one such procedure. (Because of the possible differences associated with cost at the factory, and the relative infrequent use of factory repair, costs at factory are not included in table 2.) The general rule for a decision is, when using table 2 and figure 3,

$$\Delta T_{j,i} < 0$$

choose alternative j (48)

conversely, if,

$$\Delta T_{j,i} > 0$$

choose alternative i. (49)

The step-by-step procedure is outlined below.

3.5.1.1 Step 1, Organization -

a. Select one higher modular assembly (h) that is a potential candidate for DAFM at organization.

b. Evaluate cost of discard. (Use tabular form provided by figure 3, column 2.)

c. Evaluate cost of repair of the same assembly, considering that all lower levels are repaired, e.g., modules. (Use same tabular form as b above, column 1.)

d. Compare 1c with 1b above.

e. Make a decision based on equations 48 and 49.

TABLE 2

TABULAR EVALUATION PROCEDURE

Echelon	Step	Organization Rep.	Organization Dis.	Field Rep.	Field Dis.	Depot Rep.	Depot Dis.	T_i	Compare	Decision
Organization O_2	1	h*						T_2	T_2, T_1	$\Delta T_{2,1}>0$;choose T_1
O_1			h					T_1		$\Delta T_{2,1}<0$;choose T_2
O_3	2	h	m**					T_3	$T_3, \min(T_2,T_1)$***	$\Delta T_{3,min}>0$;min $\Delta T_{3,min}<0$;T_3
O_4	3	h		m				T_4	$T_4, \min(T_3,T_2,T_1)$	$\Delta T_{4,min}>0$;min $\Delta T_{4,min}<0$;T_4
O_5	4	h				m		T_5	$T_5, \min(T_4,T_3,T_2,T_1)$	$\Delta T_{5,min}>0$;min $\Delta T_{5,min}<0$;T_5
Field F_2	5			h				T_7	T_7, T_6	$\Delta T_{7,6}>0$;T_6
F_1					h			T_6		$\Delta T_{7,6}<0$;T_7
F_3	6			h	m			T_8	$T_8, \min(T_7,T_6)$	$\Delta T_{8,min}>0$;min $\Delta T_{8,min}<0$;T_8
F_4	7			h		m		T_9	$T_9, \min(T_8,T_7,T_6)$	$\Delta T_{9,min}>0$;min $\Delta T_{9,min}<0$;T_9
Depot D_2	8					h		T_{11}	T_{11}, T_{10}	$\Delta T_{11,10}>0$;T_{10}
D_1							h	T_{10}		$\Delta T_{11,10}<0$;T_{11}
D_3	9					h	m	T_{12}	$T_{12}, \min(T_{12},T_{11})$	$\Delta T_{12,min}>0$;min $\Delta T_{12,min}<0$;T_{12}
D vs. F	10			$\min(T_{12},T_{11},T_{10})$, $\min(T_9,T_8,T_7,T_6)$						$\Delta T_{D,F}>0$;T_F $\Delta T_{D,F}<0$;T_D
min(D,F) vs. O	11	$\min(T_{12},T_{11},T_{10},T_9,T_8,T_7,T_6)$, $\min(T_5,T_4,T_3,T_2,T_1)$								$\Delta T_{min,O}>0$;O $\Delta T_{min,O}<0$;min

*h = Higher Modular Assembly
**m = Module
***$\min(T_2,T_1)$ = Least cost estimate between T_2 and T_1, etc.

3.5.1.2 Step 2, Organization -

a. Select one of the possible module (m) configurations that is a potential candidate for DAFM. The higher modular assembly is repaired by replacing DAFM modules.

b. Evaluate cost of policy described above. (Use column 1, figure 3.)

c. Evaluate least cost result of step 1 again; remember that the things that are constant for step 1 (and cancelled out) will not necessarily be constant in the revised policy appropriate to step 2. (Use column 2, figure 3.)

d. Make a decision based on equations 48 and 49.

3.5.1.3 Steps 3 and 4, Organization - These steps evaluate the same module repair at field and at depot. Higher modular assembly repair is performed at organization level with the repaired modules.

3.5.1.4 Steps 5, 6, and 7, Field - These steps evaluate the same higher modular assembly and same module configuration, but bypass the organizational level. Step 5 repeats the detail of paragraph 3.5.1.1, step 6 repeats the detail of paragraph 3.5.1.2, etc.

3.5.1.5 Steps 8 and 9, Depot - These steps evaluate the same higher modular assembly and the same module configuration but bypass the organizational and field levels. Step 8 repeats the details of paragraph 3.5.1.1 and step 9 repeats the details of paragraph 3.5.1.2.

3.5.1.6 Step 10, Depot vs. Field - This step evaluates the least cost estimate of depot policy (figure 3, column 1) against the least cost estimate for field acquisition and support policy (figure 3, column 2).

3.5.1.7 Step 11, Min (F, D) vs. Organization - This step evaluates the least cost estimate determined in paragraph 3.5.1.6 (figure 3, column 1) against the least cost estimate of organization level (figure 3, column 2).

3.5.1.8 Result - The result of this step-by-step procedure is the evaluation of a least cost estimate of acquisition, operation, and support for <u>one</u> higher modular assembly and <u>one</u> module configuration. Also, by using the tabular procedure, the location of the least cost level of maintenance is developed.

3.5.1.9 Reapplication - By successive application of the step procedure to different configurations of the hardware, the least cost system is determined. The optimum (least cost) configuration is established based upon system cost minimization and it does not necessarily result in the least cost for a specific module alternative. The cost analysis is always directed to that level of assembly at which demonstrable system cost differences arise. For some alternatives, this may require analysis only at the module level. For other alternatives, costs developed at the module level must be combined with other costs at higher levels of assembly to determine differences in system cost. Table 3 illustrates the logic of the decision process in obtaining a least cost estimate. Section (a) of the table delineates the procedure used in elimination alternatives. Section (b) states the alternatives involved in the hardware breakdown and section (c) shows the corresponding alternatives requiring evaluation. In actual practice many alternatives are quickly eliminated, e.g., discard at the subsystem level.

3.5.2 Simplified Sparing - Tables have been prepared to simplify the sparing routing. The routine is as follows:

a. Determine spares of all types required at a site to meet operational readiness.

b. Determine total spares for all sites.

c. Determine additional spares by type, if any, for depot inventory. If spares by type, for all sites, exceed requirements for a single depot, based on total failures, the depot need not have spares of that type.

3.5.2.1 Spare Requirement for DAFM - Table 4 was prepared to indicate DAFM spare requirements as a function of unreadiness, failure rate, and sparing location. Also shown, where applicable, are the unused spares at the end of life cycle as a result of meeting unreadiness conditions and minimum lifetime purchase requirement.

Where

λ = aggregate failure rate of item type per year

Q = unreadiness

S_1 = initial spare requirements at 1 site

S_{10} = initial spare requirements for 10 sites

S_D = spare requirements if spares are located at depot.

TABLE 3
LEAST COST ESTIMATE

a. Systematic Elimination of Alternative Design & Support Configurations **(For SYSTEM(A) but illustrated at the equipment level)**

Config	Step	Compare Least Cost Estimates	Decision
A'	1 ... 11	$T_{A'}, T_A$	If: $\Delta T_{J,I} > 0$, choose alternative I; and if: $\Delta T_{J,I} < 0$, choose alternative J.
A	1 ... 11		
A''	1 ... 11	$T_{A''}, \min(T_{A'}, T_A)$	
...	...	...	
J	1 ... 11	$T_J, \min(T_I, \cdots, T_{A''}, T_{A'}, T_A)$	
...	...	...	
N	1 ... 11	$T_N, \min(T_{N-1}, \cdots, T_J, \cdots, T_A)$	

b. Hardware Alternatives for a Specific System (A)

Level	Alternative: Discard	Alternative: Repair
System	A_{01}	A_{02}
Subsystem	A_{11}	A_{12}
Equipment	A_{21}	A_{22}
Assembly	A_{31}	A_{32}
Module	A_{41}	A_{42}
Part	A_{51}	

c. Hardware Cost Comparisons for Various Levels of Assemblies for System (A)

Step	Compare	Decision
1	T_{21}, T_{11}	If: $\Delta T_{j1,i1} > 0$, choose alternate A_{i1}; and if: $\Delta T_{j1,i1} < 0$, choose alternate A_{j1}.
2	$T_{31}, \min(T_{21}, T_{11})$	
3	$T_{41}, \min(T_{31}, T_{21}, T_{11})$	
4	$T_{51}, \min(T_{41}, T_{31}, T_{21}, T_{11})$	

TABLE 4

DAFM SPARE REQUIREMENTS

λ (10^X/yr.) X=	Q (10^X) X=	S_1	S_{10}	S_D	U_L (10^X) X=	ΔS_{10}	ΔS_D	M	ΔQ ($10^X Q$) X=	T_{10}	T_D
-7		0	0	0	-5	0	0	0	-6	0	0
-6		0	0	0	-4	0	0	0	-5	0	0
-5		0	0	0	-3	0	0	0	-4	0	0
-4		0	0	0	-2	0	0	1	-3	1	1
-3	-3	0	0	2	-1	0	2	2	-2	2	2
-2		2	20	3	0	19	2	3	-1	20	3
-1		3	30	5	1	20	-5	5	0	30	10
0		5	50	18	2	-50	-82	18	1	100	100
1		18	180	125	3	-820	-875	125	2	1000	1000
-7		0	0	0	-5	0	0	0	-5	0	0
-6		0	0	0	-4	0	0	1	-4	1	1
-5		0	0	0	-3	0	0	1	-3	1	1
-4		0	0	1	-2	0	1	1	-2	1	1
-3	-4	1	10	2	-1	10	2	2	-1	10	2
-2		2	20	3	0	19	2	3	0	20	3
-1		3	30	7	1	20	-3	7	1	30	10
0		7	70	21	2	-30	-79	21	2	100	100
1		21	210	125	3	-790	-875	125	3	1000	1000
-7		0	0	0	-5	0	0	1	-4	1	1
-6		0	0	1	-4	0	1	1	-3	1	1
-5		1	10	2	-3	10	2	2	-2	10	2
-4		2	20	2	-2	20	2	2	-1	20	2
-3	-5	2	20	3	-1	20	3	3	0	20	3
-2		3	30	4	0	29	3	4	1	30	4
-1		4	40	8	1	30	-2	6	2	40	10
0		8	80	24	2	-20	-76	24	3	100	100
1		24	240	125	3	-760	-875	125	4	1000	1000
-7		1	10	2	-5	10	2	2	-3	10	2
-6		2	20	2	-4	20	2	2	-2	20	2
-5		2	20	2	-3	20	2	2	-1	20	2
-4		2	20	2	-2	20	2	2	0	20	2
-3	-6	2	20	3	-1	20	3	3	1	20	3
-2		3	30	4	0	29	3	4	2	30	4
-1		4	40	10	1	30	0	6	3	40	10
0		10	100	26	2	0	-74	26	4	100	100
1		26	260	140	3	-740	-860	140	5	1000	1000

U_L = expected lifetime usage (10 years)

ΔS_{10} = net spares required by unreadiness condition between 10 site sparing and expected lifetime demand. (Plus equals unused, minus indicates reorder is necessary.)

ΔS_D = net spares required by unreadiness conditions between depot sparing for 10 sites and total lifetime demand.

T_S = total spares requirements for 10 sites, at site location, over lifetime (10 years) of equipment.

T_D = total spares requirements for 10 sites, at depot location, over lifetime (10 years) of equipment. Where depot spares for one year permit a one each allocation to sites with some left over, it is anticipated that all spares would be kept at the depot. If spares were allocated to sites, a reduction in unreadiness due to the order time could be achieved.

M = minimum buy based on first year supply. If spare requirement is less than one, requirement is based on lifetime unreadiness permissible.

ΔQ = expected unreadiness decrement resulting from transportation and such for shipment from depot to site (if spares are centralized at depot).

$$N_{R-D}[t/(VL)] = \text{unreadiness} \qquad (50)$$

where

N_{R-D} = number of depot demands

t = .01 year, i.e., downtime, due to transportation

V = number of sites = 10

L = equipment life = 10 years

3.5.2.2 Spare Requirement for RAFM - Table 5 has been developed for the RAFM philosophy. This table shows the relationship between unreadiness, aggregate item type failure rate, repairable spares, and pipeline supply cycle [2,3,4].

Figures 4, 5, and 6 also present the above information in graphical form.

TABLE 5

UNREADINESS

Failure Rate λ (part/hours)	Spares 0	1	2	3	4	5	6	7	8	9	10	11
	Supply Cycle - 2 weeks											
.001	.285	.0226	.00164	.000102	.00000540	.00000025	.00000001	.00000000				
.0003	.0970	.00243	.0000546	.00000104	.00000002	.00000000	.00000000					
.0001	.0329	.000274	.00000204	.00000001	.00000000							
.00003	.0100	.0000248	.00000006	.00000000								
.00001	.00336	.00000280	.00000000									
.000003	.00101	.00000025	.00000000									
.000001	.000336	.00000003	.00000000									
.0000003	.000101	.00000000										
.0000001	.0000336	.00000000										
	Supply Cycle - 4 weeks											
.001	.488	.0727	.0102	.00124	.000129	.0000118	.00000096	.00000007	.00000000			
.0003	.183	.00893	.000394	.0000148	.00000047	.00000001	.00000000	.00000000				
.0001	.0648	.00107	.0000159	.00000020	.00000000	.00000000						
.00003	.0198	.0000987	.00000044	.00000000								
.00001	.00668	.0000112	.00000002	.00000000								
.000003	.00200	.00000100	.00000000									
.000001	.000672	.00000011	.00000000									
.0000003	.000201	.00000001	.00000000									
.0000001	.0000672	.00000000										
	Supply Cycle - 6 weeks											
.001	.632	.132	.02677	.00475	.000732	.0000990	.0000119	.00000128	.00000013	.00000001	.00000000	
.0003	.261	.0187	.00122	.0000681	.00000326	.00000014	.00000000	.00000000	.00000000	.00000000		
.0001	.0970	.00243	.0000546	.00000104	.00000002	.00000000						
.00003	.0296	.000221	.00000147	.00000001	.00000000							
.00001	.0100	.0000248	.00000006	.00000000								
.000003	.00300	.00000225	.00000000									
.000001	.00101	.00000025	.00000000									
.0000003	.000302	.00000002	.00000000									
.0000001	.000101	.00000000										

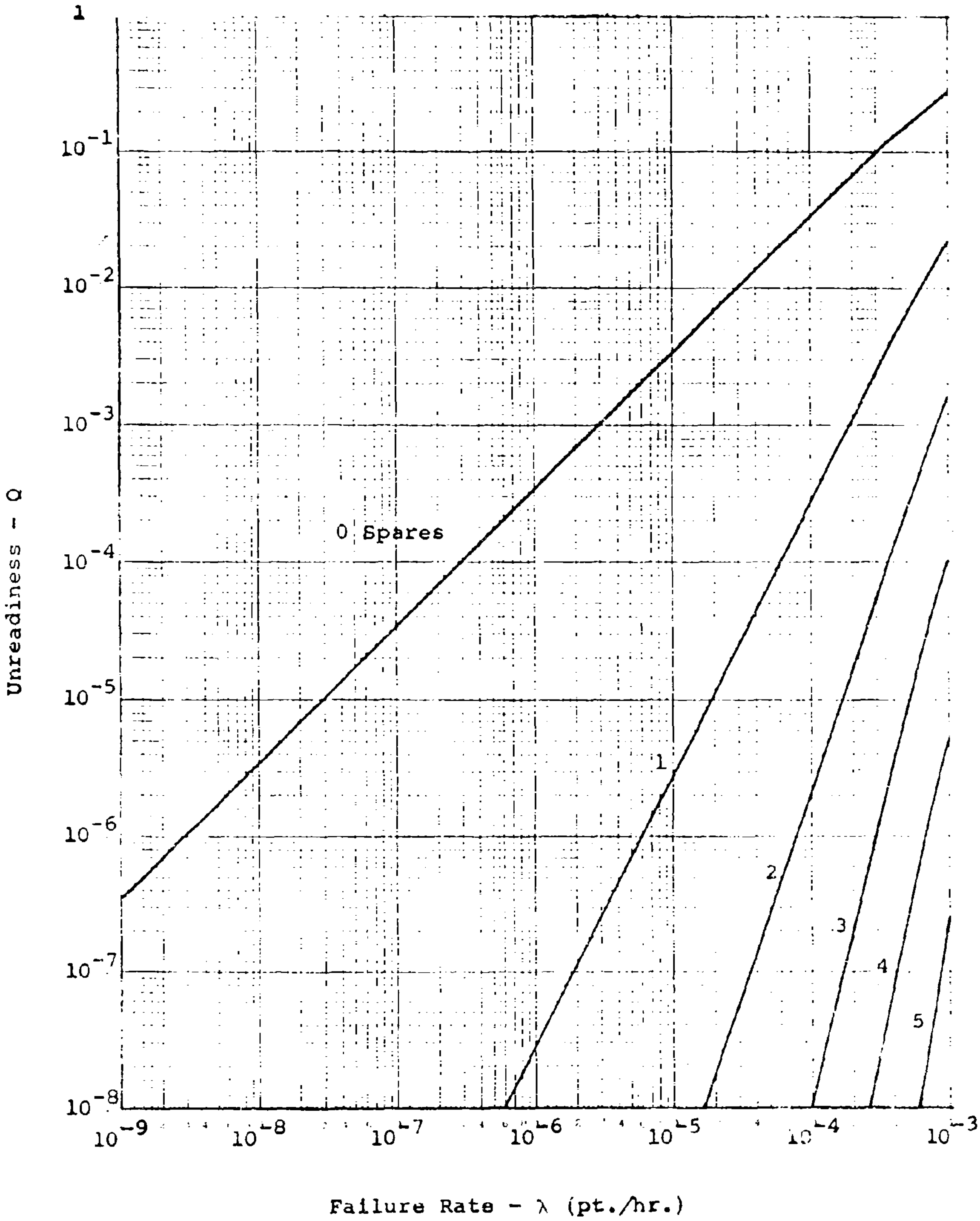


FIGURE 4. UNREADINESS - 2-WEEK SUPPLY CYCLE

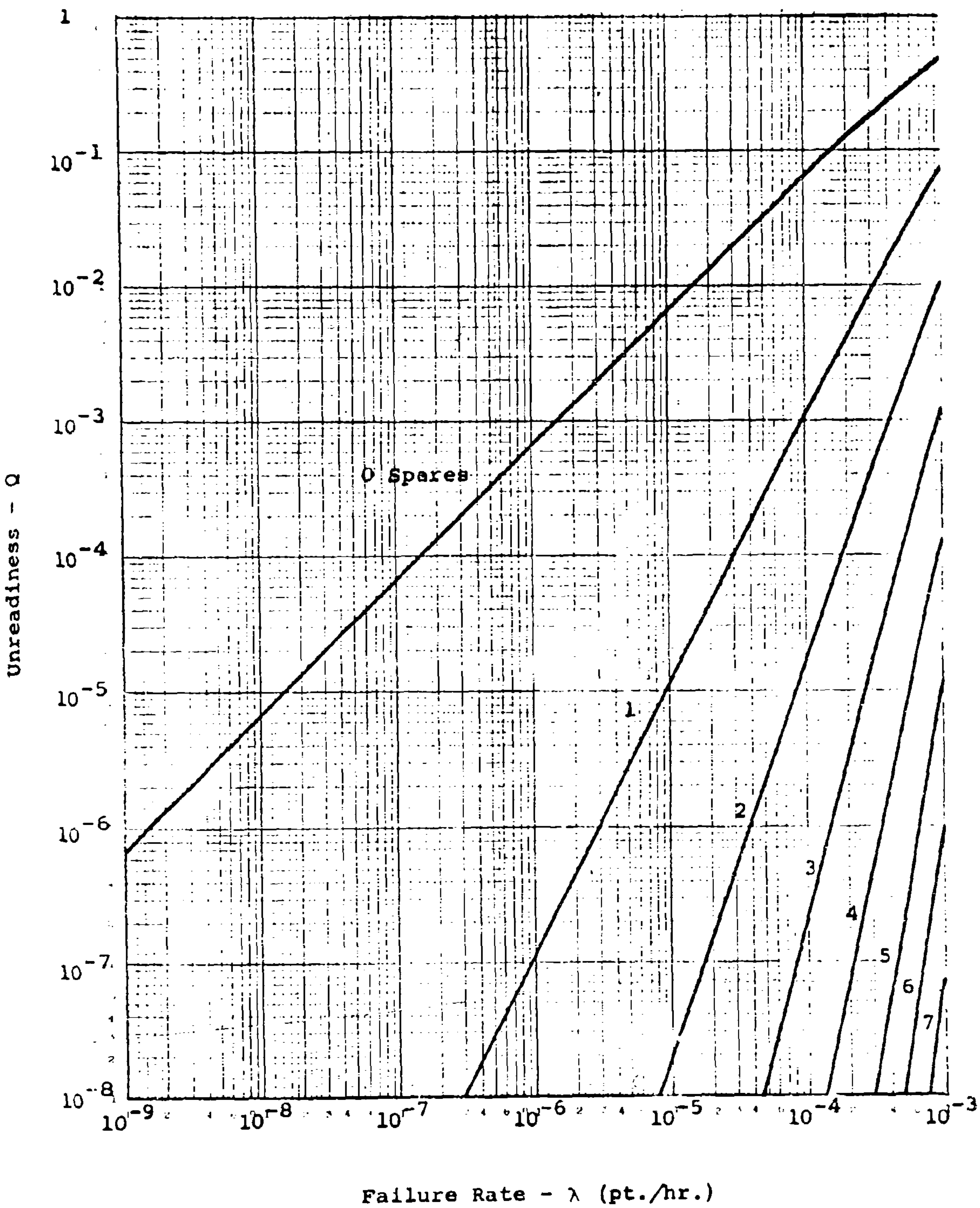


FIGURE 5. UNREADINESS - 4-WEEK SUPPLY CYCLE

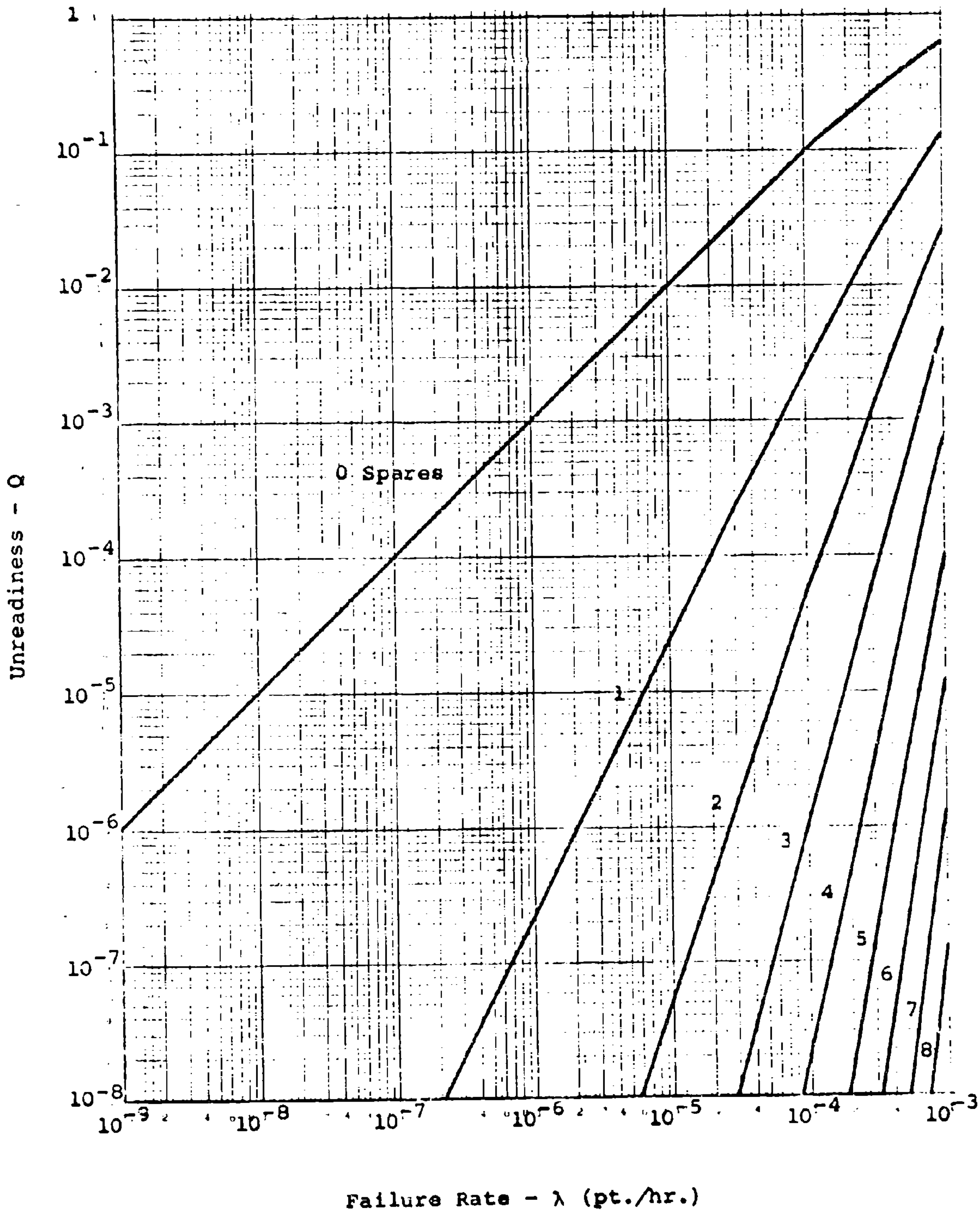


FIGURE 6. UNREADINESS - 6-WEEK SUPPLY CYCLE

3.5.3 Modularization and Standardization Cost Effects - Although it is not realistic to generalize about module size in terms of either number of parts per module or failure rate per module, due simply to the complexity of circuits and other constraints; it is possible to indicate basic cost trends as a result modularization and standardization. The diagram following has been developed to illustrate the principles involved.

Configuration	Modules	Relations
1	λ_T	λ_T
2.1	λ_A | λ_A	$2\lambda_A = \lambda_T$
2.2	λ_A | λ_B	$\lambda_A + \lambda_B = \lambda_T$; $\lambda_A = \lambda_B$
3.1	λ_A | λ_B | λ_C	$\lambda_A + \lambda_B + \lambda_C = \lambda_T$; $\lambda_A = \lambda_B = \lambda_C$
3.2	λ_A | λ_A | λ_C	$2\lambda_A + \lambda_C = \lambda_T$; $\lambda_A = \lambda_C$
3.3	λ_A | λ_A | λ_A	$3\lambda_A = \lambda_T$

Assume a component having an aggregate failure rate λ_T. It is desired to determine the cost effect of further modularization and standardization at each level of modularization.

Let

N_O = the number of locations the basic component will be used.

= 1 or 10

Q = the permissible level of unreadiness (aggregate) per location.

= .01 or .001

T_D = depot turn around (pipeline) time.

= 4 weeks

λ_i = failure rate associated with each module at each level of modularization.

S = aggregate number of spares for specific combinations of N_O, U, module configuration.

C = resultant cost measured in term basic component. The cost of the module is prorated on the relative failure rate of the module to the failure rate of the basic component.

3.5.3.1 Tabular Array - The tabular array below summarizes the results of modularization and standardization for these configurations. (Table 5, section 3.5.2.2, used for computation purposes.)

λ_T = .001, T_D = 4 wks.

Q	.01		.001		.01		.001	
N_O	1		1		10		10	
Configuration	S	C	S	C	S	C	S	C
1	3	3	4	4	30	30	40	40
2.1	3	3/2	4	2	30	15	40	20
2.2	4	2	6	3	40	20	60	30
3.1	5	5/3	7	7/3	50	17	70	23
3.2	4	4/3	5	5/3	40	13.3	50	17
3.3	3	1	4	4/3	30	10	40	13.3

For the stated assumptions the following observations may be made.

a. Spares increase as the readiness requirement increases.

b. Increasing modularization, per se, does not insure lower cost; compare configurations 2.1 and 3.1.

c. At any level of modularization increasing standardization decreases cost.

d. The cost and cost difference are linearly related to the number of location applications.

3.5.3.2 Acquisition Cost Implications - Appendix V reflects the module cost dependence upon the quantity produced. Bringing this experience to bear upon the findings above clearly indicated a multiple payoff from standardization, i.e., reduction in unit price through increased production quantity, reduction in unit price through decreased size, and reduction in support cost through decreased spares requirements.

Barring the realities of circuit constraints, interconnection, and scheduling problems. A least cost module configuration would provide maximum module standardization at the minimum module size.

One practical approach to achieve standardization at the module level has been to provide non-functioning parts to modules in otherwise similar circuit applications. This provides interchangability in maintenance, and, also, above for larger production runs.

3.6 Model Parameter Responsibilities

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 operation 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 government, providing costs of human resources, handling, and the like.

The approach used is to take the estimate of a parameter from the source having the best information concerning it. In the two paragraphs following, information to be supplied by the contractor and all government-furnished information is listed.

3.6.1 Information Required of Contractor -

Development Cost, ________________

Fabrication Cost, ________________

Installation Cost, ________________

Test Equipment Cost per Location

Organization, ________________

Field, ________________

Depot, ________________

Special

Contractor furnished, ________________

Government furnished, ________________

Standard

Contractor furnished, ________________

Government furnished, ________________

Tools and fixtures costs

Contractor furnished, ______________

Government furnished, ______________

Number of new line items

Parts, ________________

Modules, ______________

Higher level of assembly, ______________

Contractor processing costs

Parts, ______________________

Modules, ____________________

Higher level of assembly, ________________

Manuals-Documentation, __________________

C_i = item type i cost, __________
(based on expected quantity produced)

λ_i = failure rate of ith item, __________
(item designates any level of assembly that will require sparing, e.g. part)

μ_i = repair rate for ith type item, __________

n_i = number of item i in equipment, __________

N_{R-y} = number of demands for factory level services, ______________

C_y = cost for factory repair (if applicable), ______________

Methods for obtaining operational readiness:

a. Time to restore equipment to operable status, ___________.

b. Expected unreadiness due to waiting (if applicable):

Spares

Parts, ______________

Module, ______________

Higher level of assembly, ______________ 3.6.2 Government-Furnished Information -

Operational Parameters:

L = Expected life of equipment, ______________

E = Number of equipments scheduled for operation, ______________

r = Fraction of time equipment will operate per hour. ______________

Operational readiness goal, ______________

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

Reliability (to equipment level, if applicable), ______________

F_S = Number of field shops, ______________

L_p = Expected length of phase-out of equipment, ______________

Self-Sufficiency Restrictions:[14, 15]

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, 34.00[16]

M = Line item maintenance Cost Per Year, 19.00[1]

D = Documentation per repair (Debit and Credit), 14.00[1]

R = Cost of maintaining stock item (MRS), per year, 29.00[1]

Facilities and Utilities:

Floor Space, 20.00 per square foot

Air Conditioned, ______________ (The costs are to be individually investigated.)

White Room, ______________

B = Constant representing the average number of parts replaced per failure, 3[17]

c_d = Depot level direct and indirect costs as incurred.*

Personnel costs by classification per year,[13]

CMSgt - E-9, $12,423

MSgt - E-7, 8,939

SSgt - E-5, 5,172

A2C - E-3, 2,292

Airman Basic - E-1 2,292

+ $191 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 must be provided by the Air Force user organization:

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

* See appendix VI.

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

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 Schedule by Location.

Periodicity, ______________

Duration, ______________

Team Personnel Requirements, ______________

3.7 Proposal Development Implications

The mode of application of the model has been limited to information obtainable in the design/definition phase of system development. However, an important potential area of application is in competitive contractor proposal development. This opportunity is the result of the ability to project alternative designs into the total support environment of the system and thus designs may be directed to minimizing total expected cost (acquisition and support) in conjunction with meeting operational capability requirements.

The basic differences between the proposal development and design definition phases are as follows:

a. Proposal development time is limited.

b. Proposal cost is generally that incurred by the contractor.

As a result of these constraining conditions it will generally not be to explore all feasible design/support alternatives in extensive detail. However, it will be possible to ferret out potentially costly alternatives. This comes about because the model and its mode of application is such that it permits the following:

a. Proposal design directed to the support system since at all times the design is evaluated with respect to total support system.

b. A rapid evaluation of significantly different design alternative since only cost difference are considered.

A significant feature of the technique is that, in general, as the differences between alternatives become less cost significant, information requirements become more detailed. Thus, in general, the more important cost decisions will be possible with less exact information.

4. VALIDATION

4.1 General

The basic requirement of the model is that it measures differences in resource cost as a result of RAFM-DAFM design/support alternatives. It is not feasible to experiment with the model for existing systems in the sense of sampling for cost incurred, using DAFM for a period of time versus cost incurred using RAFM, for a like period. It is necessary to evaluate the model validity using other criteria. These other criteria are the predictors of inputs to the model. The aggregate error associated with prediction inputs to the model will be used to measure model validity.

4.2 Equipment Survey

A survey of the AN/GKA-5 Data Link Transmitter, AN/FST-2 Coordinate Data Transmitting Set, AN/FPS-35 Search Radar, and the AN/FSQ-7 Computer, was performed to evaluate the most appropriate hardware for use in model validation. The criterion established for equipment selection was that it be transistorized (all transistorized equipment was modularized). As practical, selection of transistorized equipment is based on the military's rapidly expanding utilization of semiconductors in electronic systems and anticipated expanded microcircuit applications.

4.2.1 AN/GKA-5 - A survey of hardware comprising the AN/GKA-5 indicated that two groups of equipment, the Multiplexer Group and the Transmitter Control and Antenna Switching Group, satisfy the criterion. The characteristics of these groups are that they contain digital circuitry, are transistorized, and are modularly constructed. Together, these groups comprise approximately 56 percent of the AN/GKA-5 system.

4.2.2 AN/FST-2 - A survey of hardware comprising the AN/FST-2 indicated that the only equipment satisfying the criterion is the Decoder Power Supply Group. The characteristics of this group are that it contains digital circuitry, is transistorized, and is modularly constructed. This group comprises approximately 7 percent of the AN/FST-2 system.

4.2.3 AN/FPS-35 - A survey of hardware comprising the AN/FPS-35 indicated that the only unit partially satisfying the criterion is the Monitor and Control Unit. The characteristics of this unit are that it contains analog circuitry, is approximately 11 percent transistorized, and is modularly constructed. The Monitor and Control Unit comprises a small portion of the overall system.

4.2.4 AN/FSQ-7 - A survey of hardware comprising the AN/FSQ-7 indicated that this computer is totally comprised of vacuum tube circuits. Since computers of the future will consist (to a large extent) of semi-conductors, it is felt that this particular equipment is not representative of forthcoming computer systems. Therefore, the AN/FSQ-7 was eliminated as a candidate for application to the mathematical model.

4.2.5 General Procedure - Three sites (organization level) were examined for each equipment. The equipment exhibiting the greatest span of maintenance activity (in terms of maintenance echelons) would be selected for model application. Given that one of the equipments was a candidate for DAFM, the economic feasibility of redesign would be analyzed for minimum cost.

The initial selection of the AN/GKA-5, AN/FST-2, and AN/FPS-35 restricted observations to equipments in a somewhat specialized category. These equipments are all one-per-site, each site having its own maintenance shop that does not differentiate between field and organization. The modules are not specially coated or encapsulated, so that on-site repair of modules is practical.

None of the initial equipments selected were good candidates for DAFM. (See appendix I for site findings.) As a result, project personnel covered a fifth equipment, subsystem F105D-FCS-BTC, which was previously established to have essentially all module repair work performed at depot level.

4.3 Bomb Toss Computer Technique Application

The general procedure that will be used in the application of the model to the equipment evaluated will be:

a. Description of system and subsystem in which the equipment fits.

b. Predicted and measured parameter information.

c. Establishment of pertinent cost factors using predicted information.

d. Evaluation of discard feasibility using predicted information.

e. Evaluation of discard feasibility using measured information.

f. Evaluation of sources of error.

The ways in which a prediction model or technique may not fully meet stated objectives are as follows.

a. The model may assert an inaccurate, incorrect, or inadequate functional relation between the dependent variable and the independent variables. This may be the case for only certain ranges of values of one or more of the independent variables.

b. The model may omit significant independent variables.

c. The model may include superfluous independent variables which have no appreciable effect on the dependent (output) variable.

d. The model may omit significant dependent variables.

e. A valid model may apparently fail as a result of inaccurate parameter predictions. That is, inaccurately predicted values of an independent variable substituted into the model may yield an incorrect value for the dependent variable,whereas accurate predictions would have yielded an acceptable value. The revised model in section 3 is a result of investigations into the error sources a, b, c, and d of the model reported in RADC-TDR-63-140.

This section of the report contains an analysis of the predictive capability of the model developed in section 3 and an illustration of the mode of application. The validation program consisted of two relatively distinct phases. The first phase involved evaluating the initial model for its fit to the problem it was to describe, and introducing appropriate modifications where necessary (see Appendices I and II). The second phase of the validation program consisted of application of the revised model to one of four (later five) candidate equipments examined in the field.

4.3.1 The System - The F105D was designed as an all weather fighter and is presently operational. An F105D wing at Seymour Johnson AFB consists of three squadrons of eighteen aircraft each. Personnel allocation must be such that a squadron, along with ground support equipment, may be detached without compromising the operational readiness of either the detached squadron or wing remnants. This system consists of a number of subsystems, each of which requires special skill fields and each of which contributes to the unreadiness of the system.

Under normal circumstances, the organization and field shops function on a two-shift basis but must be capable under alert conditions to perform around the clock.

4.3.2 The Subsystem - The F105D fire control subsystem (FCS or AN/ASG-19) is a combination of semi-automatic air-to-air and air-to-ground fire control, navigational aid, and automatic bomb delivery control. The three main operating subsystems of the FCS are as follows:

a. Radar (R14A)

b. Attack Display (AD)

c. Bomb Toss Computer (BTC)

4.3.2.1 Description of FCS Support Environment - The support environment consists of three distinct but interdependent maintenance activities.

a. Organization: Personnel of this activity perform maintenance directly on the operational aircraft.

b. Field: Personnel of this activity perform maintenance on black boxes which comprise the subsystems.

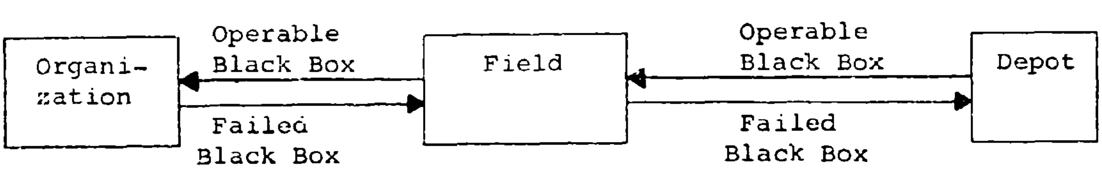
c. Depot: Personnel of this activity perform maintenance on black boxes which, for one of the following reasons, are not serviced in the field:

(1) Skill requirements.

(2) Test equipment requirements.

(3) Parts nonavailability.

4.3.2.2 Maintenance Plan - The diagram below illustrates the relationship between the maintenance activities:



Since the FCS-BTC is a subsystem of the FCS, it is maintained by the same organization personnel. Hence, it is necessary to direct attention to the entire FCS, up to and including field maintenance activity.

4.3.3 Support System Parameter Values - The value of the parameters that follow were established through information obtained at SJAFB, WRAFB, and WPAFB (see Appendix I.).

4.3.3.1 System Parameters -

E	=	operational system per site	=	50
E_T	=	number of operational systems	=	700
r	=	operating time per subsystem and equipment per unit calendar time	=	.044
F_S	=	number of sites (number of field shops)	=	14
O	=	mean operational hours (flying) per fifty aircraft per month (SJAFB)	=	1648
L	=	system life (yr)	=	10
B	=	maintenance work schedule adjustment factor		
	=	operational time/maintenance shift hour	=	2

Let

λ = failure rate/operational time

Then the failure rate per unit calendar time (λ_B) becomes:

$$\lambda_B = B\lambda$$

Adjustment B is made, for non-flying days and non-working hours, as follows:

$$B = J/\left[(J-Z)H\right]$$

$$= 30.8/\left[(22.8)(2/3)\right]$$

Where

J	=	average number of days in month	=	30.8
Z	=	number of days in J which are non-flying	=	6
H	=	fraction of hours during a day when work is performed	=	2/3

4.3.3.2 Equipment Parameters -

			Predicted	Measured
λ_{FC}	=	failure rate of an FCS (failure/hr)	= .082	.067
	=	$\lambda_{AD} + \lambda_{BTC} + \lambda_{R14A}$		
λ_{BTC}	=	failure rate of BTC (failure/hr)	= .009	.008
T_o	=	service time at organization (hr)	= 3.5**	3.5*
T_A	=	Service time at assembly level (hr)	= 2	2
T_{SA}	=	service time at module level (hr)	= 1	4
T_D	=	pipeline time at depot (wk)	= 6	-
T_t	=	turnaround time for subassembly repair, given that assemblies are repaired at the location (assumed) (days)	= 1.5	-

The time involved in the assumption T_t permits module repair work to be delayed, i.e., module repair requires four hours. As it turns out, T_t may be varied by a factor of three in either direction without affecting either unreadiness or cost. It is used primarily as a device for computing spares.

4.3.3.3 Cost Factors - Transportation per assembly shipment is based on SJAFB to WRAFB. Most MATS trips are nonchargeable. Further, under existing conditions, transportation is included in D (below). Either way the cost will not affect the decision.

FCS procurement cost (Radar, Attack and Display, and Bomb Toss Computer) = $85,000

BTC procurement cost = $25,000

Assembly (BTC) mean procurement cost = $2,500

Module (BTC) procurement cost mean = $150

Part Repair (3 parts average usage) = $10

* This time is associated with the FCS and is not broken down into times associated with individual equipments, e. g., BTC
** This time is measured, in practice it must be predicted

Line Item (C) constants are as follows:

a. D = $14

b. R = 29

c. M = 19

d. I = 34

Line Items Per Assembly Level (unique to BTC) are as follows:

a. N_{Lp} = 5 Part types

b. N_{Lm} = 15 Module type

c. N_{La} = 10 Assembly types

4.3.4 Higher Modular Assemblies - Table 6 represents a breakdown of higher assemblies with their respective failure rates.

TABLE 6

BTC ASSEMBLIES

Assembly	Failure Hour/Site	
	Predicted	Measured
1. Power Supply	.00084	.00075
2. Amplifier	.00344	.00306
3. Comparator	.00136	.00121
4. Angle Position Drive	.00495	.00450
5. Roll Angle Repeater	.00224	.00200
6. Time and Range Drive	.00124	.00100
7. Angle Function B	.00157	.00140
8. Angle Function A	.00130	.00160
9. Angle Function E	.00064	.00056
10. Drift Angle and Range Wind Drive	.00214	.00190

The failure rate of BTC assemblies was established as follows:

a. A parts count reliability analysis was performed, the results of which are contained in appendix IV.

b. From field reliability programs, the failure rate of the BTC was established.

c. The measured failure rate for the BTC assemblies was established by:

$$\lambda_{Mhi} = (\lambda_{phi}/\lambda_{pT})\lambda_{BTC} \qquad (50)$$

Where

λ_{Mhi} = measured failure rate of the i th higher modular assembly.

λ_{phi} = predicted failure rate of the i th higher modular assembly.

λ_{pT} = total predicted failure rate of the BTC.

λ_{BTC} = measured failure rate of the BTC.

4.3.5 Modules - Table 7 presents a breakdown of modules with their respective quantity.

TABLE 7

BTC MODULES

Module Number	Quantity
C352	1
C441	11
D159	1
D539	6
D574	2
D548	1
D549	1
D557	1
D562	1
D565	1
D566	1
D568	2
D569	1
D580	1
D5396-2	1

The failure rate of the modules was established as follows:

a. Predicted - The modules have about 20 percent of the total predicted failure rate of the BTC (.009 fail, 1 hr). Each module has about the same complexity and there are 32 modules in all, so (.09)(.2)/32 $\cong$ = .000065 fail/hr) the total contribution of modules to the predicted failure rate was .00208 fail/hr.

b. Measured - The measured failure rate of a module type was established from

$$\lambda_{Mmi} = (N_i \lambda_{pmi} / \lambda_{pT}) \lambda_{BTC} \tag{51}$$

Where

λ_{Mmi} = measured failure rate of the i th module type

N_i = number of i th module in BTC

λ_{pmi} = the predicted failure rate of module i

4.3.6 Derived Failure Rates - The total BTC failures are estimated to be

		Predicted	Measured
a.	Per site per year	= 174	155
b.	Per site per 1000 hours (depot pipeline time)	= 19.8	17.3
c.	All sites per year (14 sites)	= 1439.	1272
d.	All sites for 10 years (14 sites)	= 14388.	12720

Total BTC modules failures are:

a.	Per site per year	= 38	33.8
b.	All sites per year (14 sites)	= 317	282
c.	All sites per ten years (14 sites)	= 3170	2820
d.	Per site per 1000 hours (6 weeks)	= 4.4	3.9

4.3.6.1 Detailed Module Demands - The detailed module demands are presented in table 8. The importance of turnaround time for modules, at field and depot, lies in their availability as replacements for failures; i.e., module repair time does not reflect directly on the unreadiness of the system considered unless a wait occurs. Further, the objective at the point of maintenance is always to repair the highest spare level of assembly by module replacement, if possible, and repair the module during idle time (when a work demand for an assembly does not exist). For the present model application, it has been assumed that a 1.5-day period will provide sufficient time to repair a failed module. This time has been labeled turnaround time, and the spare module requirements are based on this time and permissible level of unreadiness. As it turns out, this assumed value may be varied by a factor of three in either direction without significantly affecting the spare quantity.

TABLE 8

PREDICTED BTC MODULE DEMANDS

Module Number	Fail/Hr per Site	Fail/Hr All Site	Fail/1000 hr per Site	Fail/10 yr All Sites	Fail/1.5 day Turnaround per Site
C441	0.00154	0.0119	1.54	104	0.00555
D539	0.00084	0.0065	0.84	57	0.00320
D547	0.00028	0.0027	0.28	19	0.00110
D568	0.00028	0.0027	0.28	19	0.00110
C352	0.00014	0.0011	0.14	9.5	0.00050
D159	0.00014	0.0011	0.14	9.5	0.00050
D548	0.00014	0.0011	0.14	9.5	0.00050
D549	0.00014	0.0011	0.14	9.5	0.00050
D557	0.00014	0.0011	0.14	9.5	0.00050
D562	0.00014	0.0011	0.14	9.5	0.00050
D565	0.00014	0.0011	0.14	9.5	0.00050
D566	0.00014	0.0011	0.14	9.5	0.00050
D569	0.00014	0.0011	0.14	9.5	0.00050
D580	0.00014	0.0011	0.14	9.5	0.00050
D5396-2	0.00014	0.0011	0.14	9.5	0.00050

4.3.7 Repair Case Sparing - The general criterion for sparing is to allow only a fixed amount of unreadiness contribution because of the unavailability of spares. The unreadiness level selected is 0.0001 for the aggregate contribution. This would permit approximately 0.005 aircraft down because of lack of spares from the BTC, which, allowing the other subsystems the same unreadiness, would leave approximately one-half aircraft down because of lack of spares.

4.3.7.1 Repair At Depot - The quantity of assembly spares at depot, required for the repair case has been established using table 5 applied to each spare type. In cases where the range of the table is inadequate, separate calculations were made. The permissible unreadiness level established for spares by type is approximately 0.00001. This yields an unreadiness chargeable to assembly spares of approximately 0.0001.

4.3.7.2 Assembly Repair At Field - Assembly spares at field for repair were determined from reference 3. The unreadiness contributed by assembly spares in conjunction with the assigned number of personnel is approximately 0.001. (See paragraph 4.3.9, manning analysis.) The spares determined from the tables of reference 3 refer to a complete set (i.e., one each)of assembly spares.

4.3.7.3 Turnaround Period At Field - Spare modules by type were determined using table 5 and the two-week supply cycle. Since 1.5 days is approximately equal to 0.1 x 2 weeks, the failure rate, predicted or measured, was divided by 10. The resulting adjusted failure rate was used to enter in table 5. The unreadiness permitted per type is approximately 0.000007, yielding an aggregate unreadiness, because of module spares, of approximately 0.0001.

4.3.7.4 Total Spares - Table 9 shows the total assemblies required.

TABLE 9

ASSEMBLY SPARES REQUIRED

Assembly Number	Per Site Six-Week Pipeline	All Sites	Per Site Repair On Site	All Sites
1	5	70	1	14
2	11	154	1	14
3	5	70	1	14
4	13	182	1	14
5	8	112	1	14
6	5	70	1	14
7	6	84	1	14
8	5	70	1	14
9	5	70	1	14
10	8	112	1	14
	71	994	10	140

Table 10 shows the total modules required.

TABLE 10

MODULE SPARES REQUIRED

Module Number	Per Site Six-Week Pipeline	All Sites	Per Site 1.5 Days Turnaround	All Sites
C441	10	140	4	56
D539	7	98	3	42
D547	4	56	2	28
D568	4	56	2	28
C352	3	42	2	28
...	...	...	...	...
D5392-2	3	42	2	28
	58	812	33	462

4.3.8 <u>Discard</u> - Since, in all cases, the confidence buy for one year is exceeded by the expected usage over 10 years of life. there are no spares left at phase-out. Hence the spare assemblies required are equal to the number of failures (14388) and the spare modules are equal to the number of module failures (3170). There is no essential difference in operational readiness achieved at the field or at organization between discard or repair at either the assembly or module level.

4.3.9 <u>Manning Analysis</u> - Since perhaps the most critical cost factor of an RAFM-DAFM decision is potential difference in manning, this aspect of the model will be dealt with in proportionately greater detail. A second purpose of the more exhaustive treatment of manning analysis is to convey more clearly the complexity of the task and manning dependency upon other factors.

4.3.9.1 Manning Requirements as Related to Operational Readiness - Corrective maintenance cannot be scheduled in advance. Individual repairs are irregular in occurrence and varying in time-to-repair. In order to achieve a relatively high operational readiness, maintenance personnel must usually be available to work on an equipment as soon as a failure is discovered, and/or a spare equipment must be available to replace the failed one. Consequently, it will often be necessary that maintenance men be idle or engaged in tasks which can be dropped when repair of a failure is required.

4.3.9.2 Maintenance Manning - To determine the requirements for maintenance personnel and spares, the demands for maintenance, in terms of manhours and skills, must be determined. Following the manning method developed in references 2, 3, and 4, the maintenance teams are established.

C = Number of service channels (maintenance teams).

N = Maximum number of units which may demand service at a particular instant (aircraft).

S = Number of spare units which may replace units being serviced or awaiting service (subsystem spares).

P = Utilization factor (λ/μ).

where:

λ = Failure rate of one unit.

μ = Service rate of one channel.

Tables [3] exist for determining:

d = Mean number of failed units, per N, for which no spares (S) are available.

n_d = Mean number of units, per N+S, either awaiting or undergoing service.

From these parameters may be obtained:

D = Mean number of failed units for which no spare is available

$$= dN \tag{52}$$

N_d = Mean number of units either awaiting or undergoing service

$$= n_d(N+S) \tag{53}$$

R = Operational readiness

$$= N_o/N \tag{54}$$

where:

N_o = Mean number of units operating or ready

= $N-dN$

= $N(1-d)$ (55)

U = Utilization of units

= $N_o/(N+S)$ (56)

c = Utilization of service channels

= $P(N-D)/C$ (57)

4.3.9.3 Manning for Operation - Ordinarily, the number of operators required is unaffected by the selection made as a result of this decision rule. There may be options for the system design which will affect operator requirements, but decisions with respect to these details are made prior to the RAFM-DAFM decision. Differences in the maintenance skill required of the operator may arise from different design and support alternatives especially, where the demand for maintenance in some alternatives is so low that the utilization of a full-time maintenance man would be very small.

If manning and equipment at the organization are identical for several alternative philosophies of maintenance of a particular type of packaging, the only one which could be the optimum is the one which involves performing the most maintenance in the organization for a particular operational readiness requirement, given the same acquisition cost for both packaging configurations. Thus, the others in this group may be eliminated from further consideration. For example, if modules may be repaired at the organization rather than at the depot without requiring additional men or equipment, the organization repair will always be the less costly of the two.

4.3.9.4 Manning Cost - In general, to assess the costs of either RAFM or DAFM, the following steps will be required.

a. Determine the personnel organization neglecting additional personnel required, if any, to repair or discard faulty modules.

b. Determine additional personnel (direct, indirect, and overhead) required for RAFM.

c. Determine additional personnel (direct, indirect, and overhead) required for DAFM.

The real personnel cost is established from steps a and b for RAFM and steps a and c for DAFM. However, the difference method makes it possible to evaluate steps b and c only and to neglect step a.

4.3.9.5 FCS and BTC Manning - The following are the details establishing that module repair can be carried on at field level without contributing significantly to system unreadiness. In computing idle time (IT) and free time (FT), the calculation of the utilization factor (P) has to be modified as follows:

Let

$$P_T = P + P_S \tag{58}$$

where

P_T = modified utilization factor

P_S = preventive maintenance work load

The module workload (MWL) is

$$MWL = kP_T(N-D) \tag{59}$$

where

k = proportion of workload contributed by modules

$$IT = (1-c)16 \tag{60}$$

in team hours

$$FT = IT - MWL \tag{61}$$

The results of the application are:

a. FCS - Organization* (Predicted)

(1) $P = (\lambda/\mu)(rB) = (.082/.286)(.044)(2) = .032$

(2) $P_S = .007$

(3) $P_T = .032$

(4) C = 4 (from reference 3: $N \cong 50$, S = 0)

(5) c = .363

(6) IT = 10.2 team hours

*Personnel who service the aircraft subsystems directly

b. BTC - Field* (Predicted)

(1) $P = .0014$

(2) $P_S = 0$

(3) $P_T \cong .001$

(4) $C = 1$ (from reference 3, $N \cong 50$, $S = 1$)

(5) $c = .001$

(6) IT = 14.9 team hours

(7) MWL = .06

(8) FT = 14.8 team hours

The following summarizes the results.

a. Although no manifest gain is achieved in having more than one BTC field repair channel, three teams per shift are necessary to maintain squadron mobility and self-sufficiency.

b. A minimum of one repair team per shift at field is required; this affords ample time for module repair.

c. It is also clear that the idle time experienced at organization is necessary to assure the availability of a maintenance team upon demand.

d. It should not be inferred that idle time is wasted time. Most of this time is utilized in training or engaging in secondary priority work such as module repair.

4.3.10 Analysis of Alternatives - The sequence of analysis will be:

a. Organization Alternatives

b. Field Alternatives

c. Depot Alternatives

d. Field versus Depot Alternatives

e. Organization versus Min(Field, Depot)

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*Personnel who fix components (black boxes).

This sequence permits selection of support alternatives without making detailed comparison of all alternatives. This method of analysis will permit elimination of alternatives so that minimum computational effort is required.

4.3.10.1 Organization Analysis - The difference between organization and field maintenance is one of skill rather than location. The wing has the capability to form three separate squadrons, each with its own field maintenance responsibility. As such, field and organization maintenance are potentially (on a squadron breakout) at the same location and are in fact at the same location, based on wing structure.

4.3.10.1.1 Assembly Level - The present breakout of assemblies in the FCS corresponds to physical functional packaging. This design packaging is consistent with packaging constraints, simplifies fault isolation, and generally enhances removal and replacements. Fault isolation capability at flightline exists to the assembly level. However, it is not technically feasible, in general, to anticipate what assembly failed and bring that spare. The reasons follow:

a. Since the failure is not known prior to checkout of the FCS, the spare is not taken along with the maintenance team. This necessitates a return trip to the ready inventory point. Hence, a return trip is required in case of either discard or repair of the assembly.

b. Approximately 50 percent of the failures involve the radar synchronizer units. The same synchronizer is always kept with the same subsystem, if possible, because of extensive adjustment required.

c. Prior to being placed in the aircraft, each replacement black box is checked out on a mock-up to insure operability. Mock-ups are kept at field maintenance. Keeping mock-ups and spares at flightline does not offer a practical alternative, since the only difference between locations is a matter of minutes, with no other chargeable costs.

4.3.10.1.2 Module Level - Suppose an attempt should be made to either discard or repair at the module level. The following would hold true.

a. The number of personnel would be increased if removal to module level at organization were performed.

b. Downtime per failure would be increased at least 1.5 hours. Presently, removal and replacement at the module level, in general, would extend the downtime per failure at least 1.5 hours. This results because a 1.5-hour repair time per black box is required at field shop.

c. Unbounded module inventory could not compensate for the increase in unreadiness in b.

4.3.10.1.3 Test Equipment Requirements - The test equipment used at flightline is independent of subassembly level and, hence, independent of RAFM-DAFM decision.

4.3.10.1.4 Transportation Costs - The transportation costs are not affected by discard or repair. Transportation services are available necessarily for other reasons.

4.3.10.1.5 Spares - If spares were taken to the aircraft, a complete set would be required for each maintenance team. This would be for both radar and BTC, since each subsystem is serviced by the same personnel. However, because of the sensitivity of the FCS to the radar synchronizer, even this policy would be at most 50 percent effective.

The additional drawbacks are:

a. Loading and unloading: special vehicles are not available and a common transportation pool is used.

b. Potential damage to spares.

c. Requirement for constant updating of operability status of all spares - this would increase work load through normal usage and maintenance handling errors.

d. The resultant minimum additional cost would be at least $85,000 per maintenance team required considering only spares.

e. All other cost contributors would increase:

(1) Workload

(2) Personnel

(3) Supply handling

(4) Test equipment usage

(5) Test equipment quantity

4.3.10.1.6 Summary of Organization RAFM-DAFM Analysis - There is no practical alternative to removing and replacing at black-box level and deferring the discard-repair decision to the field shop for the BTC. This follows from consideration of the following facts:

a. No change in personnel.

b. No significant increase in operational readiness would result through assembly discard.

c. No effect on test equipment requirements.

d. No effect on transportation cost.

e. No effect on facilities and utilities since mock-ups and checkout requirements of assemblies would be unchanged.

f. All depot costs at this point are unaffected.

Any alternative would decrease operational readiness and increase cost.

4.3.10.2 Other Alternatives - Table 2 (Section 3) gives the order in which the other alternatives are to be considered. Steps 1 through 4 and step 11 are eliminated, with the elimination of organizational level as a feasible alternative. Steps 5 through 10 are left, comparing the following alternatives:

Field-F_1	Discard higher modular assembly (in this case, a black box or component); number 6 in table 1.
Field-F_2	Part repair higher modular assembly; number 8 in table 1.
Field-F_3	Repair higher assembly by replacing discarded module; number 7 in table 1.
Field-F_4	Repair higher assembly by replacing with depot repaired modules; number 20 in table 1.
Depot-D_1	Discard higher modular assembly; number 11 in table 1.
Depot-D_2	Part repair higher modular assembly; number 10 in table 1.
Depot-D_3	Repair higher assembly by replacing with discarded module; number 9 in table 1.

4.3.10.2.1 Tabular Procedure - Tables 11 through 16 use the tabular procedure called out in figure 3. The tabular procedure is to show the entries in tables 11 through 16 on the even pages followed by the details of the calculation on the odd pages. In showing the details applicable paragraph and/or table numbers are immediately below the symbols in the equations and in the same order as the symbols occur.

TABLE (11)
COST DECISION ELEMENTS
(STEP 5)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (5) $A_{(7)}$	Step (5) $A_{(6)}$
Design	D	3		NA*	
Fabrication	F	3		NA	
Installation	I	3		NA	
Manuals	M	3		NS**	
Test Equipment	T	3,4		ND***	
Organization	To	4		ND	
Field	Tf	4		ND	
Depot	Td	4,5		ND	
Standard	Tds	5		ND	
Special	Tdx	5		ND	
Tools and Fixtures	X	3,6		ND	
Organization	Xo	6		ND	
Field	Xf	6		ND	
Depot	Xd	6,7		ND	
Standard	Xds	7		ND	
Special	Xdx	7		ND	
Line Item Documentation	L	3		ND	
				$S_{(7)}$	$S_{(6)}$
Organization	o	8,9			
Personnel	om	9,10		ND	
Facilities	of	9,11			
Utilities	ofu	11	3.4.2.1.2	ND	
Materials for Maintenance	ofm	11	3.4.2.1.2	ND	
Materials for Test Equip.	oft	11	3.4.2.1.2	ND	
Spares	os	9,12			
Parts	osp	12,13,14	3.4.2.1.3.1	ND	
Modules	osm	12,17,18	3.4.2.1.3.2	ND	
Higher Assemblies	osh	12,19,20	3.4.2.1.3.3	ND	
Transportation	ot		3.4.2.1.4	ND	
Field	f	8,21			
Personnel	fm	21,22		ND	
Facilities	ff	21	3.4.2.2.2	ND	
Utilities	ffu	11	3.4.2.1.2	ND	
Materials for Maintenance	ffm	11	3.4.2.1.2	ND	
Materials for Test Equip.	fft	11	3.4.2.1.2	ND	

TABLE (11) (CONT.)
COST DECISION ELEMENTS
(STEP 5)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (5) $S_{(7)}$	Step (5) $S_{(6)}$
Field (cont.)					
Spares	fs	21,23			
Parts	fsp	23,24,25	3.4.2.2.3.1	31,700	
Modules	fsm	23,26,27	3.4.2.2.3.2	69,300	
Higher Assemblies	fsh	23,28,29	3.4.2.2.3.3	350,000	35,970,000
Depot	d	8,30			
Personnel	dm	30,31,32,33	3.4.2.3.1	NA	
Facilities	df	30,34	3.4.2.3.2	NA	
Materials for Maintenance	dfm	11	3.4.2.1.2	NA	
Materials for Test Equip.	dft	11	3.4.2.1.2	NA	
Spares	ds	30,35		NA	
Parts	dsp	35,36,37	3.4.2.3.3.1	NA	
Modules	dsm	35,38,39	3.4.2.3.3.2	NA	
Higher Assemblies	dsh	35,40,41	3.4.2.3.3.3	NA	
Transportation	dt	30,42		ND	
Organization	dto	42,43		ND	
Field	dtf	42,44		ND	
Utilities	du	30,45		NA	
Power	due	45,46	3.4.2.3.5	NA	
Buildings	dub		3.4.2.3.5	NA	
Line Item	l	30,47			
New	N_I	47		680	
Maintenance	N_{LM}	47		3,800	
MRS	N_{LR}	47		ND	
Debit and Credit	N_D	47		ND	
Factory	V^K	8		NA	
Total Cost ($T_{(7)}$ and $T_{(6)}$)		1		455,480	35,970,000
Cost Difference ($\Delta T_{(7),(6)}$)		2		-35,514,520	
Prefer T_7-(F_2)					

* NA = not applicable
** NS = not significant
*** ND = no difference

TABLE 11 (CONT.)
COST DECISION ELEMENTS
DETAILS - STEP 5

Cost Element	S (7)	S (6)
$C_{fsp}=N_{R-pf}\bar{c}_p$		
(4.3.6) (4.3.3.3)		
=(3170) (10)	31,700	
$C_{fsm}=S_{mf}\ c_m$		
(Table 10) (4.3.3.3)		
=(462) (150)	69,300	
$C_{fsh}=S_{hf}\ c_h$		
(Table 9) (4.3.3.3)		
=(140) (2500)	350,000	
$=S_{hf}\ c_h$		
(4.3.6) (4.3.3.3)		
=(14388) (2500)		35,970,000
$C_l\ =N_L I$		
$=(N_{Lp}+N_{Lm}) I$		
(4.3.3.3)		
=(5+15) (34)	680	
$+N_L LM$		
$=(N_{Lp}+N_{Lm}) LM$		
(4.3.3.3)		
=(5+15) (10) (19)	3,800	
T	455,480	35,970,000
$\Delta\ T_{7,6}$	-35,514,520	

TABLE (12)
COST DECISION ELEMENTS
(STEP 6)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (6) $A_{(8)}$	Step (6) $A_{(7)}$
Design	D	3		NA*	
Fabrication	F	3		NA	
Installation	I	3		NA	
Manuals	M	3		NS**	
Test Equipment	T	3,4			
Organization	To	4		ND***	
Field	Tf	4		ND	
Depot	Td	4,5			
Standard	Tds	5		ND	
Special	Tdx	5		ND	
Tools and Fixtures	X	3,6			
Organization	Xo	6		ND	
Field	Xf	6		ND	
Depot	Xd	6,7			
Standard	Xds	7		ND	
Special	Xdx	7		ND	
Line Item Documentation	L	3		ND	
				$S_{(8)}$	$S_{(7)}$
Organization	o	8,9			
Personnel	om	9,10		ND	
Facilities	of	9,11			
Utilities	ofu	11	3.4.2.1.2	ND	
Materials for Maintenance	ofm	11	3.4.2.1.2	ND	
Materials for Test Equip.	oft	11	3.4.2.1.2	ND	
Spares	os	9,12			
Parts	osp	12,13,14	3.4.2.1.3.1	ND	
Modules	osm	12,17,18	3.4.2.1.3.2	ND	
Higher Assemblies	osh	12,19,20	3.4.2.1.3.3	ND	
Transportation	ot		3.4.2.1.4	ND	
Field	f	8,21			
Personnel	fm	21,22		ND	
Facilities	ff	21	3.4.2.2.2		
Utilities	ffu	11	3.4.2.1.2	ND	
Materials for Maintenance	ffm	11	3.4.2.1.2	ND	
Materials for Test Equip.	fft	11	3.4.2.1.2	ND	

TABLE (12) (CONT.)
COST DECISION ELEMENTS
(STEP 6)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (6) $S_{(8)}$	Step (6) $S_{(7)}$
Field (cont.)					
Spares	fs	21,23			
Parts	fsp	23,24,25	3.4.2.2.3.1		31,700
Modules	fsm	23,26,27	3.4.2.2.3.2	475,500	69,300
Higher Assemblies	fsh	23,28,29	3.4.2.2.3.3	ND	
Depot	d	8,30			
Personnel	dm	30,31,32,33	3.4.2.3.1	NA	
Facilities	df	30,34	3.4.2.3.2		
Materials for Maintenance	dfm	11	3.4.2.1.2	NA	
Materials for Tes. Equip.	dft	11	3.4.2.1.2	NA	
Spares	ds	30,35			
Parts	dsp	35,36,37	3.4.2.3.3.1	NA	
Modules	dsm	35,38,39	3.4.2.3.3.2	NA	
Higher Assemblies	dsh	35,40,41	3.4.2.3.3.3	NA	
Transportation	dt	30,42			
Organization	dto	42,43		ND	
Field	dtf	42,44		ND	
Utilities	du	30,45			
Power	due	45,46	3.4.2.3.5	NA	
Buildings	dub		3.4.2.3.5	NA	
Line Item	l	30,47			
New	$N_L l$	47			170
Maintenance	$N_L LM$	47			2,650
MRS	$N_{RS} LR$	47		ND	
Debit and Credit	$N_R D$	47		ND	
Factory	y	8		NA	
Total Cost ($T_{(8)}$ and $T_{(7)}$)	--	1		475,500	104,020
Cost Difference ($\Delta T_{(8),(7)}$)		2		371,480	
Prefer T_7-(F_2)					

* NA=not applicable
** NS=not significant
*** ND=no difference

TABLE 12 (CONT.)
COST DECISION ELEMENTS
DETAILS - STEP 6

Cost Element	S (8)	S (7)
$C_{fsp}=N_{R-pf}\bar{C}_p$		
(4.3.6) (4.3.3.3)		
=(3170) (10)		31,700
$C_{fsm}=S_{mf}C_m$		
(Table 10) (4.3.3.3)		
=(462) (150)		69,300
$=S_{mf}C_m$		
(4.3.6) (4.3.3.3)		
=(3170) (150)	475,500	
$C_1 \;=N_L I$		
$=N_{Lp}I$		
(4.3.3.3)		
=(5) (34)		170
$+N_L LM$		
$=N_{Lm}LM$		
(4.3.3.3)		
=(15) (10) (19)		2,850
T	475,500	104,020
$\Delta T_{8,7}$	371,480	

TABLE (13)
COST DECISION ELEMENTS
(STEP 7)

Cost Element (C)	Subscript	Refer to: Equation	Refer to: Paragraph	Step (7): $A_{(9)}$	Step (7): $A_{(7)}$
Design	D	3		NA	
Fabrication	F	3		NA	
Installation	I	3		NA	
Manuals	M	3		NS	
Test Equipment	T	3,4			
Organization	To	4		ND	
Field	Tf	4		ND	
Depot	Td	4,5			
Standard	Tds	5		ND	
Special	Tdx	5		ND	
Tools and Fixtures	X	3,6			
Organization	Xo	6		ND	
Field	Xf	6		ND	
Depot	Xd	6,7			
Standard	Xds	7		ND	
Special	Xdx	7		ND	
Line Item Documentation	L	3		ND	
				$S_{(9)}$	$S_{(7)}$
Organization	o	8,9			
Personnel	om	9,10		ND	
Facilities	of	9,11			
Utilities	ofu	11	3.4.2.1.2	ND	
Materials for Maintenance	ofm	11	3.4.2.1.2	ND	
Materials for Test Equip.	oft	11	3.4.2.1.2	ND	
Spares	os	9,12			
Parts	osp	12,13,14	3.4.2.1.3.1	ND	
Modules	osm	12,17,18	3.4.2.1.3.2	ND	
Higher Assemblies	osh	12,19,20	3.4.2.1.3.3	ND	
Transportation	ot		3.4.2.1.4	ND	
Field	f	8,21			
Personnel	fm	21,22		ND	
Facilities	ff	21	3.4.2.2.2		2,100*
Utilities	ffu	11	3.4.2.1.2	ND	
Materials for Maintenance	ffm	11	3.4.2.1.2	ND	
Materials for Test Equip.	fft	11	3.4.2.1.2	ND	

TABLE (13) (CONT.)
COST DECISION ELEMENTS
(STEP 7)

Cost Element (C)	Subscript	Refer to: Equation	Refer to: Paragraph	Step (7): $S_{(9)}$	Step (7): $S_{(7)}$
Field (cont.)					
Spares	fs	21,23			
Parts	fsp	23,24,25	3.4.2.2.3.1	ND	
Modules	fsm	23,26,27	3.4.2.2.3.2		69,300
Higher Assemblies	fsh	23,28,29	3.4.2.2.3.3	ND	
Depot	d	8,30			
Personnel	dm	30,31,32,33	3.4.2.3.1	19,020	
Facilities	df	30,34	3.4.2.3.2	300*	
Materials for Maintenance	dfm	11	3.4.2.1.2	ND	
Materials for Test Equip.	dft	11	3.4.2.1.2	ND	
Spares	ds	30,35			
Parts	dsp	35,36,37	3.4.2.3.3.1	ND	
Modules	dsm	35,38,39	3.4.2.3.3.2	121,800	
Higher Assemblies	dsh	35,40,41	3.4.2.3.3.3	ND	
Transportation	dt	30,42			
Organization	dto	42,43		ND	
Field	dtf	42,44		25,000	
Utilities	du	30,45			
Power	dus	45,46	3.4.2.3.5	NS	
Buildings	dub		3.4.2.3.5	NS	
Line Item	l	30,47			
New	N_LI	47		ND	
Maintenance	N_LLM	47		2,850	
MRS	N_RLR	47		4,350	
Debit and Credit	N_RD	47		44,380	
Factory	y	8		NA	
Total Cost ($T_{(9)}$ and $T_{(7)}$)		1		217,700	71,400
Cost Difference ($\Delta T_{(9),(7)}$)		2		146,300	
Prefer T_7 (F_2)			*Ovens at $150		

TABLE 13 (CONT.)
COST DECISION ELEMENTS
DETAILS - STEP 7

Cost Element	S_9	S_7
$C_{ff} = C_{ffu} + C_{ffm} + C_{fft}$		
$= C_{ffm}$*		
(4.3.3.1)		
=(150) (14)		2,100
$C_{fsm} = S_{mf}\, c_m$		
(Table 10) (4.3.3.3)		
=(462) (150)		69,300
$C_{dm} = [(N_{R-md}/\mu_m) + (N_{R-hd}/\mu_d)]\, c_d$		
$= (N_{R-md}) (T_{SA})\, c_d$		
(4.3.6) (4.3.3.2) (3.6.2)		
=(3170) (1) (6)	19,020	
C_{dfm}* =	300	
$C_{dsm} = S_{md}\, c_m$		
(Table 10) (4.3.3.3)		
=(812) (150)	121,800	
$C_{dt} = C_{dto} + C_{dtf}$		
$= C_{dtf}$	25,000**	
$C_1 = N_L LM$		
$= N_{Lm} LM$		
(4.3.3.3)		
=(15) (10) (19)	2,850	
$+ N_{RL} LR$		
$= N_{Lm} LR$		
=(15) (10) (29)	4,350	
$+ N_R D$		
$= (N_{R-md}) D$		
(4.3.6) (4.3.3.3)		
=(3170) (14)	44,380	
T	217,700	71,400
$\Delta T_{9,7}$	146,300	

*Oven at $150 each
**Approximately

TABLE (14)
COST DECISION ELEMENTS
(STEP 8)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (8) $A_{(11)}$	Step (8) $A_{(10)}$
Design	D	3		NA	
Fabrication	F	3		NA	
Installation	I	3		NA	
Manuals	M	3		NS	
Test Equipment	T	3,4			
Organization	To	4		ND	
Field	Tf	4		ND	
Depot	Td	4,5			
Standard	Tds	5		ND	
Special	Tdx	5		450,000**	
Tools and Fixtures	X	3,6			
Organization	Xo	6		ND	
Field	Xf	6		ND	
Depot	Xd	6,7			
Standard	Xds	7		ND	
Special	Xdx	7		ND	
Line Item Documentation	L	3		ND	

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	$S_{(11)}$	$S_{(10)}$
Organization	o	8,9			
Personnel	om	9,10		ND	
Facilities	of	9,11			
Utilities	ofu	11	3.4.2.1.2	ND	
Materials for Maintenance	ofm	11	3.4.2.1.2	ND	
Materials for Test Equip.	oft	11	3.4.2.1.2	ND	
Spares	os	9,12			
Parts	osp	12,13,14	3.4.2.1.3.1	ND	
Modules	osm	12,17,18	3.4.2.1.3.2	ND	
Higher Assemblies	osh	12,19,20	3.4.2.1.3.3	ND	
Transportation	ot		3.4.2.1.4	ND	
Field	f	8,21			
Personnel	fm	21,22		ND	
Facilities	ff	21	3.4.2.2.2		
Utilities	ffu	11	3.4.2.1.2	ND	
Materials for Maintenance	ffm	11	3.4.2.1.2	ND	
Materials for Test Equip.	fft	11	3.4.2.1.2	ND	

TABLE (14) (CONT.)
COST DECISION ELEMENTS
(STEP 8)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (8) $S_{(11)}$	Step (8) $S_{(10)}$
Field (cont.)					
Spares	fs	21,23			
Parts	fsp	23,24,25	3.4.2.2.3.	ND	
Modules	fsm	23,26,27	3.4.2.2.3.	ND	
Higher Assemblies	fsh	23,28,29	3.4.2.2.3.3	ND	
Depot	d	8,30			
Personnel	dm	30,31,32,33	3.4.2.3.1	153,636	
Facilities	df	30,34	3.4.2.3.2		
Materials for Maintenance	dfm	1	3.4.2.1.2	NS	
Materials for Test Equip.	dft	11	3.4.2.1.2	NS	
Spares	ds	30,35			
Parts	dsp	35,36,37	3.4.2.3.3.1	[illegible],700	
Modules	dsm	35,38,39	3.4.2.3.3.2	ND	
Higher Assemblies	dsh	35,40,41	3.4.2.3.3.3	2,485,000	35,970,000
Transportation	dt	30,42			
Organization	dto	42,43		ND	
Field	dtf	42,44		ND	
Utilities	du	30,45		100,000*	
Power	due	45,46	3.4.2.3.5		
Buildings	dub		3.4.2.3.5		
Line Item	l	30,47			
New	N_{LI}	47		680	
Maintenance	N_{LM}	47		3,800	
MRS	N_{LR}	47		7,250	
Debit and Credit	$N_{R}D$	47		201,432	
Factory	y	8		NA	
Total Cost ($T_{(11)}$ and $T_{(10)}$)		1		3,433,498	35,970,000
Cost Difference ($\Delta T_{(11),(10)}$)		2		-32,536,502	
Prefer T_{11} - (D_2)					

*At $10,000 upper bound per year
**Three mock-ups @ ($50,000) (3). The factor of 3 is to assume cost of standard test equipment

TABLE 14 (CONT.)
COST DECISION ELEMENTS
DETAILS - STEP 8

Cost Element	A_{11}	A_{10}
C_{Tdx}	450,000**	
	S_{11}	S_{10}
$C_{dm} = [(N_{R-md}/\mu_m) + (N_{R-hd}/\mu_h)]\ c_d$		
$= [(N_{R-md}T_{SA}) + (N_{R-hd}T_A)]\ c_d$		
[(4.3.6) (4.3.3.2) + (4.3.6) (4.3.3.2)]		
(3.6.2)		
= [(3170) (1) + (14388-3170) (2)] 6	153,636	
$C_{dsp} = N_{R-pd}c_p$		
(4.3.6) (4.3.3.3)		
= (3170) (10)	31,700	
$C_{dsh} = S_{hd}c_h$		
(Table 9) (4.3.3.3)		
= (994) (2500)	2,485,000	
$= S_{hd}c_h$		
(4.3.6) (4.3.3.3)		
(14388) (2500)		35,970,000
C_{du}	100,000*	
$C_l = N_L I$		
$= (N_{Lp} + N_{Lm})\ I$		
(4.3.3.3)		
= (5+15) (34)	680	
$+ N_L LM$		
$= (N_{Lp} + N_{Lm})\ LM$		
(4.3.3.3)		
= (5+15) (10) (19)	3,800	
$+ N_{RL} LR$		
$= (N_{Lm}N_{Lh})\ (LR)$		
(4.3.3.3)		
= (15+10) (10) (29)	7,250	
$+ N_R D$		
(4.3.6) (4.3.3.3)		
= (14388) (14)	201,432	
T	3,433,498	35,970,000
$\Delta T_{11,10}$	-32,536,502	

TABLE (15)
COST DECISION ELEMENTS
(STEP 9)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (9) $A_{(12)}$	Step (9) $A_{(11)}$
Design	D	3		NA	
Fabrication	F	3		NA	
Installation	I	3		NA	
Manuals	M	3		NS	
Test Equipment	T	3,4			
Organization	To	4		ND	
Field	Tf	4		ND	
Depot	Td	4,5			
Standard	Tds	5		ND	
Special	Tdx	5		ND	
Tools and Fixtures	X	3,6			
Organization	Xo	6		ND	
Field	Xf	6		ND	
Depot	Xd	6,7			
Standard	Xds	7		ND	
Special	Xdx	7		ND	
Line Item Documentation	L	3		ND	

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	$S_{(12)}$	$S_{(11)}$
Organization	o	8,9			
Personnel	om	9,10		ND	
Facilities	of	9,11			
Utilities	ofu	11	3.4.2.1.2	ND	
Materials for Maintenance	ofm	11	3.4.2.1.2	ND	
Materials for Test Equip.	oft	11	3.4.2.1.2	ND	
Spares	os	9,12			
Parts	osp	12,13,14	3.4.2.1.3.1	ND	
Modules	osm	12,17,18	3.4.2.1.3.2	ND	
Higher Assemblies	osh	12,19,20	3.4.2.1.3.3	ND	
Transportation	ot		3.4.2.1.4	ND	
Field	f	8,21			
Personnel	fm	21,22		ND	
Facilities	ff	21	3.4.2.2.2		
Utilities	ffu	11	3.4.2.1.2	ND	
Materials for Maintenance	ffm	11	3.4.2.1.2	ND	
Materials for Test Equip.	fft	11	3.4.2.1.2	ND	

TABLE (15) (CONT.)
COST DECISION ELEMENTS
(STEP 9)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (9) $S_{(12)}$	Step (9) $S_{(11)}$
Field (cont.)					
Spares	fs	21,23			
Parts	fsp	23,24,25	3.4.2.2.3.1	ND	
Modules	fsm	23,26,27	3.4.2.2.3.2	ND	
Higher Assemblies	fsh	23,28,29	3.4.2.2.3.3	ND	
Depot	d	8,30			
Personnel	dm	30,31,32,33	3.4.2.3.1		19,020
Facilities	df	30,34	3.4.2.3.2		
Materials for Maintenance	dfm	11	3.4.2.1.2		300*
Materials for Test Equip.	dft	11	3.4.2.1.2	NS	
Spares	ds	30,35			
Parts	dsp	35,36,37	3.4.2.3.3.1		31,700
Modules	dsm	35,38,39	3.4.2.3.3.2	475,500	
Higher Assemblies	dsh	35,40,41	3.4.2.3.3.3	ND	
Transportation	dt	30,42			
Organization	dto	42,43		ND	
Field	dtf	42,44		ND	
Utilities	du	30,45			
Power	duo	45,46	3.4.2.3.5	ND	
Buildings	dub		3.4.2,3.5	ND	
Line Item	l	30,47			
New	N_LI	47			170
Maintenance	N_LLM	47			950
MRS	$N_{R_L}LR$	47			4,350
Debit and Credit	N_RD	47			44,380
Factory	V	8		NA	
Total Cost ($T_{(12)}$ and $T_{(11)}$)		1		475,500	100,870
Cost Difference ($\Delta T_{(12),(11)}$)		2		374,630	

*Ovens at $150

Prefer T_{11} (D_3)

TABLE 15 (CONT.)
COST DECISION ELEMENTS
DETAILS - STEP 9

Cost Element	S_{12}	S_{11}
$C_{dm} = [(N_{R-md}/u_m) + (N_{R-hd}/u_h)] c_d$		
$= (N_{R-md})(T_{SA})(c_d)$		
$= (3170)(1)(6)$		19,020
C_{dfm}		300*
$C_{dsp} = N_{R-pd}\bar{c}_p$		
$= (3170)(10)$		31,700
$C_{dsm} = S_{md}c_m$		
(4.3.6)(4.3.3.3)		
$= (3170)(150)$	475,500	
$C_1 = N_L I$		
$= N_{Lp} I$		
$= (5)(34)$		170
$+ N_L LM$		
$= N_{Lp} LM$		
$= (5)(10)(19)$		950
$+ N_{RL} LR$		
$= N_{Lm} LR$		
$= (15)(10)(29)$		4,350
$+ N_R D$		
$= (3170)(14)$		44,380
T	475,500	100,870
$\Delta T_{12,11}$	374,630	

TABLE (16)
COST DECISION ELEMENTS
(STEP 10)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (10) $A_{(11)}$	Step (10) $A_{(7)}$
Design	D	3			
Fabrication	F	3			
Installation	I	3			
Manuals	M	3			
Test Equipment	T	3,4			
Organization	To	4			
Field	Tf	4			
Depot	Td	4,5			
Standard	Tds	5			
Special	Tdx	5		450,000	
Tools and Fixtures	X	3,6			
Organization	Xo	6			
Field	Xf	6			
Depot	Xd	6,7			
Standard	Xds	7			
Special	Xdx	7			
Line Item Documentation	L	3			
				$S_{(11)}$	$S_{(7)}$
Organization	o	8,9			
Personnel	om	9,10			
Facilities	of	9,11			
Utilities	ofu	11	3.4.2.1.2		
Materials for Maintenance	ofm	11	3.4.2.1.2		
Materials for Test Equip.	oft	11	3.4.2.1.2		
Spares	os	9,12			
Parts	osp	12,13,14	3.4.2.1.3.1		
Modules	osm	12,17,18	3.4.2.1.3.2		
Higher Assemblies	osh	12,19,20	3.4.2.1.3.3		
Transportation	ot		3.4.2.1.4		
Field	f	8,21			
Personnel	fm	21,22			69,300
Facilities	ff	21	3.4.2.2.2		
Utilities	ffu	11	3.4.2.1.2		
Materials for Maintenance	ffm	11	3.4.2.1.2		
Materials for Test Equip.	fft	11	3.4.2.1.2		

TABLE (16) (CONT.)
COST DECISION ELEMENTS
(STEP 10)

Cost Element (C)	Subscript	Refer to Equation	Refer to Paragraph	Step (10) $S_{(11)}$	Step (10) $S_{(7)}$
Field (cont.)					
Spares	fs	21,23			
Parts	fsp	23,24,25	3.4.2.2.3.1		
Modules	fsm	23,26,27	3.4.2.2.3.2		
Higher Assemblies	fsh	23,28,29	3.4.2.2.3.3		350,000
Depot	d	8,30			
Personnel	dm	30,31,32,33	3.4.2.3.1	153,636	
Facilities	df	30,34	3.4.2.3.2		
Materials for Maintenance	dfm	11	3.4.2.1.2		
Materials for Test Equip.	dft	11	3.4.2.1.2		
Spares	ds	30,35			
Parts	dsp	35,36,37	3.4.2.3.3.1		
Modules	dsm	35,38,39	3.4.2.3.3.2		
Higher Assemblies	dsh	35,40,41	3.4.2.3.3.3	2,485,000	
Transportation	dt	30,42		115,[illegible]	
Organization	dto	42,43			
Field	dtf	42,44		100,000	
Utilities	du	30,45			
Power	due	45,46	3.4.2.3.5		
Buildings	dub		3.4.2.3.5		
Line Item	l	30,47			
New	$N_I I$	47			
Maintenance	$N_I LM$	47			
MRS	$N_{RI} LR$	47		7,250	
Debit and Credit	$N_R D$	47		201,432	
Factory	Y	8			
Total Cost ($T_{(7)}$ and $T_{(11)}$)		1		3,512,318	419,300
Cost Difference ($\Delta T_{(7),(11)}$)		2		3,093,018	
Prefer $T_{--}(F_{-})$					

TABLE 16 (CONT.)
COST DECISION ELEMENTS
DETAILS - STEP 10

Cost Elements	A_{11}	A_7
C_{Tdx}=(Table 14)	450,000	
	S_{11}	S_7
$C_{fsm}=S_{mf}C_m$ (Table 11) =(462)(150)		69,300
$C_{fsh}=S_{hf}C_h$ (Table 11) =(140)(2500)		350,000
$C_{dm}=[(N_{R-md}/\mu_m)+(N_{R-hd}/\mu_d)]C_d$ =[(3170)(1)+(14,388)(2)]6	153,636	
$C_{dsh}=S_{hd}C_d$ (Table 14) =(994)(2500)	2,485,000	
C_{dt} =(25,000)(14,388/3170) (Table 13)	115,000*	
C_{du} =(Table 14)	100,000	
$C_1=N_{RL}LR$ (Table 14)	7,250	
$+N_RD$ (Table 14)	201,432	
T	3,512,318	419,300
$\Delta T_{11,7}$	3,093,018	

*Estimated by means of parts to module ratio.

4.3.10.2.2 Summary of Analysis - Table 17 shows a summary of the analysis. The preferred location is field level. The maintenance procedure consists of RAFM both for the higher modular assemblies (for the BTC-black boxes) and for modules.

4.3.11 Model Validity - The original model validation approach was based on the assumed validity of the model developed in reference 1. The method of validation originally planned was designed around a conventional approach of direct comparison of actual and predicted cost.

The revised model, based on demonstrable differences, in both acquisition and support cost, required a different approach to validation. This comes about since the model does not presuppose a specific type of statistical correlation, and assuming that a systematic analysis, detailed to the cost implications involved may be performed. Additionally, since the technique is directed to establishing the combination of where to perform maintenance in conjunction with whether to perform maintenance, it is recognized that the technique is directed to establishing a best maintenance plan based on the characteristic of the system.

Thus the important aspect of validity related to the model, and associated technique of application, is whether the technique will permit selection of the least costly alternative. To this end, the technique is self-fulfilling, thus where the difference in resource cost between two alternatives is large and the cost error associated with each alternative relatively small, by comparison, the choice among alternatives is clear. Where the difference between alternatives is small and the relative error associated with the alternatives large enough to mask to cost savings, two courses of action are possible: accept either alternative or increase the level of detail evaluation. Thus the question of technique (model) validity is reduced to seeking error sources and associated magnitudes of error.

Section 7.3 of this report contains an examination of general error sources. The following sections discuss the technique validity associated with this particular application of the model.

4.3.11.1 Comparisons of Predicted and Measured Cost Differences - Table 18 provides a comparison of cost differences resulting from differences in predicted and measured reliability and maintainability for each alternate support plan. Cost entries preceded with a minus sign indicate overestimation of the cost, using predicted parameter values. Non-signed costs indicate underestimation of that amount. (The exception to this rule is ΔT_{jii} both adjusted and predicted.)

4.3.11.2 Method of Establishing Differences - The method of establishing the cost difference, caused by failure rate error, was to find the difference between the measured and predicted

TABLE 17
SUMMARY OF ALTERNATIVES

Echelon	Step	Field Req.	Field Dis.	Depot Req.	Depot Dis.	T_i	Differential Cost $\Delta T_{j,i}$	Amount (dollars)
F_2	5	h				T_7	$\Delta T_{7,6}$	-35,514,520
F_1			h			T_6		Prefer F_2
F_3	6	h	m			T_8	$\Delta T_{8,7}$	371,480
F_2		h				T_7		Prefer F_2
F_4	7	h		m		T_9	$\Delta T_{9,7}$	146,300
F_2		h				T_7		Prefer F_2
D_2	8			h		T_{11}	$\Delta T_{11,10}$	-32,536,502
D_1					h	T_{10}		Prefer D_2
D_3	9			h	m	T_{12}	$\Delta T_{12,11}$	374,630
D_2				h		T_{11}		Prefer D_2
D_2	10			h		T_{11}	$\Delta T_{11,7}$	3,093,018
F_2				h		T_7		Prefer F_2

Decision Rule: $\Delta T_{j,i} > 0$; prefer i, If $\Delta T_{j,i} < 0$; prefer j

TABLE 18
MEASURED COST DIFFERENCES

Cost Error Source	Step 5		Step 6		Step 7	
	F_2	F_1	F_3	F_2	F_4	F_2
C_f						
C_{frm}						
C_{fs}						
C_{fsp}	-3,500			-3,500		
C_{fsm}			-52,500			
C_{fsh}		-4,170,000				
C_d						
C_{dm}					48,660	
C_{dt}						
C_1						
$N_R D$					-4,900	
Total Cost Error	-3,500	-4,170,000	-52,500	-3,500	43,760	0
Predicted Total	455,480	35,970,000	475,500	104,020	217,700	71,400
Adjusted Total	451,980	31,800,000	423,000	100,520	261,460	71,400
$T_{j,i}$ (Adjusted)	-31,348,020		322,480		190,060	
$T_{j,i}$ (Predicted)	-35,514,520		371,480		146,300	
$T_{j,i-A} - T_{j,i-P}$	4,166,500		-49,000		43,760	

TABLE 18 (CONTINUED)
MEASURED COST DIFFERENCES

Cost Error Source	Step 8		Step 9		Step 10	
	D_2	D_1	D_3	D_2	D_2	F_2
C_d						
C_{dm}	41,244			48,660	41,244	
C_{ds}						
C_{dsp}	-3,500			-3,500		
C_{dsm}			-52,500			
C_{dsh}		-4,170,000				
C_{dt}					-2,234	
C_1						
$N_R D$	-23,352			-4,900	-23,352	
Total Cost Error	14,392	-4,170,000	-52,500	40,260	15,658	0
Predicted Total	3,433,498	35,970,000	475,500	100,870	3,512,318	419,300
Adjusted Total	3,447,890	31,800,000	423,000	141,130	3,527,976	419,300
$T_{j,i}$(Adjusted)	-28,352,110		281,870		3,108,676	
$T_{j,i}$(Predicted)	-32,536,502		374,630		3,093,018	
$T_{j,i-A}-T_{j,i-P}$	4,184,392		92,760		15,6[illegible]8	

failure rate of the BTC. The predicted failure rate was overestimated by approximately 10 percent. This error was carried over to the modules. An error of three hours was made in the predicted mean-time-to-repair of modules. This major error was caused by neglecting the oven-bake cycle necessary to reseal the module. The predicted time was one hour.

4.3.11.3 Consequences of Error - Discard cost error is proportioned to the error in failure rate estimation for high demand items; however, granting that procurement is spread over time, this would be a self-correcting cost.

An error in repair cost may be significant when heavy dependence on depot is planned. This results from the linear relation between significant depot costs, failure rate, and repair time. The error in module repair time was not sufficient to affect either personnel (field or organization) or the quantities of spares required.

In summary, most of the error occurred in estimation of:

a. Depot repair costs as a result of an error in estimation of repair rate.

b. Discard assembly and module costs as a result of an error in failure rate estimation.

(For the present case, since the usage rate is high, the cost error would not have been sufficient, since the purchase of spares would be spread over time and based on usage experienced.)

4.3.11.4 Results - Examining table 18, it can be seen that not one step in the comparison process would have been reversed. Step 10, the final step, is almost exact with

$$\Delta T_{ji-A} - \Delta T_{jii-P} = \$16,000$$

from individual differences (ΔT_{jii}) of over $3,000,000. In no case did the difference between costs, resulting from using predicted failure and repair rates, affect the repair/discard decision.

4.3.11.5 Extrapolation to Discard at Failure Maintenance - For high demand systems, where lifetime usage exceeds a procurement purchase of one year's supply, the predicted cost of discard will closely approach the experienced cost, because of the buy as required policy that becomes established.

For low demand systems, the initial buy may be expected to exceed the lifetime usage and, thus, leftover spares will be available. These spares, however, will be anticipated in that both purchase quantity and predicted usage will be available.

Based on sites visited and the foregoing application of the module, the cost error in discard at failure maintenance will lie with the error associated with expected failure rate of the item considered.

For predicted low usage items, less than one year procurement buy exceeds lifetime usage. Excessive unreadiness will be experienced where the usage has been underestimated, and unused spares will result where the usage has been overestimated. For specific levels of unreadiness, the cost error, at worst, will vary directly with the error in predicted usage.

4.3.11.6 Analysis of Variation of Number of Parts per Module - It is appropriate to consider cost ramifications using the module size as measured by parts per module as an independent variable, without regard to standardization.

There are approximately 1000 electronic parts in the FCA-BTC. Assume the module cost is proportional to the number of parts on the module and use $150.00 as a base cost for 30 part module. Table 15 gives cost, number of module types, and aggregate failure rate per site as a function of module sizes based on field repair of modules (S_7).

TABLE 19

PARTS PER MODULE

Number of Parts	Types	Cost	λ^*/hr.
10	100	50	.000044
20	50	100	.000088
30	33	150	.000132
40	25	200	.000176
50	20	250	.000220
75	13	375	.000330
100	10	500	.000440

Table 16 gives the cost incurred for discard and repair cases.

Present Module Configuration Cost

Types	Spares	X14 Sites	Depot	Parts	Total
15	33	69,300	3,360	31,700	104,360

The total above clearly shows (neglecting acquisition cost variables) that based on the parts per-module principle:

a. The minimum discard module cost occurs with smallest number of parts per module. (10)

b. The minimum repair module cost occurs at (20) parts per module.

c. Comparison of the cost in two above with the cost incurred for the present modules in the BTC shows that an optimum cost based on parts per module is not optimum since it does not consider cost savings to be achieved through standardization by module type.

Since the total cost of spares, either discard or repair, increases monotonically with the duration of depot pipeline time, it is not necessary to perform analysis of parts per module variation for each alternative considered in the foregoing section.

TABLE 20

DISCARD VS. REPAIR

Discard

Parts/Mod.	Spares Cost	Depot Cost M_L(I+10M)	Total Cost
10	158,500	22,400	[180,900]
20	317,000	11,200	328,200
30	475,500	7,467	482,967
40	634,000	5,600	639,600
50	792,500	4,480	796,980
75	1,188,700	2,910	1,191,610
100	1,585,000	2,240	1,857,240

Repair

Parts/Mod.	Cost Site	X14 Site	Part Cost	Depot Cost	Total Repair Cost
10	5,000	90,000	31,700	22,400	144,100
20	5,000	90,000	31,700	11,200	[132,900]
30	9,900	126,000	31,700	7,467	165,167
40	10,000	140,000	31,700	5,600	177,300
50	10,000	140,000	31,700	4,480	176,180
75	10,000	140,000	31,700	2,910	174,610
100	10,000	140,000	31,700	2,240	173,900

5. FEASIBILITY OF REDESIGN OF BTC FOR DAFM

5.1 Modifications

By postulating a fault isolation capability to the module level (lower level than present assemblies), without increasing down-time, three alternatives are available. (This isolation and re-pair is to be done at organization only.)

a. Availability of higher skill level personnel.

b. Built-in fault isolation equipment which is capable of determination of the faulty module.

c. Auxiliary test equipment which permits isolation to the module level. It is presumed that there would not be a significant decrease in operational readiness.

5.2 Discussion

5.2.1 Alternative a - Alternative a is clearly impractical at this time, since it would require realignment of USAF personnel policy.

5.2.2 Alternative b - Alternative b is virtually impossible with the present BTC because of space limitations of the F105D aircraft. The BTC could have been designed originally to include fault isolation equipment, but that would have meant additional equipment, increased spares, possible additional personnel to maintain the built-in test equipment, and an increased acquisition cost.

5.2.3 Alternative c - Alternative c would appear, on the surface, to be the only feasible alternative. However, the following factors must be considered.

a. Field maintenance personnel cost would be unaffected, since already the minimum of personnel are assigned and must remain for assembly repair not involving modules (approximately 75 percent of failures).

b. Subassembly spares would be unaffected.

c. Assembly cost would be unaffected.

d. Test equipment cost would be increased in the order of $25,000 per maintenance team (based on module tester at depot which does not have all fault isolation capabilities required for flightline maintenance) or a total of $1,400,000, assuming no spares, for the 14 airfields.

5.3 Conclusion

It is concluded that none of the modifications proposed is feasible.

6. IMPACT OF MICROMINIATURIZATION ON RAFM-DAFM

6.1 General

At present, integrated circuits are being introduced into new systems/equipments. With this taking place, some comments are offered concerning the potential impact on RAFM/DAFM planning.

6.2 Advantages of Integrated Circuits

Circuit reliability improvement is imminent. The failure rate associated with integrated circuits presently approaches the failure rate of military transistors.

Costs of integrated circuits are being reduced. Integrated circuits are already available at the cost level of high reliability transistors. With increased demand and production (through improved process control), this cost is anticipated to be further reduced. Moreover, competition among integrated circuit manufacturers has increased significantly in the last few years.

6.3 Results

From the advantages of integrated circuits as indicated above, it would seem that the state of art equipments could be made more reliable at reduced cost. Historically, most new equipments are directed toward improving the state of art; thus, it may be anticipated that:

a. The potential increase in equipment reliability will be partially offset by an increase in circuitry.

b. The continued increased complexity of new systems will require new skill fields (this will tend to increase available direct labor at the using locations).

c. Additional built-in self-test devices will increase equipment up-time, but will create additional failures. This will partially offset increased reliability at the circuit level.

d. Extended flexibility of module design will be permitted. Integrated circuit application will increase the design alternatives in selection of module size and methods of standardizing module types. This may permit module size variation having little difference in acquisition cost but significant difference in support cost.

e. There may be an increase in unused spares over the lifetime of an equipment. This may come about as a result of high reliability modules and an increased diversification of module types.

6.4 Repair of Modules With Integrated Circuits

There presently exist several packaging methods for integrated circuits. Some require optical aids for soldering the leads on printed boards, whereas others provide positive orientation and keying of the integrated circuits, along with pressure type contacts. This aspect of integrated circuits is in such a state of flux as to not warrant any meaningful conclusions in terms of impact on the repair echelons.

7. SUMMARY

7.1 General

The findings of the program dictate the need for a comprehensive analysis to be performed in order to establish either discard or repair philosophy along with the optimum module size.

7.2 Results

7.2.1 General - The results of this program are:

a. A practical and valid method has been developed, commensurate in detail to the importance of the decision required.

b. The method may be used as a design tool rather than a design constraint.

c. Exercise of the method encourages the generation of alternate design configurations, each of which may be evaluated with respect to cost implications.

7.2.2 Specific - Among the specific findings of this study are the following.

a. The decision of where to perform the maintenance is equally as important and necessary as the decision of whether to repair; this is equally applicable to provisioning.

b. Tables for computing unreadiness reflect significant economic advantages to be achieved using the unreadiness principle to establish a spares complement. This results from the fact that spares usage is spread over an interval of time. Sparing to a confidence level will require invariably more spares and it does not provide an estimate of expected unreadiness.

c. For the DAFM philosophy, minimum spares buy will necessitate leftover spares at system life completion; only in a high usage system will the quantity bought approximate usage.

7.3 Model Source of Error

7.3.1 General - The following comments are directed to potential sources of error incorporated in the methodology proposed. In many cases, a sensitivity analysis may be performed to establish the magnitude of error in cost estimation as a result of a prediction error in a model variable. Tables 4 and 5 and reference 4 are devices which will serve this end for manning and sparing.

A major point to bear in mind is that a support network is designed for a system/equipment (it is not a statistical entity), and can adapt to changing circumstances as well as make self-fulfilling predictions. Examples of this are depot pipeline time which is controllable and field turnaround time which is also controllable.

The amount of error introduced into the cost analysis from the various inputs will depend generally upon the characteristic of the specific system under analysis. In general, the error output of the cost model will be less than the error input. As a worse case, the cost error will be linearly related to the error input, and this will occur for high demand systems; i.e., high failure rate and long maintenance times.

For low demand systems, a significant error in inputs (failure rate, service times) will generally not influence the cost predictions.

Where prediction errors are in the same direction for RAFM-DAFM (e.g., over estimate of failure rate), the effect of the error tends to cancel out, since it is the difference in cost which is being investigated.

7.3.2 Support Cost

7.3.2.1 Manning Cost Error Sources - The major sources of error in manning will be due to errors in failure and maintenance rates. Where self-sufficiency dictates a manning relatively independent of work load, this source of error becomes negligible. Where a significant amount of work is performed at a location, a sensitivity analysis may be performed to establish potential cost error. Refinement in predictions may be made if significant differences are found. For the depot, the labor cost prediction error varies linearly with failure rate or repair time error.

7.3.2.2 Spares Cost Error Sources - The spares cost errors will be as follows:

a. Discard

For high demand spares, the error associated with spare cost over the life of the equipment will not be significant as the purchased quantity can be adjusted to meet demand experienced.

For low demand spares, the initial buy may be significantly more than the expected demand over the lifetime of the equipment. A sensitivity analysis may be performed to estimate the magnitude of error introduced in the cost.

b. Repair

The error in repairable spares cost may derive from the following sources:

(1) Depot Turnaround Time

Between systems, the average time may vary significantly. This time is controllable through high value item concept and is a major determinant of spares where depot repair is used. Note that the repair time is not usually significant.

(2) Field and Organization Repair Time

For both field and organization there are tradeoffs between personnel and spares in meeting operational requirements. The cost error associated will arise from error in prediction of repair and failure rates. Sensitivity analysis may be used to evaluate the potential magnitude of any cost error involved.

7.3.3 Acquisition Cost Error - This source of error is controllable in that the estimated cost provided by the hardware manufacturer becomes a self-fulfilling prediction and may be controlled by contractual commitment. However, two potential cost errors may arise, as follows.

a. Procurement Cost of Spare

Item cost is intimately bound up in production quantity. If more than one production run is necessary, the cost associated with the item based on the first production run will generally provide an over-estimate of the item cost.

b. Test Equipment Error Sources

(1) Charging for already expended funds, e.g., government-furnished equipment.

(2) Cost of special test equipment not contractually committed in the initial contract for the system/equipment development.

7.3.4 Model Constants - Depot constants and military pay are relatively stable. These constants, it is anticipated, will be updated with time.

7.3.5 Cost Sources Not Anticipated to Influence Decision - The following cost sources are not anticipated to have a significant effect on the RAFM/DAFM decision.

a. Manuals

The cost of manuals will remain relatively unaffected between alternatives.

b. Facilities and Utilities

These costs are important in determining whether to repair a higher level of assembly. Cost of facilities and utilities for module repair, given assembly repair, will not be significant between alternatives.

c. Training Costs

These costs will not generally be reflected in the RAFM/DAFM decision given assembly repair.

7.3.6 Other Error Sources

a. Expected System/Equipment Life

Although the present deployment planning anticipates systems with lifetime expectancies of 10 years, some systems may become quickly outdated whereas others may extend considerably beyond a 10-year life cycle. This feature may weigh heavily in favor of RAFM.

b. Expected Usage

The usage objective capability of the system/equipment may be significantly different than the expected usage. Systems must be manned and spared for anticipated deployment conditions as opposed to training conditions.

7.4 Conclusions

The RAFM-DAFM decision must be based on recognition of the military mission and its related support environment. Thus, the same equipment in different support environments could justify different RAFM in one environment and DAFM in the other. Based on the analysis performed, conclusions are as follows.

a. Personnel idle time will generally be necessary. This results from:

   (1) Mission requirement necessitating standby personnel

   (2) Pipeline personnel being required to replace skilled personnel leaving the service.

   (3) The random nature of the arrival of work requiring available personnel to insure low unreadiness.

b. Test equipment for module repair will generally be available through requirements of higher levels of assembly maintenance.

c. Based on equal performance systems (functional performance and operational readiness achievable), acquisition cost will weigh heavily in the optimum design-support configuration; thus, optimum cost cannot be based on support cost analysis alone.

7.5 Recommendations

It is recommended that:

a. The methodology developed under this program be implemented. To accomplish this, it is recommended that the following steps be taken:

   (1) Development of a specification requiring the recommended analysis to be implemented on proposed systems.

   (2) Development of permissible error bounds by contractors required to use the methodology.

b. Sparing methods should be based on unreadiness principles developed in appendix III. These principles are equally applicable to existing systems.

c. Additional model applications to existing systems should be conducted. The increased practicality of application of the technique, along with the potential cost savings, justifies this recommendation.

d. The responsibility of module repair for the F105D-FCS-BTC should be assigned to field maintenance together with baking ovens. This recommendation is based on the findings of section 4.

e. An increased emphasis should be placed on the development of methods to reduce unreadiness end item equipment. The methods should include investigation of increased retentivity of personnel, methods of training, and built-in and auxiliary test equipment.

f. An analysis of existing depot procedures should be performed, directed to trading off the high utilization of personnel presently existing at depot levels with increased spares that are consequently necessitated.

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EXPLANATION OF TERMS

1. Acquisition Cost - The total cost incurred to the government to place an item(s) in initial operation in the field. (This includes both government (e.g., GEEIA) and contractor cost (e.g., Band D.)

2. Black Box - A discrete, physical component (sub-unit) of an operational unit to which may be identified or assigned a rate of failure and a time to repair, and which may be moved from one location to another independent of the next higher level of assembly.

3. Constraint - Any restriction or condition which bounds the value a variable or parameter may assume; e.g., manning must not exceed 100 men. For example, number of men available and training facilities available frequently act as constraints on the training program which can be undertaken to obtain a particular number of men with particular skills.

4. Design Alternative - An alternate design layout of modules and higher modular assemblies, types, and sizes within an equipment.

5. Design/Support Alternative - An alternative involving a change in a module configuration and/or a maintenance plan.

6. Discard at Failure Maintenance (DAFM)

7. Downtime - Time during which the operational unit or subsystem is not available for operational use because of maintenance or other factors.

8. Echelon - A maintenance level consisting of one or more maintenance shops responsible for performing certain specified maintenance tasks; e.g., organizational, field, and depot. These levels serve to break down the functions of maintenance into smaller, more manageable units, and designate responsibilities for performing tasks in different units.

9. Exponential Distribution - A probability distribution having the form

$$P(t=T) = \frac{1}{\mu} e^{-T\mu}, \quad \mu > 0, \; T \geq 0, \quad \text{frequency distribution}$$

$$P(t=T) = 1-e^{-T\mu} \quad \text{cumulative distribution}$$

where the mean and standard deviation are both μ^{-1}.

In this report the time between failures of equipment and time to repair failures both are assumed to be distributed exponentially.

10. Failure Rate - Number of failures (non-scheduled interruptions of operation) of the item per unit operational time.

11. Levels of Assembly - A rough measure of the size and/or complexity of a subdivision of an equipment. Except for the lowest level of assembly, the part, each level of assembly is made up of several members of lower levels of assembly. Below are listed, from high to low level of assembly, two examples of members of various levels of assembly. (See also figure 1.)

Aircraft	Radar set
Engine	Rack
Oil pump	Drawer
Cylinder assembly	Printed-wiring board assembly
Gasket	Resistor

Line Item - An item of supply which is listed in a Federal Stock Catalog, and to which is assigned a Federal Stock Number.

12. Maintainability - Ease of repairing an item given a particular combination of maintenance equipment and replacement parts and sub-assemblies. Generally measured in terms of mean-time-to-repair (MTTR) or its inverse repair rate (μ).

13. Maintenance Channel - Combination of men and equipment required to perform a particular task or groups of tasks.

14. Maintenance Plan - See Support System.

15. Manning Requirements - A detailed breakdown of the manning required to meet specified operational requirements of a new weapon system.

16. Maximum Allowable Downtime - Time that a system may remain inoperative for the performance of a maintenance task.

17. Mean Time Between Failures (MTBF) - Average time per item between occurrence of failures. May be estimated by dividing operating time by the number of failures occurring during this time. It is the reciprocal of the mean failure rate (λ).

18. Mobility - A measure of how quickly the system/equipment can be relocated.

19. Module Configuration - A particular design layout of modules within an equipment.

20. Module Size - The average number of parts per module.

21. Operational Readiness - The average percent of on-line units which are operational at a given time when they are intended to be.

22. Operational Requirements - A statement of operational readiness level required of the operational units, total operational hours, capability of the operational units during a specified period of time, and the number of missions required of the operational unit during the specified period.

23. Operational Unit - A unit of equipment which is capable of operating alone; can be assigned a mission, and is the basis for a calculation of operational readiness.

24. Parameter - A quantity to which may be assigned arbitrary values, as distinguished from a variable, which assumes only values that the form of the function makes possible. For example: the operational readiness specified. Values may be arbitrarily assigned.

25. Personnel Availability - A measure of resources of men and skills that are available outside the system to man the system.

    Pipeline Spares - Reparable items which are furnished to a maintenance echelon to provide a spare parts stock.

26. Preventive Maintenance - The care and servicing by user personnel for the purpose of maintaining equipment in satisfactory operating condition by providing for systematic inspection and correction of incipient failures either before they occur or before they develop into a major failure.

27. Primary Duty Assignment - The type of duty to which personnel are allocated during their normal on duty shift period, and which is directly connected with the operation and maintenance of the weapon system.

28. Queue - A waiting line of units which require some form of service (normally maintenance repairs).

29. Repair at Failure Maintenance (RAFM)

30. Repair Channel - See Maintenance Channel.

31. Repair Rate - The reciprocal of the average time spent per channel in repairing an item excluding delays such as "wait for spare part to be delivered," etc.

32. Skill Levels - The classification system used to rate maintenance personnel as to their relative abilities to perform maintenance.

33. Spare(s) (noun) - Systems, equipments, black boxes or modules kept in reserve, unused until needed to replace a similar failed item so that there will not be a reduction of the number of operational systems of equipments. When the failed item is repaired, it becomes a spare if it is not needed to provide the desired number of operational systems or equipments. Do not confuse with spare parts.

34. Spare Parts - Non-repairable items at lowest level of assembly held to replace similar items whose failure caused failure of a higher level of assembly.

35. Subsystem - Major functional equipment or group of equipments of operational unit or support system, essential to operational completeness.

36. Service Rate - The reciprocal of mean time to restore an item to operable status, including waiting, and travel time.

37. Support Alternative - An alternative maintenance plan.

38. Support System - The maintenance personnel, equipment, spares, and spare parts as organized into shops, echelons, with assigned responsibilities.

39. Unreadiness - State of an equipment or system not being available to perform its primary mission. The complement of Operational Readiness.

40. Utilization Factor - A ratio, the failure rate of an item, divided by the repair rate of the item. Queuing tables are usually based on the utilization factor, since it is invariant with changes in number of operational items and repair channels.

41. Variable - A quantity that may assume a succession of values that need not be distinct, but which can only assume those values that the form of the function makes possible.

42. Workload - Average manhours of effort of a particular skill caused by the operation of an item or group of items when they are operated according to specified requirements.

MAJOR SYMBOLS

A = Acquisition Cost - see figure 3 for cost elements.

B = Operating time per maintenance shift hour.

C = Cost designator - see figure 3 for detailed breakout of cost elements.

D = Debit and Credit Cost - used for inventory accountability at the depot.

d = Subscript used to designate depot.

E = Total number of equipments per location.

E_T = Total number of equipments.

F_S = Number of field sites.

f = Subscript used to designate field.

H = Maintenance shift hours per day.

I = Line item entrance cost.

J = Calendar days per month.

L = Expected equipment life.

M = Cost per year of maintaining a line item in the supply system.

m = Subscript used to designate module.

N_L = Number of line items introduced into the supply systems.

N_{RL} = Number of line items repaired by depot.

N_{R-d} = Total expected repair demands at the depot.

N_{R-f} = Total expected repair demands at the field.

N_{R-o} = Total expected repair demands at the organization.

P = Utilization Factor - a ratio formed by dividing an equipment failure rate by its repair rate.

Q = Operational Unreadiness - the mean number of equipments not operable divided by total number of equipments.

R	= Cost per year of maintaining a stock item on the Material Repair Schedule (MRS).
r	= Operating time per unit calendar time.
S	= Support and Operation Cost - see figure 3 for a detailed breakout.
s	= Designation of spares. When used, level of assembly and location are indicated by subscripts.
T	= Total Cost.
Z	= Number of non-working days during a month.
λ	= Failure rate per operating hour, reciprocal of mean time between failure (MTBF).
μ	= Repair rate, reciprocal of mean time to repair (MTTR), or service rate, depending on context.

See paragraph 4.3.9 for symbols used in manning.

APPENDIX I

FIELD DATA

(Data contained in this appendix is UNCLASSIFIED)

1. INTRODUCTION

This appendix consists of a review of the information that was received on the SAGE sites, summary of what was learned at the Air Materiel Areas visited, and summary of the FCS maintenance at Seymour Johnson AFB.

2. SAGE SITES

There were seven sites visited in all. Listed below are the types of information that were obtained from each of the organizations for the various major equipments.

	A	B	C	D	E	F	G
AN/GKA-5							
Organization	A	B	C	D	E	F	G
Site Questions	X	X			X		X
Work Order Prefix Data	X	X	X		X		X
Labor Distribution Code Data	X	X	X		X		
AN/FPS-35							
Site Questions	X	X			X		
Work Order Prefix Data	X	X					
Labor Distribution Code Data	X						
AN/FST-2							
Site Questions	X	X			X		
Work Order Prefix Data	X	X		X	X	X	
Labor Distribution Code Data	X	X		X	X		

Figure I-1 reproduces the site questionnaire. Table I-1 summarizes the information gathered from the field by means of the site questionnaire. The answer to question 26 gives the various equipments considered under the major equipment heading, e.g., AN/GKA-5.

As called for in AFM 66-1, the work order number serves as a base for reporting and control procedures. The first part of the work order number, the prefix, is a two character alphabetic code. The first character denotes the type of equipment. The second character of the prefix identifies the type of work to be done, e.g., B equals unscheduled maintenance. Table I-2 shows the various work order prefixes grouped by equipment type and organization. Table I-3 shows the proportion, in percent, of the several work order prefixes to the total of all work order prefixes for each organization and for each equipment.

SITE QUESTIONS

Date:

Station:

Equipment being evaluated:

1. Number of equipment per site?

2. On what schedule do you operate?

3. What spares do you have for equipment?

   a. All parts? Yes ___ No ___ If no, which ones?

   b. All modules? Yes ___ No ___ If no, which ones?

   c. All assemblies? Yes ___ No ___ If no, which ones?

   Comment:

4. What do you do with failed modules or assemblies?

   Discard ______ Repair ______

   Proportion _________ Proportion _________

FIGURE I-1. SITE QUESTIONNAIRE

5. How is the decision to repair or discard made?

6. Where do you send NRTS items?

7. What are the most common reasons for not making a repair?

8. What is the observed equipment failure rate?

9. What is the average mean-time-to-repair?

10. What is the average repair cycle time?

11. What percentage of technician time is spent on paper work?

FIGURE I-1. SITE QUESTIONNAIRE (CONT.)

12. How many men comprise the maintenance crew at present?

AFSC	Rank	Qty.	Longevity	Living On Off	Married Yes No (Dep)	Time Charged To Equip. (in %)

12a. What is the authorized Table of Organization?

AFSC	Rank	Quantity

FIGURE I-1. SITE QUESTIONNAIRE (CONT.)

13. What is the total available number of direct labor manhours per week?

14. What percentage of technician time is spent on administrative duty, such as guard duty, quarters maintenance, etc.?

15. What training does a technician receive prior to being assigned to maintenance team?

    a. Name of course(s): b. Length of course(s):

16. What is the total number of officers associated with equipment?

17. Who performs test equipment preventive maintenance?

    ( ) Local Technicians ( ) Mobile Repair Team

    ( ) ________________

18. Who performs test equipment corrective maintenance?

    ( ) Local Technicians ( ) Mobile Technicians

    ( ) ________________

FIGURE I-1. SITE QUESTIONNAIRE (CONT.)

19. What is the frequency of preventive maintenance on test equipment?

20. When using test equipment, is it used On Line or Off Line?

21. Do you use the supplied special test equipment (such as module tester etc.) most of the time?

22. a. Do you make repairs on modules if special test equipment is down?

    b. How?

    c. What do you do if you do not have the parts to repair an item?

23. Do you usually have the spare parts you need for repair?

FIGURE I-1. SITE QUESTIONNAIRE (CONT.)

24. How many men are assigned per maintenance shift?

25. Do they (or he) have specific assignments per shift?

26. Data on split of repair time among various equipments. (AFTO's)

FIGURE I-1. SITE QUESTIONNAIRE (CONT.)

TABLE I-1

SUMMARY OF FIELD FINDINGS

Quest	Equipment	AN/G[illegible]A-5				AN/FPS-35			AN/FST-2		
	Organization	A*	B	E	G	A	B**	E**	A	B	E
1	No. of equip./site	1	1	1	1	1	1	1	1	1	1
2	Schedule of oper.	24 hr/day	24 hr/day	24 hr/day	24 hr/day	24 hr/day	24 hr/day	24 hr/day	24 hr/day	24 hr/day	24 hr/day
3	Spares a. All parts If no, which ones?	No V,F	No V,F,Q,CR	No CR,Q,F	No NA	No Less than 100 LI	No Few R&C,V	No V,F,I,K,C,R	NA	No E,CR,V,Q,C	No Q,CR,V,K,F
	b. All type modules If no, which ones?	No 75% of total	No 80% of total	No 97% of total	Yes	No None	No 3% of total	No 50 types	NA	No 95% of total	No 60% of total
	c. All assemblies If no, which ones?	No NA	No NA	No NA	No [illegible]	No Approx 8 of 400	No 1% of total	No 150 (est.)	NA	No NA	No NA
4	What do you do with failed modules, etc?	Repair 100%	Repair 100%	Repair 100%	Turn over to Mat. Cont.	Repair 100%	Repair 100%	Repair 100%	Repair 100%	Repair 100%	Repair 100%
5	How is the decision to repair or discard made?	NA	NA	NA	No discard	NA	NA	No discard	No discard	NA	NA
6	Where do you send NRTS items?	Mat. Cont.	Mat. Cont.	Mat. Cont.	Mat. Cont.	Mat. Cont.	Mat. Cont.	Rome Depot	Mat. Cont.	Mat. Cont.	Mat. Cont.
7	What are the most common reasons for not making a repair	1. Test Equip 2. Parts	1. Skill level 2. Parts 3. Test Equip	NA	1. Skill level	1. Parts 2. Skill level	1. Test Equip 2. Parts 3. Special tools	1. Parts	1. Parts	1. Parts 2. Test Equip	NA
8	Obs. failure rate (per hour)	0.0025 (equipment)	0.0018 (equipment)	0.016 (equipment)	0.00019 (system, est)	0.0099 (system, est)	(Mostly operable)	(operable 1 mo. out of 6)	0.0073 (equipment)	0.011 (equipment)	0.029 (equipment)
9	Obs. mean-time-to repair (man-hours)	2.2	1.4	1.8	2.5 (est.)	6.1	NA	NA	3.6	2.8	2.1
10	Mean repair cycle Priority NORS (days)	NA	never	NA	3 (est)	3	NA	NA	2 hr (est)	2 day to 3 wk.	3
	A (days)	2	5	NA	NA	3	8	NA	NA	2 da. to 3 wk.	2
	B (week)	2	2	2	3	NA	4	NA	NA	1 wk to 1 mo.	NA
11	What time is spent on paper work (hr)?	NA	0.5	0.5	0.5	1.0	0.5	1	0.5	1.0	1.0

NA-Information not available   *Not air conditioned   LI= Line Item   ** Manned by FAA

TABLE I-1 (cont.)

SUMMARY OF FIELD FINDINGS

Quest.	Equipment	AN/GKA-5				AN/FPS-35			AN/FST-2		
	Organization	A*	B	E	G	A	B**	E**	A	B	E
12	How many man are in maintenance crew?										
	Level										
	E-1										
	E-2 (W-4)						(2)	(1)			
	E-3 (W-11)		6	11	6		(4)	(5)	1	1	3
	E-4 (GS-7)						(1)				
	E-5 (GS-9)	12	8	5	5	16	(11)	(10)	8	7	5
	E-6										
	E-7	3	1	2		1	(8)	(10)			
	E-8 (GS-12)						(5)	(5)	2	2	1
	E-9 (GS-13)			1	1	1	(1)	(1)			
	Total	15	15	19	12	18	(32)		11	10	9
12a	How many men are authorized?										
	Level										
	E-3 (W4.11)	3	3	3	3	5	(5)	(5)	2	2	2
	E-5 (GS-9)	10	10	10	10	9	(4)	(4)	5	4	4
	E-7 (GS-11)	3	3	3	3	7	(16)	(16)	2	2	2
	E-9 (GS-12)	1	1	1	1	1	(5)	(5)			
	(GS-13)						(1)	(1)			
	Total	17	17	17	17	22	(31)	(31)	9	8	8
13	What is the total available amount of direct MH/wk.?	222	249	325	NA	635	NA	NA	190	206	98
14	% of tech. MH/wk. spent on other than direct MH	66	39	44	NA	28	NA	NA	44	44	67
15	What training does a technician receive prior to being assigned to team?										
	a. Course	Electron theory	Basic Electronics	1. Grd. Comm Rep 2. AN/GKA-5	1. AN/GKA-5 2. AN/GKA-5	1. AC & W.	1. FAA, Okl. City	Min. req. GS-9 5 yr trade and education exp	1. Elec Dig. Data Proc. Rep.	1. Elec Dig. Data Proc. Rep.	1. Elec Dig. Data Proc. Rep.

NA-Information not available *Not air conditioned MH-Manhour *Manned by FAA

TABLE I-1 (cont.)

SUMMARY OF FIELD FINDINGS

Quest.	Equipment	AN/GKA-5				AN/FPS-35			AN/FST-2		
	Organization	A*	B	E	G	A	B**	E**	A	B	E
	b. How long?	NA	36 wk	1. 38 wks. 2. 6 wks. (RCA)	1. 10 wks. (AF) 2. 6 wks. (RCA) (1 or 2)	1. 32 wks.	2. 5 to 7 mo. GS-9		1. 42-45 wks.	1. 46 wk.	1. 43 wk.
1	Officers?	0	0	0	0	0	NA	NA	NA	NA	0
1	Test Equip PM	PMEL, Bolling AFB	Local & Mobile Rep.	PMEL, Suffolk AFB	PMEL, McGuire AFB	PMEL, Common Local Tech. Spl.	Local tech. Comm PMEL, Spl.	PMEL	PMEL	PMEL	PMEL
1	Test Equip CM	(see above)	PMEL Olmstead AFB	(see above)	(see above)	(see above)	(see above)	PMEL and Local tech.	PMEL	PMEL	PMEL
1	Freq. of test equip PM	NA	2 hrs./mo.	NA	NA	6 mo.	6 mo.	NA	NA	5 or 6 mo.	PMEL
20	Is Test Equip used on-line or off-line	Off Line	Both	On Line	PM-On Line CM-Off Line	Both	On Line	Both	50% On-Line 50% Off-Line	Both	On Line
21	Use of special Test Equipment	For receiver	No	Yes	Yes	Yes	No	50% usage	No	Use only SIF test	No
22	a. Do you repair modules if special test equipment is down?	NA	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes
	b. How?	NA	Std. Test Equip.	Std. Test Equip.	Std. Test Equip.	Std. Test Equip.	Std. Test Equip.	NA	Std. Test Equip.	Std. Test Equip.	Std. Test Equip.
	c. No part to repair an item?	NA	Order through material cont.	Order through material cont.	Order through material cont.	Cannabalize from other ch.	Order from mat. cont.	Order from mat. cont.	Order from mat. cont.	Order from mat. cont.	Order from mat. cont.
2	Spare parts needed?	not for modules	Yes	Yes	Yes	No, see 22c	40%	No	Yes	Yes	Yes
24	How many men assigned per shift?	2 (min.) Day-4	2	2	2	3 Day-6	5 Day-10	6	2 Day-7	2 Day-3	1 Day-6
2	Do they have specific assignments?	Yes	Yes	Yes PMI-60%	Yes PMI-35%	Yes	Yes	Yes	Yes	Yes	Yes
26	Data on split time? ( )	NA				NA					
	TDDL		10		30 (est.)						
	AN/GRT-2		55								
	AN/GRR-7		30	most of time spent	70 (est.)						
	AN/GRC-27		5								

NA-Information not available *Not air conditioned MH=Manhour *Manned by FAA

TABLE I-1 (cont.)

SUMMARY OF FIELD FINDINGS

Quest.	Equipment	AN/GKA-5				AN/FPS-35			AN/FST-2		
	Organization	A*	B	D	G	A	B**	D**	A	B	D
26 cont	AN/FST-2								NA	90	100
	AN/FST-1								NA		
	AN/FPS-35						63	80			
	AN/FPS-8						6	10			
	AN/UPX-514						2				
	Microwave Link							10			
	Spl. Proj. & Training						29			10	

NA-Information not available *Not air conditioned MH-Manhour *Manned by FAA

TABLE I-2

WORK ORDER PREFIX DATA

Equipment	Type of Maintenance	Service EA		Unscheduled EB		Special Inspection EC		Scheduled ED, EE, EF		Depot ER		Shop ES		TO Compliance ET, EW		Total		Time	Notes
	Organization	MH	Units	MH	Units	MH	Units	MH	Units	MH	Units	MH	Units	MH	Units	MH	Units	Months	
AN/GKA-5	A	1	1	25	10	35	22	343	409	0	0	27	4	0	0	431	446	5	
	B	3	1	35	9	9	4	336	287	0	0	0	0	0	0	383	301	4	
	C	142	265	141	19	495	1876	348	293	0	0	0	0	0	0	1128	2453	5	
	E	9	6	87	26	101	239	347	406	0	0	3	2	0	0	547	679	5	
	G	0	0	43	12	31	7	462	370	0	0	0	0	0	0	536	389	5	
	Subtotal	155	273	333	76	671	2148	1836	1765	0	0	30	6	0	0	3025	4268		
AN/FPS-35	A	5553	571	1976	335	1174	158	3162	7897	2603	42	68	21	547	12	15083	9036	5	
	B	39	10	161	117	2	1	107	157	0	0	25	22	0	0	334	307	5	Manned by FAA
	Subtotal	5592	581	2137	452	1176	159	3269	8054	2603	42	93	43	547	12	15417	9343		
AN/FST-2	A	781	154	2183	248	98	43	2109	1176	0	0	80	74	319	2	4570	1697	5	
	B	101	15	307	28	28	12	974	1531	0	0	11	16	818	2	2239	1604	4	
	D	1	1	776	214	424	231	2542	2793	0	0	101	74	219	2	4063	3315	5	
	E	162	53	611	166	90	67	1621	2600	0	0	54	64	320	4	2858	2954	5	
	F	563	52	1301	256	303	86	24	36	0	0	291	173	0	0	2482	603	4	
	Subtotal	1608	275	4178	912	943	439	7270	8136	0	0	537	401	1676	10	16212	10173		
All	Total	7355	1129	6648	1440	2290	2746	12375	17955	2503	42	660	450	2223	22	34654	23784		

TABLE I-3
WORK ORDER PREFIX RATIO DATA

Organization	AN/GKA-5 MH	AN/GKA-5 Units	AN/FFS-35 MH	AN/FFS-35 Units	AN/FST-2 MH	AN/FST-2 Units	TOTAL MH	TOTAL Units
ES-Shop/Total (%)								
A	6.26	0.90	0.45	0.23	1.75	4.36	0.87	0.89
B	0	0	7.49	7.17 *	0.49	1.00	1.22	1.72
C	0	0					0	0
D					2.49	2.32	2.49	2.32
E	0.55	0.29			1.89	2.17	1.67	1.82
F					11.72	28.69	11.72	28.69
G	0	0					0	0
Subtotal	0.99	0.14	0.60	0.46	3.31	3.94	1.90	1.89
EB-Unscheduled/Total (%)								
A	5.80	2.42	13.10	3.71	25.89	14.61	15.85	5.30
B	9.14	3.00	48.20	38.11 *	13.71	1.75	17.02	6.96
C	12.68	0.77					12.68	0.77
D					19.10	6.46	19.10	6.46
E	15.90	3.83			21.38	5.62	20.50	6.61
F					52.42	42.45	52.42	42.45
G	8.02	3.08					8.02	3.08
Subtotal	11.01	1.78	13.86	4.84	25.77	8.96	19.18	6.05
ED,EE,EF - Scheduled/Total (%)								
A	79.58	91.70	20.96	87.39	46.15	69.30	27.95	84.82
B	87.73	95.35	32.04	51.14 *	43.50	95.45	47.94	89.29
C	30.85	11.94					30.85	11.94
D					62.56	84.25	62.56	84.25
E	63.44	59.79			56.72	88.02	57.80	82.74
F					0.97	5.97	0.97	5.97
G	86.19	95.12					86.19	95.12
Subtotal	60.69	41.35	21.20	86.20	44.84	79.98	35.71	75.49
(EA,EC,ER,ET,EW)/Total (%)								
A	8.36	4.98	65.49	8.67	26.12	11.73	55.33	8.99
B	3.13	1.65	12.27	3.58 *	42.30	1.80	33.82	2.03
C	56.47	87.29					56.47	87.29
D					15.85	6.97	15.85	6.97
E	20.11	36.09			20.01	4.19	20.03	8.83
F					34.89	22.89	34.89	22.89
G	5.79	1.80					5.76	1.80
Subtotal	27.31	56.73	64.34	8.50	26.08	7.12	43.21	16.57

*MANNED BY FAA

Table I-4 shows the total work order prefix manhours versus the total manhours available. Tables I-3 and I-4 can be used to give an estimate of how much work goes into the various types of direct labor. For example, for the AN/GKA-5, the total work order prefix manhours is about 5% of the manhours available (table I-4). However, only about 12% of the work involves either unscheduled and shop maintenance as identified by work prefixes (table I-3). These numbers are multiplied together and result in less than 1% of the work being spent on unscheduled and shop maintenance.

3. AIR MATERIEL AREA VISITS

3.1 ROAMA

3.1.1 Maintenance Policy - It became apparent that present practices and policies for maintenance and logistic support of ground C-E-M equipment appear to differ significantly from those considered in RADC-TDR-63-140. Key features of these differences are as follows.

a. For Air Force ground C-E-M especially, repairable modules are repaired at the field or organization level whenever possible. This may be done as a part of direct repair of equipment or as repair of a defective module which was replaced by a good spare in the repair of the equipment. For example, a rough estimate was made that about 65% of GKA-5 board repairs were made in the field by field personnel. The primary reasons for not making repairs at organization and field are that:

   (1) Necessary test equipment and/or skills are not available.

   (2) Necessary repair parts are not available.

b. Even where discard at failure is planned, spare parts may be ordered incurring line-item costs the same as would arise from an RAFM policy. Insufficient spares or other defects in the logistic support system have led to shortages of boards intended as DAFM. Consequently, these boards have become "supply critical" items and have been repaired both in the field and at the MDA on an emergency basis.

c. Boards shipped to the depot for repairs may be batched so that paperwork costs per repair may be much less than would be indicated by the RADC-TDR-63-140 model. This model assumes that there is more or less individual handling of boards and associated paper work or, at

TABLE I-4

WORK OPDER PREFIX MANHOURS VS. TOTAL MANHOURS AVAILABLE

Organization	PREFIX MH	PREFIX Months of Data	PREFIX MH/Month	AVAILABLE MH	AVAILABLE Months of Data	AVAILABLE MH/Months	(MH/MONTH) Pre./Av. %
			AN/GKA-5				
A	431	5	86.2	14,189	5	2837.8	3.03
B	383	4	95.8	10,576	6	1762.7	5.43
C	1128	5	225.6	18,187	5	3637.4	6.20
E	547	5	109.4	12,552	5	2510.4	4.36
Subtotal	2489	19	131.0	55,504	21	2643.0	4.96
			AN/FPS-35				
A	15,083	5	3016.6	19,071	5	3814.2	79.09
			AN/FST-2				
A	4570	5	914.0	7288	5	1457.6	62.71
B	2239	4	559.8	9622	6	1603.7	34.91
D	4063	5	812.6	6938	5	1387.6	58.56
E	2858	5	571.6	6392	5	1278.4	44.71
Subtotal	13,730	19	722.6	30,240	21	1440.0	50.18
			Total				
A	20,084	15	1338.9	40,548	15	2703.2	49.53
B	2622	8	327.8	20,198	12	1683.2	19.47
C	1128	5	225.6	18,187	5	3637.4	6.20
D	4063	5	812.6	6,938	5	1387.6	58.56
E	3405	10	340.5	18,944	10	1894.4	17.97
Total	31,302	43	728.0	104,815	47	2230.1	32.64

MH=Manhours

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TABLE I-5

WORK ORDER PREFIX MANHOUR PER UNIT DATA

Organization	AN/GKA-5	AN/FPS-35	AN/FST-2	Total
	Total - MH/Unit			
A	0.97	1.67	2.69	1.75
B	1.27	1.09*	1.40	1.34
C	0.46			0.46
D			1.23	1.23
E	0.81		0.97	0.94
F			4.12	4.12
G	1.38			1.38
Total	0.71	1.65	1.59	1.46
	ES - Shop - MH/Unit			
A	6.75	3.24	1.08	1.77
B	ND	1.14*	0.69	0.95
C	ND			ND
D			1.36	1.36
E	1.50		0.84	0.86
F			1.68	1.68
G	ND			ND
Subtotal	5.00	2.16	1.34	1.47
	EB - Unscheduled - MH/Unit			
A	2.50	5.90	4.77	5.37
B	3.89	1.38*	10.96	3.27
C	7.53			7.53
D			3.63	3.63
E	3.35		3.68	3.64
F			5.08	5.08
G	3.58			3.58
Subtotal	4.38	4.73	4.58	4.62
	ED, EE, EF - Scheduled - MH/Unit			
A	0.84	0.40	1.79	0.59
B	1.17	0.68*	0.64	0.72
C	1.19			1.19
D			0.91	0.91
E	0.85		0.62	0.65
F			0.67	0.67
G	1.25			1.25
Subtotal	1.04	0.41	0.89	0.69

ND = NO DATA   * Manned by FAA   MH = Manhours least, that the average cost of handling and paper work for all items repaired at the depot provides a good picture of the handling cost per board however it is handled.

d. A significant fraction of line items, in terms of those required to repair boards, is already in DOD inventory.

e. Most items must be acquired in quantities providing one year's supply, except that minimum order value must be $40. Order costs are large; one estimate was $160. Consequently, significant order costs would be incurred under current purchasing practices for DAFM. Where individual relatively "high-demand" parts are "inexpensive," $40 may buy more than one year's supply of the part where total demand is small. Line-item and ordering costs are significant only when total demand is small.

f. Modules are generally sent to Stationary Repair Activities (SRA) (i.e., depot) because of some special facility such as clean room, silver plating, removal and replacement of coating capability (e.g., epoxy), and such, or presence of an expensive item to test equipment or a mock-up.

3.1.2 Line Item Costs - The working estimate of cost per new line item was $1,000, but there was no mention of this value referring to its source as a specific amount. However, the constituents were mentioned and were described as including costs incurred in documentation by the manufacturer as well as the government. The $1,000 was described as an average cost per new line item. The total cost of processing all parts, including those not new line items, is divided by the number of new line items.

Further investigation required to determine the magnitude of reduction of total cost resulting from DAFM elimination of parts and from use of "standard" parts already having Federal Stock Numbers.

3.1.3 Other Item of Note

a. Prime responsibility for module repair is the Sacramento AMA.

b. Mobile Depot Activity (MDA) performs repairs on modules which "supply critical" and will perform maintenance on others if it has necessary test equipment and/or mock-ups.

c. The Technical Services Branch Inventory Management Division, Directorate of Material Management (RONUSB), said that cost of labor for board repairs on-site (field and organization) was considered to be negligible because "the maintenance men have to be there anyway."

d. AFLCM 65-1, "Electronic Maintenance and Repair Policy, presents some of the current AF thinking with respect to repair-discard alternatives. Among the key points made are:

(1) Ground equipment is more suitable for RAFM than airborne.

(2) If 75% or more repairs are possible at the field, no provision is made for repair at the depot.

(3) At least 400 items per year are required to justify establishing depot capability.

3.2 SMAMA

3.2.1 Costs

3.2.1.1 Depot Accounting Practices

3.2.1.1.1 Work Centers - A work center consists of men and equipment engaged in reconditioning or repair of a collection of similar items. At SMAMA, one was concerned with C-E-M, another missiles, another airborne radar; for example, the FPS-35, FST-2, and several other equipments were the responsibility of a single work center.

Costs are accumulated by work center rather than by product so that there is no direct means of determining costs attributed to a specific task or group of tasks unless these constitute the whole of the work performed by the work center. This is not the case in the relevant work centers at SMAMA.

The data will provide average costs per hour of direct labor in a work center, including certain "overhead" charges as well as wages. Where this is combined with estimates and/or standard times for performing tasks, a cost of repair may be derived. This cost, in general, will be sufficiently accurate for the purpose of the model.

3.2.1.1.2 Directorates and Offices - There are four directorates at SMAMA: Material, Maintenance, Supply and Transportation, and Procurement and Production Planning. These are the major AMA operating organizations. In addition, there are seven offices which report to the AMA commander and provide services for the directorates. Among these are Comptroller (includes account and data services), Personnel, and Administration.

Charges are accumulated for work centers within each of these organizations but there is no formal charging one directorate for services provided by any of the other directorates or offices (this is the most straightforward way of avoiding double counting, and such). As a consequence, cost estimates for relevant services must be obtained from the officer or directorate which furnishes them.

3.2.1.1.3 Overhead - Overhead as counted in accounting at SMAMA more nearly represents expenditures made than expenses incurred. The major elements and proportion of overhead charged to the Electronics and Armament shop are:

a. Personnel benefits such as leave, pensions, and such, about 37%.

b. Material, both direct and indirect about 16%.

c. Management and management services, about 31%.

d. Travel, about 16%.

These are average values for all electronics and armament maintenance. The values for module repair appear to be significantly lower than average in two particular categories. Travel is negligible, and branch and other management is lower since both of these categories have major contributions due to various detachments which do not perform depot level maintenance on modules.

Excluded from overhead or other charges to directorate accounts are:

a. Rent or ammortization of buildings.

b. Heat, light, and other utilities.

c. Building maintenance.

Where these are applicable, estimates must be obtained outside of the using directorate.

Personnel benefits received by an individual are approximately in proportion to his wages so that this element of overhead charge can be reasonably estimated as a percentage of direct labor costs.

Material costs are impractical to derive from this source because the diversity in items repaired leads to diversity in the material-to-labor cost ratio within a work center. Parts cost data is better obtained from documents such as IPB and PPB's.

Direction accounts for approximately 20% of E&A charges for direction and management services charges,but only about one quarter of this is attributable to depot operation, the balance being from detachments.

Industrial Engineering is a large enough organization to have its size vary according to workload. This variation is not necessarily proportional to the workload,because the amount of effort associated with a particular task depends on its complexity rather than its frequency for a given type of study. However, the tasks expected to have low frequencies are studied less intensively than more common ones so that there does not appear to be significant error in assuming proportionality.

A similar situation is found in production control where approximately 1/4 to 1/3 of the time is spent on hard-to-get items. These should rarely be encountered under planned RAFM scheduled for the depot (they might be common where most repairs are made at field or organization). In compensation, it should be noted that module repairs on the average take less time than other maintenance actions performed in the shop. The average overhead charge for production control appears to be slightly higher than the incremental cost would be for typical module repair; however, it does appear to be close enough to meet the standard of accuracy attainable in many other factors in the decision. Greater accuracy would require extensive, expensive study which does not appear to be justified at the moment.

Quality Control cost estimation involves similar complications and, similarly, use of the average appears to be justified as giving an adequate estimate.

Relevant travel charges are so rare as to be negligible.

3.2.1.2 Transport - Where local inventories are set for immediate needs rather than for full equipment life, transport of inventory replenishments will be about the same for RAFM and DAFM so that this aspect can, in general, be ignored. However, the cost of sending defective modules to the depot for repair will be incurred under RAFM but not DAFM and therefore must be considered as being one of the real cost differences between the alternatives.

According to Code STT,the means of transport used in normal peacetime operation are, under current practice:

a. Within Zone of Interior

Railway Express
Air Express
LOGAIR (only when most convenient)

b. From outside Zone of Interior

MATS to ZI with LOGAIR continuation
Commercial Airlines

Railway Express, Air Express, and other commercial rates are readily obtainable from the appropriate organizations. Code STT was unable to supply equivalent charges for MATS and LOGAIR, but he felt that this data was available from Code SGT at Headquarters AFLC.

3.2.1.3 Inventory and Handling Within the Depot - Because the accounting system is work center oriented, costs for performing particular tasks are not normally accumulated. As a consequence estimates must be derived, at best, on an averaging basis unless extensive special studies are undertaken. Standard costs provide an alternative estimate.

Our particular interest in the cost of handling failed modules was described to Code SME. He reviewed available data and found that this data would provide only average costs which would include some items differing by a factor of 100 or more in bulk and/or cost and/or lot size. Since these differences could conceivably result in averages differing significantly from the values appropriate to our problem, it was decided that it would be better to provide no data at all rather than data which might be misleading.

Estimates of the various costs can be made from S-153 reports according to procedures of Appendix II of RADC-TDR-63-140. These estimates will have all of the disadvantages cited in the data which is available at SMAMA above. In addition, they will not have the advantage of the breakdowns made in the setting of standard costs.

3.2.1.4 Repair Labor - Costs are accrued on a work center basis rather than by product. Thus, estimates of average direct labor and overhead costs are available for the work center, but actual labor costs and/or hours for particular tasks, are not. Industrial Engineering develops standard time for common tasks. Tasks having high frequency are given detailed intensive time-study. Those with lower demands are given less intensive study to the extent that standard times may be developed by analysis of the task rather than by time study. In this case, standard times for particular operations are estimated by comparison with times developed from tasks which have been studied intensively.

The FST-2, GKA-5, and FPS-35 have very low frequencies of demand for module repair at the depot level. Standards for these,where they exist, are estimates of the type described above.

The foreman of the group which was assigned repair of FST-2 modules (a very small part of its total effort) said that the standard times were fairly accurate when appropriate test equipment and technical data were available,but that,lacking these tools, actual times were greater than standards by factors of two or three on the FST-2.

3.2.1.5 Test Equipment - These costs varied greatly among different operating equipments,depending on the complexity of the operating equipment, the variety of modules, the extent to which the test equipment has automatic or semi-automatic features, and,probably,the quality and quantity of effort that went into test equipment design.

Module testers for the FST-2 had a listed cost of about $18,000.

Eight pieces of test equipment for the APS-95 cost about $400,000. All of them were actually used not only for module repair but also for repair of larger assemblies. However, the technicians felt that not all of them would be required if no modules were tested.

The only special test equipment of significance used on the FPS-35 was an FPS-35 (less antenna). This would be necessary for the repair of higher levels of assembly whether or not modules were repaired.

From this it can be seen that there may be a wide range of possible costs for test equipment for modules repair at the depot. It should be further noted that there are significant potential trade-offs between test equipment and repair time.

3.2.1.6 Work Facilities - The cost of space and facilities is relevant only for those not used also for other depot level maintenance. Thus, a bench or less may often be involved. Where significant equipment is involved only in repair of modules, the cost of facilities is dependent on the type as well as the space required. Among the major considerations are:

a. Shielding for RFI and cross-talk.

b. Additional and special air conditioning requirements.

c. Venting, plumbing, and such needed for special processes such as plotting, incapsulation and the like.

To determine the relevant cost differences among alternative decisions, an analysis must be made of the conditions peculiar to the particular equipment. The analysis must consider what will be necessary for depot level maintenance irrespective of RAFM-DAFM decisions and what facilities are already available.

New construction cost of buildings without special features was estimated to be about $20 per square foot by Code MEIA.

3.2.2 Test Equipment - Fault isolation on failed modules and check-out of repaired ones were performed either on special test equipment or in actual systems (except that dummy loads are used instead of antennas). Which of the techniques is used may have a significant effect on test equipment costs and on times and costs to repair. Most of the people involved in making repairs indicated a preference for special test equipment if it could provide a good simulation of the actual operating conditions; however, they often were dissatisfied for a variety of reasons with special test equipment which they did have.

Major disadvantages cited in use of actual equipment were:

a. Large systems are too expensive (e.g. APS-59).

b. Not all circuits are utilized in some applications of some digital modules.

c. It is difficult to determine where the problem is in an analogue equipment involving feed-back loops (e.g. single side-band transmitters).

d. Access to test points is poor or non-existent and extenders are not practical (or, at least, not available).

Disadvantages of special test sets were, necessarily, directed toward specific items since the ideal test set would offer no problems. Among those mentioned were the following:

a. Tests sometimes invalid (i.e. a module which checked out satisfactorily in a test set would cause unsatisfactory operation of an equipment) (e.g. F106 computer tester).

b. Test set not modified to match equipment modifications (e.g. FST-2).

c. Insufficient technical data about the tester (e.g. F106 computer tester) so that external equipment can be used to make additional measurements on problem modules.

d. Too expensive and complicated for small simple systems.

An explanation for the deficiencies of test equipment is that often much less effort is spent designing test equipment compared to that spent on the operating equipment and that the difference shows in both performance and reliability.

Much of the equipment used to test modules is also used in the testing of higher levels of assembly and, typically, there is only one of a kind. In such instances, use of DAFM rather than RAFM would not result in any reduction in test equipment costs.

Incremental cost of test equipment for repair of modules at the depot may range from zero to hundreds of thousands of dollars. There generally will be trade-offs between cost of test equipment and time to repair. These considerations merit comprehensive study of the peculiarities of equipments being designed and/or brought into the Air Force inventory.

3.2.3 Standardization - A technical representative of Collins Radio pointed out the complications which may arise when a company establishes modules which are standard across a product line. Collins has done this for single-sideband radio where the typical module is common to half a dozen quite different sets. RCA is doing this for its data processing OGE in the Minuteman system. Undoubtedly the practice will be followed by these and other companies in appropriate situations.

Where such standardization across a product line is planned, RAFM-DAFM costs should be compared for the sure order quantity and for its effect on follow-on orders for the particular equipment or for other items making extensive use of its modules. A consequence of this may be that the RAFM-DAFM decision will be dependent upon the manufacturer who wins since one might design using parts already in the supply system whereas another might use ones which are new in some important respect and would require that many line items be added to the catalog.

3.2.4 Purchasing and Support Policy - Selection of an effectively non-repairable design for use in DAFM policy requires that contractual assurance be made of availability and cost of replacement modules.

Serious porblems have arisen when this protection has not been obtained. For example, many modules in the OA-2325/FPS-6 and OA-2325A/FPS-6 cannot practically be repaired. They are encased in cans which are assembled by soldering and then filled with polyurethane foam. The can is necessarily destroyed in its removal, and replacement cans are not available.

Where non-repairable modules (or any non-standard part) are used, the initial procurement should include provisions for obtaining needed spares in terms of prices and delivery times, with penalties imposed if delivery time is not met. If such provisions are not made, the cost of DAFM using non-repairable modules may involve not only very high cost of replacement parts, but also extensive downtime due to lack of parts (modules).

The option of procuring lifetime requirements of spares for costly items such as electronic modules is economically impractical because of the great excess over actual demand which must be procured for most items in order to assure that there will not be serious shortages in any but a very small fraction of systems. Prediction of demand is still filled with uncertainties which frequently are a factor of 10 or more.

Even where provisions are made for re-order of replacement modules, serious shortages can result if inventory policy does not provide adequate protection for low volume items. Present policies which remove items from inventory after various periods of no demand can destroy the value of good initial planning for low demand items. At present, for example, items are removed from bench stock after 3 to 6 months without demand. Removal from depot inventory requires a more extended period without demand (generally 1 to 3 years).

It should be noted that the present policy of removal from bench stock after 90 days without demand is not compatible with the assumptions of the model in RADC-TDR-63-140, nor would it be with any model directed toward achieving a high operational readiness of the system. For example, consider the rule for "Calculation of Field (or Organizational) Cost of Spare Discard Modules" (Section IV, A8, esp. d), which says that if the estimated demand over the life of the equipment is less than one, the number spared should be one. Thus, the rule might call for initial provisioning of a module to be one, even if there is less than one chance in ten that it will ever be needed. By current practice, such items would be removed from bench stock in the first 3 to 6 months if they were not used and might be removed from depot inventory if there were no use in 3 years.

Present policies appear to act detrimentally toward achievement of high operational readiness and may lead to extensive use of high priority order and delivery procedures. The choice between RAFM and DAFM may have significant effect on the operational readiness of the system because of differences in demand rates for modules and individual parts.

3.2.5 <u>Specific Equipment Repair</u>

3.2.5.1 F106 Computer - Modules are checked on a tester which generally works adequately, but it does not always identify bad boards. A further complication arises from marginal performance where a board may work in one set but not in another.

The test set was designed so that someone with little knowledge of electronics could operate it to identify most defects. However, the T. O. provides little useful information about what is actually going on in the test. Consequently, the tester cannot be fully utilized by a skilled electronics technician when the cookbook approach does not successfully lead to identification of the defective part(s).

The boards are not coated although they are used in aircraft. Accessibility keeps repair time low, the standard time being 1.25 hours for repair of a board having 30 to 40 parts. In addition,routinely, all solder connections are checked and resoldered as necessary. Standard time for this latter task is 0.5 hour but, according to the foreman, this is frequently exceeded by large margins and seems to be significantly below average time taken.

3.2.5.2 AN/FPS-35 - Major test equipment was a complete equipment except for antenna. Most of the electronic maintenance was done on multiple failures which presented some special problem in the field. Some were NRTS parts in the field. In general, the failures involved assemblies larger than the typical module. Many of the repairs are mechanical rather than electronic. Few of the repairs were relevant to the study.

Personnel manning the system averaged about two, with a maximum of four. Assignments are according to demand of work load. A significant portion of working time is spent maintaining the equipment itself. Records do not provide a breakdown of how time is spent.

3.2.5.3 Missile Electronics Repair - Some of the modules studied here were small ones encapsulated in polyurethane foam. Access to the parts to be replaced was obtained by carving away the foam with dissecting knives, otherwise, fault isolation and correction followed the normal pattern. Reencapsulation was done in a separate room because of fumes and fire hazard.

Major equipment used in the process consisted of:

	Cost	Weight
Special molds	$6,500	20 est.
Potting oven	635	190
Mixing booth and venting	1,500 est	400 est.
*Large sealed oven	2,080	1000 est.
*Vacuum pump	375	50 est.

Cost of the encapsulated modules being repaired averaged around $650.
The equipment indicated by asterisks are used for large modules in cans filled with inert gas.

3.2.5.4 AN/FST-2 - Repairs on AN/FST-2 modules are rare. The shop foreman estimated that there were about 15 to 20 during the year ending 7-31-64. The foreman makes the repairs himself in his free time and keeps no records of time spent on the job. He estimated that it took about three hours to repair modules which could be tested on the special test equipment, but 9 to 10 hours (6 to 8 if there were a high demand) for those which could not be tested on the special tester. Standard times for module repair average about 3 hours.

The foreman said that he had heard of a modification to the special tester which would permit all modules to be checked, however, he has been unable to obtain necessary drawings, instructions, and such.

Special test equipment for the AN/FST-2 costs a total of about $18,000 (including the TS-1288 at $10,580 and the TS-1167 at $5,000).

In contrast, for the TD-285 Multiplexer, a mock-up is used as test equipment. The foreman said that he would be glad to turn it in if he could obtain a good module tester. He noted that one of the draw-backs of using actual equipment is that in multi-circuit modules having multiple applications, not all circuits on the module are used in all applications.

The foreman estimated that AFTO 210 or 211 forms or other failure data from the field were received with less than 5% of the items that came to his shop for maintenance.

3.2.5.5 AN/APS-95 - Modules of the AN/APS-95 are initially coated. To remove defective parts, the technicians burn through the coating. They do not recoat the modules at the moment because the work center lacks facilities.

The special test equipment at the work center is evaluated at approximately $400,000. Each tester is used for fault isolation in higher levels of assembly as well as in modules. Without making a detailed study, technicians ventured the opinion that much, but not all, of this equipment would be needed if there were no module repair.

Here again, actual time spent on a task is not normally recorded (they are not subject to AFM 66-1). The technicians did estimate that the isolation of the defective module in an assembly takes, on the average, about 50% more time than isolation of the defective part in the module.

Designers of the equipment apparently felt that there were serious crosstalk and/or RFI problems in the circuitry. Each module and assembly was electrically shielded against high frequency penetration. One contained three separate isolated sections.

The isolation was achieved by mounting the components on a heavy aluminum base with a projecting rim and then fastening on a double walled cover with many screws. Between the double walls was a wire mesh that provided sufficient elasticity to make a good seal with the rim of the base.

It would seem that a light weight solder sealed can would provide a much less expensive but probably DAFM module (however, some solder sealed canned modules are being repaired at SMAMA).

3.2.5.6 Single Sideband Radio - This equipment represents a small class of equipments which are repaired at the depot because skills (and equipment) are lacking in the field. A typical set may operate on 20,000 channels, each of which must be on frequency within 10 cycles in a million. Several different Collins sets have most of their modules in common.

Modules are tested both in a set and with test equipment which consists, primarily of power supplies, switches, and connectors. Auxiliary standard test equipment used includes a Hewiett-Packard 524D frequency meter, a Tektronix 545 oscilloscope, and a Heterodyne voltmeter. These are used with sufficient regularity to preclude their general use at other locations.

Repair of the master oscillator is the most difficult of the common tasks. Repair time was estimated at 20 to 30 hours with about half being spent in isolating the fault to one of the six "sub-modules" and the balance in finding and replacing the defective part in the sub-module.

This equipment illustrates the importance of knowing details of available skills in the field and skill requirement for module repair. Not all options of repair at various locations may be practical or even possible where such constraints exist.

3.2.6 Problems

3.2.6.1 Technical Data - Whether or not the government has procured it, data about module performance and contents (of encapsulated modules) is often not available at the depot. In one instance, data on a module tester (for F106 Computer) was also unavailable.

Code MDIB2 and several others suggested that, for items to be repaired at depot only, no special technical documentation be made on modules or module repair. Instead, they recommended that the depot be furnished with the manufacturer's working documentation, i.e., layouts, schematics, and performance and test specifications. If this is done, there would appear to be little value to other technical documentation on modules.

For test equipment, similar information at all levels of assembly, should be adequate, if supplemented by a convenient tabulation of in-puts, out-puts, and such, which characterize each particular test condition.

3.2.6.2 Encapsulation - The justification for using a packaging technique which requires DAFM generally lies in some additional resistance to an environmental problem such as RFI moisture, or vibration, or in reduction in weight or volume. Often these features result in higher cost than would be involved in a repairable module having the same electrical performance characteristics. However, where the environmental requirements are critical, the cost of meeting them with a repairable module may be significantly greater than with one which is to be discarded.

The cost of tightly shielded (electronically) modules appears to be much greater for those readily assembled (covers attached by screws) than those having soldered, or worse, welded seals. The shielded modules in the AN/APS-95 constitute an example of the readily repairable type. The covers of these modules are made with double walls of heavy gage aluminum which make a sandwich filled with wire mat. The walls of the base fit between the walls of the cover and against the wire mat. This can be contrasted to a lighter gage, single-wall cover that is soldered to the base. The latter design would normally be intended for DAFM, but it would nevertheless be feasible to repair.

Where encapsulants are used, a requirement for repairability may lead to use of more costly materials because, ideally, then the encapsulant should be readily dissolved in a solvent which has essentially no effect on the mounting board, component insulation, connectors, or, in some instances, markings. Thus, for example, it is obvious that epoxy encapsulants cannot be used with fiberglass-epoxy boards.

The way a module is encapsulated will determine whether it is feasible to repair, and the cost of repair when repair is feasible. It also may have significant effect on the practicality of repair at field or organization rather than merely at depot.

3.2.6.3 Miscellaneous

a. Several sources noted that repairs involving soldering are easier to make on fiberglass-epoxy boards than on laminated phenolic boards.

b. It was noted that modifications are generally more expensive where DAFM modules are used than where RAFM is practical.

3.3 WRAMA

3.3.1 General - Both radar (R-14A) and bomb toss computer (BTC) receive depot level support here. There are approximately 700 operational (in aircraft) R-14A and BTC supported along with 50 mock-ups.

3.3.2 Bomb Toss Computer - There is essentially no test equipment peculiar to module repair. That is, test equipment is required for the purpose of determining whether the module is operable and making adjustments. The modules experiencing part failures at field organization level are NRTS due to nonavailability of baking oven (less than $200) for replacement of fungus sealing, and such. If ovens were committed to field, this would essentially eliminate module repair at depot.

The cost of the BTC (presently) is $25,000.00. Design and development are not included in this figure, being absorbed in the first units delivered. In general, BTC module prices range between $100 and $200; with an approximate mean of $150.00, some exceptions exist, viz., pot panels,$875.00 (individual pots $30-90).

The time required for repair of failed modules is approximately four hours, two hours of this is associated with isolation and repair, and two hours for resealing, sanding surface, application of sealer and active time in baking (24 hours). The number of BTC module repairs vary around 20 per month. This is in agreement with BTC reliability and operational rates.

A module tester (not used for repair of modules per se) exists at depot and field level). A recently purchased (last two years) G-Pack modular tester is used extensively for BTC module evaluation and frequently yields information on circuit failure within module.

There are approximately 1000 electronic parts in the BTC and 115 subassembly or higher type items. The electronic parts are essentially all common items, less than five being unique to the supply of the BTC. There is a total of 39 modules in the BTC, 32 of which consist of electronic parts.

3.3.3 Radar - This subsystem is of the electron tube vintage. The Air Force turned down a proposed transistorized revision, presumable because additional performance and delivery schedules (considering system age) did not warrant investment in additional acquisition costs. The cost (present) of the R-14A is approximately $60,000. It is modularized but modules are larger than the BTC (this is due primarily to the use of electron tubes).

There is no special test equipment for module repair; but there is for black boxes. Most module repair work is accomplished in the field. The predominate depot work load is on black boxes and assemblies for which field does not possess special test equipment, i.e., Radar Antenna Boresighting. The synchronizer assembly is comprised of modules, most of which have failed when sent back to the depot (i.e., the assembly is used as a packaging device). The failed modules are field repairable and probably came back due to lack of parts.

3.3.4 Depot Turnaround Rates - Repair cycle time for module repair is approximately 45 actual days. The goal is approximately 30 days.

3.3.5 Depot Labor Rates - The cost of repair per man-hour is projected at $6.06, this includes indirect labor and overhead costs.

4. FCS MAINTENANCE AT SEYMOUR JOHNSON AFB (SJAFB)

The maintenance support system consists of flightline personnel and Avionics and Electronics Shop (maintenance shop) personnel.

4.1 Flightline Maintenance

Flightline maintenance on the FCS consists of three distinct types of activity:

a. The diagnostic team, consisting of 2 men of seven level for each 2 shifts in operation. The function of the team is to attend the debriefing of pilots and localize faults in the FCS. They then pass on this information to the regular flightline teams.

b. Regular flightline teams normally consist of 5 people, 2 five level and 3 three level. Only the 2 five level personnel are required for maintenance with the three level personnel engaged in on the on-the-job (OJT) training. There are approximately 55 men per shift - 2 shifts per day.

c. There are 2 peak-up stations with teams of 18 men each. Each team has 3 crews consisting of 1 five level man and 3 three level men; an extra 1 1/2 crew allows continuous operation, 24 hours a day, 7 day per week. Peak-up is based on a period of 100 hours of flying time and requires an average of 72 hours to perform.

The regular flightline teams are responsible for performing both unscheduled (random) and scheduled maintenance. The scheduled maintenance, not including peak-up, is performed as follows:

a. At the end of 50 flight hours, duration 1 hour, and a crew size of 5. The crew consists of 2 five level and 3 three level personnel.

b. At the end of 100 flight hours, duration 1 hour, and a crew size of 5. The crew consists of 2 five level and 3 three level personnel.

c. At the end of 200 flight hours, duration 16 hours, and a crew size of 6. The crew consists of 1 seven, 2 five, and 3 three levels of personnel. The FCS does not contribute to downtime since other subsystems have up to 5 days of downtime.

The peak-up effort and the scheduled maintenance activity may be assumed to have rigid scheduling. The random maintenance, on the other hand, is sufficiently variable to make an activity network desirable. Figure I-2 presents the activity network for random demands.

4.1.1 Expected Time of Flight Line Team Per Call - The expected value (mean) of time for the flight line team per call is as follows:

$$E = p_1[t_2+p_2(t_{10}+t_{12})+(1-p_2)(t_{10}+t_4+t_{11})] +(1-p_1)[t_2+t_3+t_4+p_3t_{12}+p_4(t_5+t_6+t_7+t_?) +p_5t_{11}]+t_9 \quad (I-1)$$

The aircraft downtime

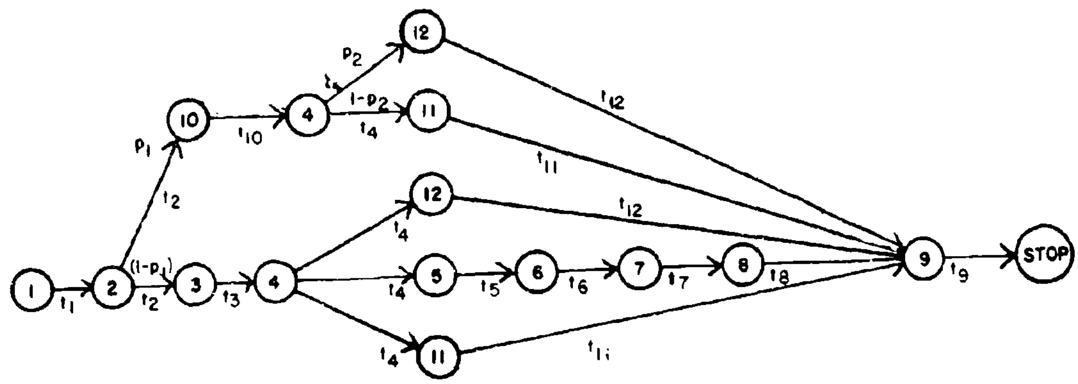
$$A_d = E+t_1-t_9 \quad (I-2)$$

Using the values of figure I-2

$E = 3.2$ and
$A_d = 3.5$ *

---

* It may reasonably be assumed that time estimates are accurate to within .25 hour. Further, involing the statistical rule for estimation of combined errors leads to assumption that the aggregate error will be less than .25 of the maximum time element estimate involved.



Activity	Estimated Values (hours)
t_1 =debriefing diagnostics	.5
t_2 =notify central control/dispatch crew	0
t_3 =get required test equipment	.2
t_4 =verify malfunction	.3
t_5 =isolate and remove black box	.5
t_6 =get black box at maintenance shops *	2.0
t_7 =return to flight line	.3
t_8 =replace box and checkout	.5
t_9 =return point of operation	.2
t_{10}=test equipment not required	.1
t_{11}=perform adjustment	1.5
t_{12}=not verified malfunction	1.5
Probability of Occurrence	(probability)
p_1	.2
$1-p_1$	.8
p_2	.05
$1-p_2$	.95
p_3	.05
$_4$	.6
p_5	.35

* See detail network in paragraph 4.1.3

FIGURE I-2.FLIGHTLINE ACTIVITY NETWORK

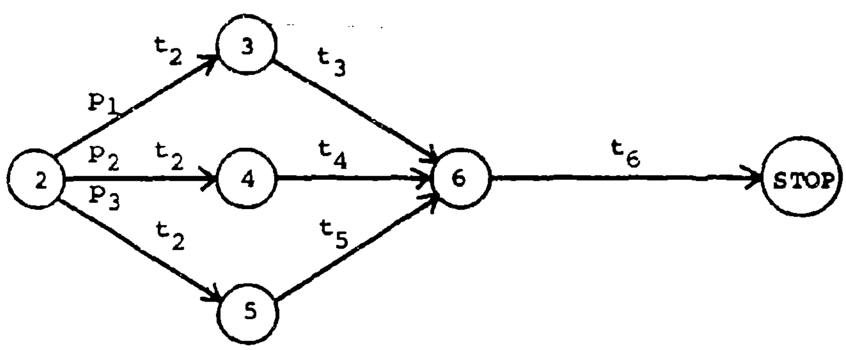
4.1.2 Sources of Data - All of the estimates above were obtained directly from flightline personnel at SJAFB. A sample of approximately 100 measurement of aircraft downtime was used in establishing the downtime per FCS failure. The mean of the sample was calculated directly from maintenance reports at flightline and was calculated to be 3.5. The measured times were separated into two types, those involving replacement of a black box and those requiring only adjustment or alignment. Approximately sixty percent of the malfunctions involved black box replacement. Those requiring a black box as a replacement had a restore to operation time of 4.5 hours, those not requiring a replacement black box average 2.5 hours. All other time estimates were obtained from flightline personnel and based directly on their experience. The estimates are verified (not statistically) by compatibility provided with other times at the FCS squadron maintenance shop.

The following observations are pertinent:

a. The RCA maintainability (active time to repair) estimates corresponds exactly to the flightline estimate, viz., t_5+t_8 = 1 hour. But, of course, does not compensate for noncatastrophe failures.

b. The proportion of failures experienced in the radar section of the FCS is essentially that predicted (90%).

4.1.3 Detail Network of Event (6) - In obtaining the black box several routes are possible; the possible routes are shown below.



The estimated values for these events of the activity network are:

Activity	Estimated Values (hours)
t_1=travel to maintenance shop	.3
t_2=place faulty box in repair line	.2

Activity	Estimated Values (hours)
t_3=take box from ready inventory	.1
t_4=await repair	1.5
t_5=obtain box from base inventory	4.0
t_6=return to aircraft	.35
p_1=probability of occurrence	.35
p_2=probability of occurrence	.60
p_3=probability of occurrence	.05

The expected time duration spent in acquiring the black box is:

$$E_{bb} = t_1+t_2+p_1t_3+p_2t_4+p_3t_5+t_6$$

$$= 2.0 \text{ hours}$$

The rule for determining the course of action is least time. Generally, 60% of the time repair is awaited; 35% of time the box in in ready inventory; 5% of time box cannot be repaired due to lack of parts and is replaced through base inventory. The time for tapping base inventory is 4 hours (this includes uncrating, calibration, travel).

4.2 Maintenance Shop

The shop is divided into specialities as follows:

a. R14A and AD subsystems

b. BTC subsystem

c. Category II test equipment

Shop works a two shift operation.

Shift 1	7:30 -	4:30
Shift 2	4:30 -	12:30

Specific number of crews per shop breakout by shift are as follows:

Shift 1

R14 and AD

3 repair teams; each team consists of two personnel of levels 5 and 3.

One supervisor

BTC

3 repair teams; each team consists of two personnel of levels 3 and 5.

Category II Test Equipment

Repair teams (3); consisting of one man, one trainee.

One supervisor

One general supervisor of 7 level.
One general administrator of 5 level.

Shift 2

R14 and AD

Same as Shift 1. One supervisor

BTC

Same as Shift 1. No supervisor

Category II Test Equipment

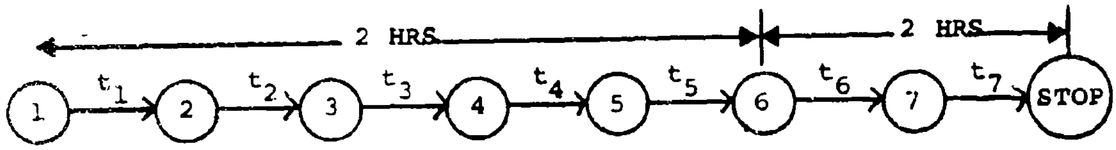
Second shift not assigned.

Personnel Complement by Grade

TSgt	1
SSgt	6
A1C	6
A2C	23
	36

Two airmen of the 36 above were not available due to school, etc.

4.2.1 Radar and Attack and Display Subsystem Activity - The following is the activity network for the R14A and AD maintenance shop.



t_1=item entered in repair shop.

t_2=item assigned (or assignment assumed by) to repair

t_3=setup for fault verification of item. (Requires test complement.)

t_4=faulty module in black box is isolated.

t_5=module is replaced and black box is checked out. (Requires mock-up).

t_6=item entered into ready inventory.

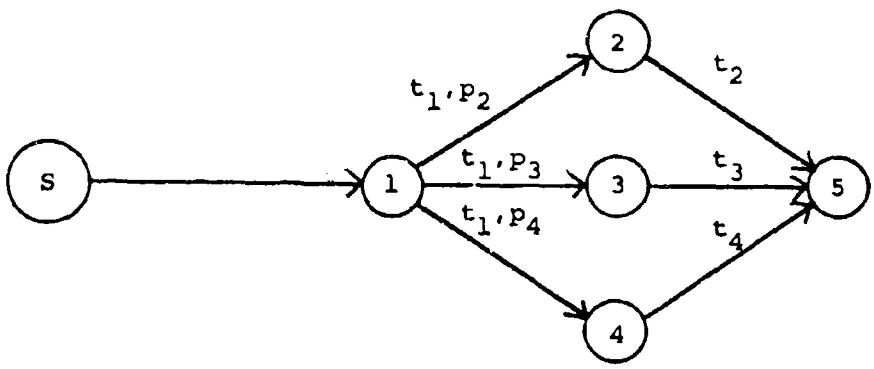
t_7=faulty module is repaired.

Faulty module repair is fill in work. A module test-isolation set is required. All R14A and AD modules are repairable at maintenance shop. All the time estimates above were obtained from supervisory personnel at the maintenance shop.

4.2.2 <u>Bomb Toss Computer Subsystem Activity</u> - The activity network for the BTC subsystem shop is equivalent to the Radar activity network. The approximate time required to process a failed unit through this shop is 2 hours. BTC modules are not repaired at site due to the problem of isolation to part level because of epoxy coating requiring special processing equipment. Supply of replacement modules is adequate and downtime of aircraft is not experienced from modules.

4.2.3 <u>Category II Test Equipment Activity</u> - This activity performs calibration and maintenance of all special test equipment associated with the FCS. The critical equipment is the analyzer since this equipment experiences the greater use and is most in demand. Also serviced by this activity is mock-ups (both types). This activity is also specialized, viz., 2 people on mock-up and 2 on analyzer. The average number of analyzers down is 2 (estimate) either for failure or calibration. These units undergo calibration every thirty days or at failure, whichever came first.

4.2.4 Ready Inventory Link - This ready inventory link corresponds to event 6 of the flightline activity network. The activity network follows:



Activity	Estimated Values (hours)
s=request for aircraft repair	-
t_1=request for spare comes from FCS maintenance shop	-
t_2=fill request from off shelf	.1-.2
t_3=order from base supply cycle	4
t_4=order from depot cycle	in excess of 30 days
t_5=satisfy request	
p_2=probability of taking this route	$>$ .95
p_3=probability of taking this route	$<$ .05
p_4=probability of taking this route	$<$ .01

Expected time in ready inventory link

$$E = p_2t_2+p_3t_3+p_4t_4$$

$$= (.95)(.15)+(.05)(4)+0$$

$$= .35 \text{ hr}$$

p_4t_4 can be neglected because personnel would not wait.

Inventory level is controlled by space at supply room. Repairable spares average two black boxes. About 100 base requests per month are made. High valued items are constantly monitored, low valued items periodically monitored.

Units which must be sent outside base (to depot, etc.) involve a pipeline time in excess of 30 days. One to two aircraft are constantly down, due to all subsystems, waiting for depot spares.

APPENDIX II

DETAILED JUSTIFICATION FOR REVISION OF MODEL

1. INTRODUCTION

The method of showing the comparison between the model outlined in RADC-TDR-63-140 and the model outlined in section 3 of this report is as follows:

a. Summarize, briefly, what RADC-TDR-63-140 states on a subject.

b. Summarize, briefly, what section 3, of this report, states on the same subject.

c. Show justification for the change from a to b.

2. DETAILED COMPARISONS

2.1 General Approach

The general form of the equations are as follows:

a. RADC-TDR-63-140.

$$\Delta C = C_{repair} - C_{discard} \qquad \text{(II-1)}$$

where only maintenance and support costs are included in ΔC, the cost item which is evaluated.

b. Section 3.

$$T_{total} = A_{(acquisition)} + S_{(operation\ and\ support)} \qquad \text{(II-2)}$$

and

$$\Delta T = T_{total\ 2} - T_{total\ 1} \qquad \text{(II-3)}$$

where any significant cost differences in design, development, fabrication, installation, operation, or support are included in ΔT. The subscripts 1 and 2 identify any two alternatives.

The alternatives are as follows:

(1) Repair module of size X versus repair module of size Y, at location j (j = organization, field, depot, or factory).

(2) Repair module of size X, at location j, versus discard of module of size Y.

(3) Repair module of size Y, at location j, versus discard of module of size X.

(4) Discard module of size X, at location i, versus discard of module.

(5) Repair higher modular assembly versus discard of higher modular assembly at location j.

c. Justification

Fabrication costs of various package types differ significantly by more than an order of magnitude. (See appendix V.) Consequently, differences in acquisition costs could conceivably far outweigh differences in maintenance costs of highly reliable items. Module cost is strongly correlated with quantity of production. (See appendix V.) Production quantity is a tradeoff in design and fabrication between module types and size.

It can be shown that some modules have to be discarded because no repair alternative exists, e.g., adverse environment affecting module repair. Differences in built-in maintainability features may result in significantly different costs as well as in differences in maintenance manning requirements. This consideration is brought out in RADC-TR-60-58 which proposes use of built-in test features to permit repair of equipment failures by operators rather than by maintenance men.

2.2 Cost Accounting Methods

2.2.1 General

a. RADC-TDR-63-140

The model described uses a cost proration principle at organization and field maintenance levels. This cost method allocates incurred costs based on total cost burden (personnel (direct and indirect), test equipment, and facilities) per direct labor hour. Thus, the assumption is made that if the work were not done (i.e., discard modules rather than repair), personnel, test equipment, and facilities could be removed.

b. Section 3

The variation in cost as a result of changing the value of a model parameter requires individual investigation.

c. Justification

The assumption made in (a) is demonstrably not true for sites visited. The cost variation in test equipment and personnel between equipments varies by orders of magnitude independent of module workload.

2.2.2 Military Mission

a. RADC-TDR-63-140

The resource cost invested in the various commodities (personnel, test equipment, and spares) is not related to the military mission of the system.

b. Section 3

All significant cost expenditures are related to the operational readiness of the system.

c. Justification

In order to optimize with respect to the discard/repair module, it is necessary that consistent dimensions be used in making tradeoffs, e.g., return in operational readiness per additional maintenance man per unit cost.

2.3 Maintenance Policy

a. RADC-TDR-63-140

The assumption is made that a maintenance policy is already established before performing the cost analysis.

b. Section 3

A determination of the system design configuration and maintenance policy is accomplished jointly to achieve both system support objectives and minimum cost.

c. Justification

The decision concerning where to spare significantly influences the cost of spares. The decision concerning where to repair significantly influences the cost of repair.

2.4 Cost of Operation and Support

2.4.1 Cost at Organization - The costs at organization are distributed in the following manner:

a. RADC-TDR-63-140

$$C_o = C_{manpower} + C_{facilities} + C_{material} + C_{intangibles} \qquad \text{(II-4)}$$

b. Section 3

$$C_o = C_{om} + C_{of} + C_{os} + C_{ot} \qquad \text{(II-5)}$$

c. Justification

While on the surface, similar equations are obtained for the two models, there are differences in basic approach as follows:

(1) Manpower

Basic considerations of reliability and maintainability, combined in queuing tables, Ref. 2,3,4, provide universal application in the section 3 model versus the restricted notion of manhours of maintenance multiplied by a constant composed of average costs and burden rates, as abstracted from a vintage 1958 report.[8]

(2) Facilities

Facilities, including test equipment, represent an acquisition cost rather than a continuing one. Facilities maintenance costs (C_{of}) are included in the section 3 model.

(3) Spares or Material

The section 3 method of sparing works directly from an acceptable level of unreadiness for both RAFM and DAFM. RADC-TDR-63-140 over-estimates spare requirements for RAFM by the use of confidence levels not tied to system unreadiness; and under-estimates the spares for DAFM by not tieing to system unreadiness. Section 3 provides a method of optimizing the cost of spares while the other model does not.

(4) Intangibles

Factors classed as intangibles cannot conveniently be associated with specific dollar values or costs. The most useful and practical approach to dealing with them is tc class them, along with cost, as factors to consider in the final selection among alternatives. In effect, this is the approach of the other model as given in section 3, paragraph E2.

(5) Transportation

This factor (C_{ot}) may be of importance, in the case of rush trips to and from the field, when considering advanced systems, and the various maintenance plans that could be devised.

2.4.2 Cost at Field - There is essentially the same justification for a change from RADC-TDR-63-140 to section 3, of this report, as indicated in paragraph 2.4.1.

2.4.3 Cost at Depot - The costs at depot are distributed in the following manner:

a. RADC-TDR-63-140

$$C_d = C_{manpower} + C_{facilities} + C_{material} + C_{intangibles} \quad (II-6)$$

$$C_{manpower} = C_{direct} + C_{administrative} + C_{non\text{-}technical} \quad (II-7)$$

b. Section 3

$$C_d = C_{dm} + C_{df} + C_{ds} + C_{du} + C_1 \quad (II-8)$$

$$C_m = C_{direct} + C_{indirect} \quad (II-9)$$

c. Justification

Essentially the same reasons that have been given before in paragraph 2.4.1 exist for the preference of the section 3 model to the other. The exceptions are:

(1) C_1 (Eq. II-8) $= C_{non\text{-}technical}$ (Eq. II-7) (II-10)

with a change only in the constant I. This constant (I) appears in the expansion of C_1 in section 3.

(2) Indirect manpower costs are prorated as in RADC-TDR-63-140.

APPENDIX III

PROVISIONING MODEL

1. MODEL DEVELOPMENT

Spares are allocated to specific locations, viz., organization, field, or depot, based on return in operational readiness per unit cost expended.

Let:

t_i = delivery time required to replace an item or equipment life for DAFM module

i = item or DAFM module

p_{ij} = probability of more than j demands during period t_i

If j spares have been allocated to item type i, the expected downtime, due to shortages of spares ($\bar{M}_{s-ij}$), will be as follows:

$$\bar{M}_{s-ij} = t_i p_{ij}/(j+1) \qquad \text{(III-1)}$$

The incremental decrease in downtime ($\Delta\bar{M}_{s-ij}$), due to adding another spare, will be

$$\Delta\bar{M}_{s-ij} = [t_i p_{i(j+1)}/(j+2)] - \bar{M}_{s-ij} \qquad \text{(III-2)}$$

and the incremental decrease per unit cost (δ_{ij}) is

$$\delta_{ij} = \Delta\bar{M}_{s-ij}/c_i \qquad \text{(III-3)}$$

where

c_i = cost of i

The probability (p_{ij}) is computed by means of the Poisson distribution in conjunction with the failure rate (λ_i) and t_i. Each item is assumed to contribute independently to downtime.

2. APPLICATION

It is required that downtime, due to lack of spares, be reduced so as to be compatible with an operational readiness goal. Let R be the goal and $\bar{M}_s$ be the permissible downtime. It will be more convenient to carry out the following steps in some tabular form.

a. Of the n item types, to be considered, compute $\bar{M}_{s-ij}$ and $\sum_{i=1}^{n} \bar{M}_{s-ij}$.

b. Compute $\Delta\bar{M}_{s-ij}$ for each of n item types, based on the addition of one spare.

c. Compute δ_{ij} for each of n item types.

d. Choose maximum value of δ_{ij} and compute the total downtime ($\bar{M}'_s$) as follows:

$$\bar{M}'_{s1} = \sum_{i=1}^{n} \bar{M}_{s-ij} \quad \bar{M}_{s-ij} \tag{III-4}$$

where $\Delta\bar{M}_{s-ij}$ is paired with maximum value of δ_{ij}.

e. Decision Rules:

(1) $\bar{M}'_{s1} \leq \bar{M}_s$, STOP, the goal has been reached.

(2) $\bar{M}'_{s1} > \bar{M}_s$, add another spare to this item type, recalculate $\Delta\bar{M}_{s-ij}$ and δ_{ij}.

f. Repeat steps d and e, always adding spares, to <u>maximum</u> value of δ_{ij}, until the goal has been reached, <u>viz.</u>, $\bar{M}'_{sn} \leq \bar{M}_s$.

3. MODIFICATIONS

The steps above are modified for locations for which spares are allocated, and for repairable and discard items.

3.1 <u>Organization</u>

a. Repairable items

(1) If repair is at site, the quantity t_i is repair time of an item.

(2) If repair is remote, t_i is turnaround time.

b. Discard items: For discard items, t_i is the reorder time for field or depot.

3.2 <u>Field and Depot</u>

a. Repairable items: Same as 3.1,a,(2).

b. Discard items: To determine total number of discard items, assume items are purchased for a supply of 1 year, with replenishments yearly. This corresponds (roughly) to present purchasing policies. This policy compensates for errors in estimation of failure rates and random processes.

The total cost of discard items over the lifetime of the system, is determined by the following model:

Let:

j_i = number of spares, per item type, computed using provisioning model

L = life of system

λ_i = total failure rate (calendar hour) per item type

If

$$L\lambda_i \leq j_i$$

then $j_i c_i$ is the total cost of the spares per item type.

If

$$L\lambda_i > j_i$$

add $(L-t_i)\lambda_i$ spares to j_i; the total cost $(j_i' c_i)$ then becomes

$$j_i' c_i = [j_i + (L-t_i)\lambda_i]c_i \qquad \text{(III-5)}$$

Where spares are allocated only to the field or depot, downtime will occur for each demand at the organization.

Where the quantity of spares required for DAFM exceed life usage, phaseout period (L_p) must be used to absorb cost.

APPENDIX IV

DATA ON THE AN/ASG-19

(Data contained in this appendix is UNCLASSIFIED)

1. RCA PREDICTION OF RELIABILITY

The objective was to assign a failure rate to each black box in the FCS. To achieve this, a gross part count was performed on each box with the assignment of mean reliability figures of merit on standard parts.

a. The reliability figures are representative of the 1959-1960 state of the art and were derived from the following:

   (1) RCA TR59-416-1 (Reliability Stress Analysis for Electronic Equipment)[9]

   (2) Military Standardization Handbook MIL-HDBK-217 (Reliability Stress and Failure Rate Data for Electronic Equipment)[10]

   (3) MIL-STD-756[11]

b. Failure rates represent average stress levels (between 20 percent and 30 percent of rated) and are based on 60 percent confidence limit.

c. Only true random catastrophic failures are considered in the analysis. Not included in this type of failure are:

   (1) Wear-out failures
   (2) Performance deterioration
   (3) Design changes
   (4) Workmanship errors
   (5) Non-operational defects

Failures of this type should be eliminated either through good design, proper derating of components, and/or efficient preventive maintenance scheduling. Table IV-1 shows the results of all these considerations.

2. RCA PREDICTION OF MAINTAINABILITY

The objective was to establish mean repair times for:

a. Each basic maintenance action (preventive, corrective)

b. Maintenance level (flightline, maintenance shop)

The estimates for corrective maintenance were obtained with a sampling technique where various levels of equipment repair were analyzed, using check lists provided with RADC-TDR-63-85, Volume II[5]. For the preventive maintenance figures, a combination of interviews was employed.

TABLE IV-1

RELIABILITY PREDICTION

THUNDERSTICK FIRE CONTROL SYSTEM= AN/ASG-19 (FCS)

Radar (R14A)	Failure Rate (λ) %/1000 Hours
Antenna Unit	192.40
Automatic Frequency Control	12.35
Electronic-Control Amplifier	384.80
Post IF Amplifier	841.75
Radar-Flight Indicator	336.70
Synchronizer	2188.55
Low Voltage P.S.	456.95
Transmitter	325.00
Radar-Calibration Control	24.05
Wave Guide Coupling	24.05
Flexible Wave Guide	24.05
Clearance Plan Indicator	48.10
Ferrite-Load Isolator	16.25
	λ_1 = 4875.00

Attack and Display (AD)	
Sight Head	107.3410
Gyro Lead Computer	46.956
Sight Amplifier	86.008
Erase Control and Power Supply	6.539
Missile Launch Computer	27.287
Display Tube Amplifier	38.272
	λ_3 = 312.40

Bomb Toss Computer (BTC)	
Power Supply	30.2445
Amplifier	114.1790
Comparator	45.7210
Angle Position Dirve	164.7880
Roll Angle Repeater	74.0610
Time and Range Drive Assembly	41.9900
Angle Function B	52.0650
Angle Function A	43.1145
Angle Function E	21.9895
Drift Angle and Range Wind	71.5390
	λ_2 = 659.69

Composite Failure Rate of FCS

$$\lambda_T = \lambda_1 + \lambda_2 + \lambda_3$$

$$= 4875.00 + 659.69 + 312.40 = 5847.09\%/1000 \text{ hours.}$$

a. Airmen now at work on century series fighter aircraft.

b. RCA Service Company field engineers who had worked on complex FCS in aircraft.

Table IV-2 gives the preventive maintenance time, while table IV-3 gives estimates of corrective maintenance time broken down to the various levels of maintenance. The times are based on the presence of the number of personnel stated as a minimum.

3. REVIEW OF RAC DOCUMENT 1950

3.1 Introduction

3.1.1 Purpose - The Republic Aircraft Corporation (RAC) Document 1950[I2] was reviewed for the following purposes:

a. To extract the time and failure data for the AN/ASG-19 subsystem.

b. To extract data on repair of the AN/ASG-19 subsystem.

3.1.2 Method - The method of obtaining the reliability estimate is a straight-forward evaluation and includes all applicable data. The method of obtaining the repair data involves a number of assumptions and all are documented.

No statistical tests are made in comparing the data with the predicted result. Instead, a range of values is set up corresponding to various degrees of failure, since the value predicted is so close to the value given by the data that statistical comparison is meaningless.

3.2 Reliability Analysis - Table IV-4 shows all the reliability data from RAC and USAF sources contained in RAC Document 1950. It is divided between, RCA and USAF, and subtotaled. The subtotals show 18 hours MTBF for the data accumulated by RAC with a total of 10,013 hours accumulated and 545 failures for the AN/ASG-19 subsystem. The USAF data shows an MTBF of 13 hours with approximately 7500 hours accumulated and 613 failures. Combining the sources of data yields an MTBF of 15 hours for the AN/ASG-19. The predicted value was 17 hours, which was quite close to the observed value. Data was available on the individual components (black boxes) at PACAF and, in general, it was in agreement with the prediction done by RCAS. However, there was too small a time sample involved for definite verification of the prediction at the black box level. On the other hand, verification at the three main equipment levels means that the predicted figures for the black boxes can be accepted since nothing unusual was involved in the production of AN/ASG-19, e.g., advances in the state of the art.

TABLE IV-2

ESTIMATES OF MEAN PREVENTIVE
MAINTENANCE TIME

	Procedure	AN/ASG-19
	Preflight	2 Men - 1/2 Hr.
	Postflight	2 Men - 1 1/2 Hr. - System
	Squadron 50 Hr. PM	4 Men - 16 Hr. - System
Field Maintenance	100 Hr. PM	4 Men - 24 Hr. - System
Field Maintenance	500 Hr. PM	4 Men - 24 Hr. - System
Field Maintenance	1000 Hr. PM	4 Men - 24 Hr. - System

TABLE IV-3

ESTIMATES OF MEAN CORRECTIVE
MAINTENANCE TIME

Procedure	AN/ASG-19		
	R14A	A&D	BTC
Preflight	If the system fails the checks outlined in the preflight procedures of F105D the system reverts to postflight maintenance times.		
Postflight (Component Replacement)	45* 2 Men	60 2 Men	30 2 Men
Squadron Maintenance (Minor Component Repair)	60 2 Men	30 2 Men	30 2 Men
Field Maintenance - Component Repair	60 2 Men	60 2 Men	60 2 Men
Field Maintenance - Module Repair	30 1 Man	30 1 Man	30 1 Man

*All times in minutes

TABLE IV-4
SUMMARY OF FAILURE AND CRAB INFORMATION

Equipment		RAC				USAF				ALL
		139 A/C	50 A/C	PACAF 15 A/C	Sub-Total	PACAF 15 A/C	ARINC NELLIS	EGLIN	Sub-Total	Total
Radar	Pred. MTBF									21
	Hours	6720	2546	747	10013	2783	1602	3700	8085	18,098
	Failures	318	125	35	478	73	150	236	459	937
	MTBF	21	20	21	21	38	11	16	18	19
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					146			146	146
	MFTBVC					9.3			9.3	9.3
Sight	Pred. MTBF									320
	Hours	6720	2546	747	10013	2783	1602	3700	8085	18,098
	Failures	23	10	2	35	8	31	24	63	98
	MTBF	290	250	370	290	350	43	150	130	180
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					19			19	19
	MFTBVC					71			71	71
BTC	Pred. MTBF									150
	Hours	6720	2546	747	10013	2783	1602	1720	6105	16,118
	Failures	25	6	1	32	10	32	49	91	123
	MTBF	240	420	750	310	280	38	31	67	130
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					13			13	13
	MFTBVC					100			100	100
AN/ASG-19	Pred. MTBF									17
	Hours	6720	2546	747	10013	2783	1602	3129	7547	17,550
	Failures	366	141	38	545	91	213	309	613	1,158
	MTBF	18	18	20	18	31	7.5	10	13	15
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					178			178	178
	MFTBVC					7.6			7.6	7.6

At PACAF, the value for the MTBF of AN/ASG-19 was 31 hours, almost exactly two times the value of 15. At PACAF, a record was kept of flight crabs which yields a mean flying time between verified crab (MFTBVC) of 7.6 hours, almost one half of the MTBF of 15 hours.

3.3 Maintainability Analysis - Table IV-5 shows the repair data. There were a number of problems in dealing with this data, viz., "other" category of removal, "bench time," and "repair manhours" are not clearly identified. Thus, it is necessary to make some assumptions which are based on actual field data.

The following is a detailed procedure of how the data was modified:

a. Bench time is divided by two. Roughly one half of the time is spent in active time and one half is spent on delay time.

b. Repair manhours is divided by two for the reason cited above and is divided again by 1.5 on the theory that half of the tasks are accomplished by one man and the other half are accomplished by two men. The overall divisor is three (2 X 1.5).

c. The sum of these two (BT + RMH) is an estimate of total active repair time (ART).

d. Some adjustment is needed for the other removals. This is appropriated at one-half hour per other removal. The adjustment is shown in the AART column.

e. The mean active repair time (MART) is found by dividing the AART by the sum of failures (F) and non-verified failures (NV). The sum is used on the theory that just as much time is spent, on the average, in checking an NV as an F.

f. The MART is listed for purposes of comparison to see the effect of removing the others. This is the quotient of ART divided by total removals (T). The figures are approximately the same.

g. Finally, the predicted MART is listed. For purposes of round-off, the predicted time for each major part of the AN/ASG-19 subsystem were predicted as listed. The value MART predicted for the AN/ASG-19 subsystem was arrived at by considering the relative probability of failure of the three major parts of the AN/ASG-19.

TABLE IV-5

MEAN ACTIVE REPAIR TIME (MART)

System	Failures	Non-Ver Fail.	Sub-Total	Other	Total Removal
	(F)	(NV)	(F+NV)	(O)	(T)
R14A	73	59	132	23	155
AD	8	7	15	12	27
BTC	10	24	34	43	77
AN/ASG-19	91	90	181	78	259

System	Bench Time	Repair Man Hours			Active Repair Time	Adj. ART [ART-.5(O)]	AART/F+NV	DT/T	Pred-icted
	(BT)	(RMH)	BT/2	RMH/2x1.5	(ART)	(AART)	(MART)	(MART)	(MART)
R14A	217	231	108.5	77.0	185.5	174.0	1.3	1.2	1.0
AD	27	32	13.5	10.7	24.2	18.2	1.2	0.9	1.0
TBC	75	42	37.5	14.0	51.5	30.0	0.9	0.7	1.0
AN/ASG-19	319	305	159.5	101.7	261.2	222.2	1.2	1.0	1.2

It can be seen that the value shown in the last three columns in table IV-5 are all of the same magnitude. Further, it is believed that the values are realistic estimates of the mean active repair time.

APPENDIX V

PROCUREMENT COST

1. INTRODUCTION

An investigation was conducted by RCA Communications Systems Division to determine the difference in cost between DAFM, RAFM, and other possible module construction.

For a given packaging technique, the number and types of parts required to perform a specific function are independent of the support repair philosophy. Therefore, it can be anticipated that no real acquisition cost difference would exist in a design or part design decision to involve either DAFM or RAFM techniques, except as choice of packaging techniques also enters the picture.

The problem becomes more complicated when dealing with cases in which other design constraints, e.g., weight, volume, configuration, mechanical rigidity, must be satisfied. In such situations, each packaging technique satisfying the imposed constraints must be evaluated with respect to DAFM or RAFM philosophy against alternative packaging techniques. (It is well to remember that some packaging techniques are inherently DAFM.)

2. COST ANALYSIS

2.1 Test Circuits

Two typical circuits were used to evaluate potential acquisition differences between DAFM and RAFM modules, and between modules differently packaged. The circuits (modules) were:

a. An IF strip used in the AN/PRC-25 (analog) equipment.

b. A flip-flop circuit used in the Navy data link (digital) equipment.

The cost of each module has been established based on two methods of construction for each module noted above, namely:

a. AN/PRC-25 (analog) equipment.

   (1) Conventional parts RAFM or DAFM

   (2) Micromodule technique (DAFM by construction)

b. Data link (digital) equipment

   (1) Conventional parts RAFM or DAFM

   (2) Cordwood (DAFM by construction)

2.2 <u>Part Cost</u>

The prices of component parts are the same for RAFM and DAFM applications using the same packaging technique.

2.2.1 <u>Comment</u> - The component industry has been leaning toward producing a one quality part. The price increase occurs when high reliability components are ordered. The ratio of component cost between high reliable Minuteman and standard military grade parts varies between 2:1 and 10:1, the average being 5:1.

2.2.2 <u>Included in Part Cost is Qualification Testing</u> - A qualification testing program includes analysis of data to determine that a vendor has the capability of manufacturing a specific component part. Included in a qualification test is a long term life test (usually 1,000 hours), the results of which are used to assign a certain level of reliability to the part in question. However, a more meaningful test is the acceptance inspection test program, which is an extensive series of tests performed on a lot-by-lot and calendar basis.

The cost of qualification test for a component part varies between $1500 and $2500. The time cycle needed to complete a qualification test is six weeks minimum. In contrast, the acceptance inspection tests provide production test data and an accurate description of the quality of the component part in terms of AQL. Acceptance inspection also provides for the component supplier to maintain his qualification status at little, if any, cost to the part buyer.

2.3 <u>Module Cost</u>

2.3.1 <u>Module Qualification Cost</u> - Modules and their component parts are tested to determine (a) the reliability of the module, and/or (b) the quality of the component parts of the module.

2.3.2 <u>Test Yield</u> - As complexity (number of parts per module) increases, yield decreases because more parts of the module are rejected whenever a more complex module is rejected. Yield problems are often less for RAFM modules than for modules designed specifically for DAFM since this latter type of module cannot be as readily repaired during the production cycle. This difference is relevant only in decisions involving alternatives which are packaged differently.

2.3.3 <u>Packaging Considerations</u> - Some packaging techniques are such that DAFM is mandatory, e.g., RCA Micromodule and Minimod (conventional cordwood). It must be clearly understood that these packaging techniques are necessarily DAFM candidates; but, the prime purpose underlying the development of each technique is weight, volume, mechanical rigidity.

Hopefully, the units produced will be inexpensive with respect to acquisition and support cost through quantity purchase and higher reliability.

2.3.4 Purchase Quantity - The most significant acquisition cost variation is the cost per module per quantity purchased. Cost estimates have been made, below, of two different packaging techniques for each of two different circuits for purchase quantit. s of 10, 100, 1,000, 5,000, and 10,000. The circuits used to illustrate the cost difference of an RAFM and a DAFM module technique are examples of modules presently in production or modules that had been in production.

Cost of modules as a function of quantity purchased is shown in the following tables:

a. Table V-1. The cost of a AN/PRC-25 DAFM module constructed using micromodule technique.

b. Table V-2. The cost of a AN/PRC-25 RAFM or DAFM module constructed using conventional components.

c. Table V-3. The cost of a data link flip-flop DAFM module constructed using conventional components.

d. Table V-4. The cost of a data link flip-flop RAFM or DAFM module constructed using conventional components.

The cost breakout is based on the module part complexity given in table V-5.

TABLE V-1

AN/PRC-25 IF AMPLIFIER (DAFM)

Micromodule Assembly					
Quantity	10	100	1,000	5,000	10,000
Printed Circuit Board	$ 5.10	$ 3.14	$ 1.85	$ 1.25	$ 1.08
Other Material	706.31	437.27	256.00	176.08	149.62
Labor & Overhead	246.35	151.47	89.30	61.43	53.50
Tools*	58.30	5.83	.58	.12	.06
Requisition Engineering	78.31	7.83	.78	.16	.08
Packaging	.45	.29	.15	.08	.08
Total Unit Cost	$1,094.82	$602.83	$348.66	$239.15	$203.12

*Tool cost is the cost per module to maintain all tools, test equipment, repair and calibrating equipment. This cost is not the acquisition cost of the tools, test equipment, etc.

TABLE V-2

AN/PRC-25 AMPLIFIER (RAFM or DAFM)

Conventional Parts					
Quantity	10	100	1,000	5,000	10,000
Printed Circuit Board	$ 4.03	$ 2.48	$ 1.46	$ 1.01	$ .85
Other Material	79.30	48.75	28.74	19.92	16.79
Labor & Overhead	17.09	10.49	6.18	4.29	3.61
Tools*	4.40	.44	.04	.01	.01
Requisition Engineering	.57	.35	.20	.14	.12
Packaging	.06	.05	.03	.02	.02
Total Unit Cost	$105.45	$62.56	$36.65	$25.39	$21.40

*Tool cost is the cost per module to maintain all tools, test equipment, repair and calibrating equipment. This cost is not the acquisition cost of the tools, test equipment, etc.

TABLE V-3

DATA LINK FLIP-FLOP (DAFM)

Mini-Module*					
Quantity	10	100	1,000	5,000	10,000
Printed Circuit Board	$ 0.57	$ 0.35	$ 0.21	$ 0.13	$ 0.12
Other Material	32.60	20.03	11.81	8.13	6.90
Labor & Overhead	23.60	14.72	8.67	5.98	5.08
Tools**	4.40	0.44	C.04	0.01	0.01
Packaging	0.03	0.02	0.02	0.02	0.02
Total Unit Cost	$61.56	$35.56	$20.75	$14.27	$12.13

*The unit cost shown represents only 1/4 of the components contained in the module represented in table V-4. Accordingly, a multiplication of figure should be used for the unit cost of table V-3 when comparing the table V-3 and table V-4 modules.

**Tool cost is the cost per module to maintain all tools, test equipment, and repair and calibrating equipment. This cost is not the acquisition cost of the tools, test equipment, etc.

TABLE V-4

DATA LINK FLIP-FLOP (RAFM or DAFM)

Quantity	10	100	1,000	5,000	10,000
Printed Circuit Board	$ 6.61	$ 4.06	$ 2.40	$ 1.65	$ 1.40
Other Material	122.43	75.28	44.37	30.52	25.93
Labor & Overhead	73.55	45.22	26.66	18.33	15.57
Tools*	4.40	0.44	0.04	0.01	0.01
Packaging	0.18	0.11	0.06	0.05	0.05
Total Unit Cost	$207.17	$127.11	$73.53	$50.56	$42.96

*Tool cost is the cost per module to maintain all tools, test equipment, and repair and calibrating equipment. This cost is not the acquisition cost of the tools, test equipment, etc.

TABLE V-5

PART COMPLEXITY

AN/PRC-25		
Part	DAFM By Design	RAFM or DAFM
Resistors	26	25
Capacitors	22	19
Transistors	6	6
Inductors	5	4

Data Link		
Part	DAFM*	DAFM or RAFM
Resistors	32	32
Capacitors	16	16
Diodes	20	20
Transistors	8	8
Connectors	4	1

*The quantities in this column have been multiplied by four because four DAFM flip-flop modules perform the same function as one RAFM module.

3. EFFECT OF DIFFERENT PACKAGING TECHNIQUES ON COST

3.1 Manufacturing Set-Up Cost

Manufacturing set-up costs which, for the present analysis, include assembly technique, quality of printed circuit board, tool costs, and such are similar for RAFM and DAFM techniques. The difference in cost between mounting components on a printed circuit board or assembling a cluster of components into a mini-module (cordwood) will range from 7 to 10 percent. Tables V-1 to V-4 show this difference in assembly cost which includes manufacturing set-up. Therefore, when manufacturing set-up costs (excluding tooling) are totaled, it has been observed that there is little difference in set-up costs for the two grades of modules.

3.2 Manufacturing Yield

Manufacturing yield is a direct product of the checks and balances a manufacturer incorporates into his production processes. A compact module should have a yield comparable to a module of the same complexity whose dimensions are larger to allow for greater spacing between components parts. The chief difference between a compactly and sparsely packaged module is the cost. A highly skilled operator is needed for assembling a compactly packaged module, whereas a lesser skilled and lower salaried operator is adequate for a sparsely packaged module. Yield decreases with complexity (number of parts per module) because of the greater opportunities for defects.

3.3 Two Dimensional (Planar) Versus Three Dimensional (Stacked)

The labor cost of three dimensional packaging for smaller quantity runs is in the order of $1.50 to $2.50. This represents the added labor cost versus a two-dimensional module. A three-dimensional module will require less structural support hardware because it offers a higher density package than the two dimensional assembly. This reduction in structural hardware will partially off-set the added labor cost.

4. SUMMARY

The major results of this analysis are summarized below:

a. There is no inherent significant cost difference between the unconstrained (weight, volume, and size are not significant constraints) DAFM and RAFM module having the same packaging.

b. The reduction in cost per module as a function of purchase quantity is significant. This could influence the RAFM, DAFM decision.

c. Significant cost variation due to different types of packaging technique exists. However, this difference is not necessarily relevant to RAFM-DAFM decision making.

d. Piece part cost is the same for DAFM and RAFM.

e. Assembly cost is a function of the compactness of the module. The rule is that cost increases significantly as the parts per unit volume increase. The compactness is not inherently related to either RAFM or DAFM; however, difficulty of repair tends to associate DAFM with the compact modules.

f. Competitive bidding cost variation may be the overriding factor. That is, within the anticipated cost variations of RAFM versus DAFM, process control, and process technique, profits and overhead may override inherent DAFM-RAFM cost differences except as different packaging is used (e.g., conventional parts versus micromodules versus integrated circuitry).

APPENDIX VI

MODEL CONSTANTS

1. PERSONNEL COSTS

1.1 General

Personnel cost is based on the following:

a. Skill level

b. Longevity

c. Rations

d. Quarters allowance

e. Clothing allowance

f. Retirement

g. Training cost

1.2 Pay

Cost contributions (a) through (e) are combined in the Standard Basic Rate Table (AFM 177-101) 1964. These standard rates are listed in table III-1, by skill level.

1.3 Retirement Cost

The contribution to personnel cost from retirement is obtained as follows:

Let:

P_i = probability of remaining in service until retirement given that the man has reached skill level i.

R_i = rate of pay at retirement.

t_{si} = expected retirement time in years.

S_{ri} = expected retirement cost per year.

The cost of retirement for a man of skill level i (S_{ri}), per year, becomes as follows:

$$S_{ri} = p_i t_{si} r_i / 40$$

Time to retirement assumed to be 20 years and the time in retirement is 30 years(two assumptions are involved here: (1) time before and (2) after retirement; the assumptions tend to cancel out the errors involved).

Values for p_i

E-3 or below	$p_3 = 0.00$
E-5	$p_5 = 0.10$
E-7	$p_7 = 0.75$
E-9	$p_9 = 1.00$

These values were established from data at Seymour Johnson AFB.[4]

The base pay at retirement.

E-1	$r_1 = 1,344$
E-3	$r_3 = 2,030$
E-5	$r_5 = 3,444$
E-7	$r_7 = 4,536$
E-9	$r_9 = 5,940$

Values for S_{ri} based on pay at retirement.

E-3 or below	$S_{r3} = 0$
E-5	$S_{r5} = 252$
E-7	$S_{r7} = 2,531$
E-9	$S_{r9} = 4,383$

1.4 Training Cost

The 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 Allowances Rate by skill level.

1.4 Summary

Total personnel cost, by skill level, is shown in table VI-1. The values shown under year total do not include the cost of training. Training is shown in a separate column as a per month training charge since the amount of training time varies widely for skill fields.

TABLE VI-1

TOTAL COST BY SKILL LEVEL

Skill Level	Standard Basic Rate	Base Pay at Retirement	Retirement Cost	Year Total	Training (Per Month)
E-1	2,292	1,344	0	2,292	191
E-3	2,724	2,030	0	2,724	-
E-5	4,920	3,444	252	5,172	-
E-7	6,408	4,536	2,531	8,939	-
E-9	8,040	5,940	4,383	12,423	-

2. DEPOT LABOR COST

This cost is obtained from the appropriate Command Workload Group, e.g., Fire Control Systems) Directorate of Material Management, at the Air Force Depot of concern. This labor cost consists of Direct and Indirect cost, with the indirect cost comprising supervision, overhead, and benefits. For WRMMA these costs are:

Direct Labor $2.54 per hour
Indirect $3.36 per hour

For SAMMA the given total cost per labor hour is $8.08

3. PARTS MATERIAL CONSTANT

The parts material constant three was obtained from an analysis of field failure data, viz., three parts replaced per one failure.

4. TRANSPORTATION COST

Transportation cost by commercial air freight varies significantly with distance and weight. There are usually minimum charges, e.g., $4.70 from 1 to 54 pounds. If commercial air freight is used for item shipment, precise quotes may be obtained from Air Freight Agencies. Where regular MATS is used, which will generally be the case, no charge should be incurred, since the absence of shipment would not influence the service. Where special MATS flights are involved, the cost incurred should be based on fuel consumption only.

Where commercial rail or trucking is used, precise price per shipment may be obtained. Where service vehicles are used, fuel consumption, and sustenance per trip should be charged. Personnel vehicles are charged only if the location required additional personnel and/or vehicles to perform this service.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Reliability Branch Engineering Division Rome Air Development Center, GAFB, NY

13. ABSTRACT
This report describes the procedure and results of an investigation to perform an empirical validation of a repair-at-failure maintenance (RAFM) versus discard-at-failure maintenance (DAFM) mathematical modeling technique previously developed by RADC under Contract AF30(602)-2681 and documented in RADC TDR-63-140. In general, the effort met all but one objective successfully. The extent to which complete and rigid statistical testing of model prediction accuracy was limited by the type and quantity of the cost data sample available on the study equipment. A resource cost field data collection and analysis was conducted on a number of operation AF ground and airborne electronic equipments to determine the degree to which model revisions would be necessary to achieve validity. Seven major changes were identified and incorporated. The revised model's validity and prediction capability were demonstrated by application to an airborne electronic equipment. It was concluded that RAFM for the AN/ASG-19 study test vehicle was more economical than DAFM for the existing maintenance and logistic support environment.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Maintenance						
Logistics						
Costs						
Mathematical Models						

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