PAPERS AND DISCUSSION

IN CONNECTION WITH

ARMY TECHNICAL MEETING

ON

QUANTIFICATION OF MAINTAINABILITY

DURING RESEARCH & DEVELOPMENT OF MATERIEL

Sponsored by: Chief of Research and Development

Pentagon, Washington, D. C. July 19, 1965

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Note: This report represents a compilation of papers and discussion pertaining to the July 19, 1965, Army Technical Meeting on Quantification of Maintainability. The viewpoints presented do not necessarily reflect approved positions of the agency represented or of the Department of the Army at this time.

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U. S. Army Missile Command

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Review and Analysis Division
Office of the Chief of Research & Development

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Review and Analysis Division
Office of the Chief of Research & Development

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Office of Assistant Director (Engineering Management)
Office of Director of Defense Research & Engineering

AVCOM RELIABILITY AND MAINTAINABILITY PROGRAM

Mr. D. D. Burchfield
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Colonel John H. Davis
Deputy President
U. S. Army Maintenance Board

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U. S. Army Engineers Research & Development Laboratories

DISTRIBUTION LIST

ABSTRACT

This report presents a compilation of papers presented and discussions recorded at the Army Technical Meeting on Quantification of Maintainability During Research and Development of Materiel sponsored by the Chief of Research and Development at the Pentagon, Washington, D. C., 19 July 1965. Several other papers which were not presented at the meeting due to such factors as late submission are also included herein.

HEADQUARTERS
DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20310

CRD/U2 19 June 1965

SUBJECT: Army Technical Meeting on Quantification of Maintainability During Research and Development of Materiel

TO: SEE DISTRIBUTION

1. The subject of maintainability is receiving rapidly increasing emphasis in the Army and the other Services in line with its increasing potential for improving materiel readiness and reducing support costs. To ensure that the Army R&D community is cognizant of the current state-of-the-art and to provide an exchange of ideas in this promising field, my office is sponsoring a meeting on maintainability, to be held in the Pentagon on 19 July 1965.

2. This will be a "working level" meeting, with the main thrust toward expressing and quantifying maintainability requirements and performance. The requirements of AR 705-26 and AR 705-12 pertaining to maintainability will be a matter of discussion. You are invited to have a representative of your organization participate in the subject meeting Pertinent details are attached as Inclosure 1.

3. The number of attendees should generally be limited to one per addressee. Volunteer presentations are encouraged and attendees are expected to have suitable experience and interests and to actively participate.

4. Names of attendees, subjects for presentation and visual aid needs should be furnished the Office of the Chief of Research and Development (CRD/U2) by 9 July 1965. It will be necessary that travel and TDY expenses be borne by attendee organizations.

1 Incl
as

WILLIAM W. DICK, JR.
Lieutenant General, GS
Chief of Research and Development

DISTRIBUTION:
Chief of Staff, U. S. Army,
ATTN: Director of Coordination & Analysis
Deputy Chief of Staff for Logistics
Assistant Chief of Staff for Force Development

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SUBJECT: Army Technical Meeting on Quantification of Maintainability During Research and Development of Materiel

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- U. S. Army Missile Command, Redstone Arsenal, Alabama
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- U. S. Army Munitions Command, Dover, New Jersey
- U. S. Army Electronics Command, Ft. Monmouth, New Jersey
- U. S. Army Test & Evaluation Command, Aberdeen Proving Ground, Maryland
- U. S. Army Supply and Maintenance Command
- Aberdeen Proving Ground, Maryland
- U. S. Army Mobility Equipment Center, St. Louis, Missouri
- U. S. Army Tank & Automotive Center, Warren, Michigan
- White Sands Missile Range, White Sands, New Mexico
- U. S. Army Electronics Research & Development Activity, Ft. Huachuca, Ariz.
- U. S. Army Aviation Command, St. Louis, Missouri
- Natick Laboratories, Natick, Massachusetts

Commanding Officers
- U. S. Army Chemical Center, Edgewood, Maryland
- Frankford Arsenal, Philadelphia, Pennsylvania
- Engineer Research & Development Laboratories (OEMTB-KI), Ft. Belvoir, Va.
- U. S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Md.
- Harry Diamond Laboratories
- Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland
- U. S. Army Transportation Research Command, Ft. Eustis, Virginia

President, U. S. Army Maintenance Board, Ft. Knox, Kentucky
Chief, Army Management Engineering Training Agency, Rock Island Arsenal, Ill.
Human Resources Research Office, Geo. Washington University
Research Analysis Corporation, McLean, Virginia
CG, U. S. Air Force Systems Command, ATTN: SCSVE, Andrews AFB, Maryland
Office of Naval Materiel, DCNM (Development) (MAT325)

ARMY TECHNICAL MEETING ON QUANTIFICATION OF MAINTAINABILITY (M)
DURING RESEARCH AND DEVELOPMENT OF MATERIEL

1. References:

a. Department of Defense Instruction 3200.6, 7 June 1962, Reporting of Research, Development and Engineering Program Information.

b. AR 705-26, 16 April 1963, Maintainability Program for Materiel and Equipment.

c. MIL-STD-778, 22 April 1964, Maintainability Terms and Definitions.

d. MIL-M-55214(EL), 8 February 1963, Maintainability Requirements, General; for Electronic Equipment.

2. Date: 19 July 1965, 8:45 A.M. to 4:15 P.M.

3. Place: Pentagon, OSD Auditorium, Room 1E801 (1 flight down from Mall or River Entrance).

4. Sponsor: Office of the Chief of Research and Development, Department of the Army.

5. Security Clearance: None required.

6. Attendee Information:

a. Experience and interests: Attendees should be Army military or civilian personnel and should have a generally creative approach to M quantification problems. They will be expected to participate actively and to make a positive contribution to the discussions. It is preferred that the attendee be the incumbent of a position having the responsibility for the actual development and supervision of the M program. Attendees should be technically qualified in at least one of the following:

(1) Maintainability (M) Design

(2) Human Engineering

(3) Systems/Equipment Design

(4) Systems Analysis

(5) Operations Research

(6) Maintenance and logistic support planning

INCLOSURE 1

b. Presentations: Attendees who desire are encouraged to prepare a formal presentation. These presentations should generally be limited to 15 minutes. Written handouts (80 copies) are desirable but content need not be limited to the verbal presentation. Handouts to be distributed without an accompanying formal presentation will also be recognized.

c. Arrangements: Arrangements for presentations should be made by contacting the Arrangements Committee prior to 9 July 1965. Vugraph, projectors, screen, and easel can be made available.

7. Purpose:

a. The primary purpose of this meeting is to explore, expose and generate ideas which hopefully will be useful in the area of M quantification.

b. A secondary purpose of this conference is an exchange of information on present procedures being followed by Army field commands, Navy and the Air Force

8. Background:

a. References 1a and 1b prescribe policies and responsibilities to assure the development of materiel and equipment of known and quantitatively specified M characteristics, including the following:

(1) Planning documents such as Technical Development Plans must describe how M will be achieved, including a specific plan for quantification of M and test plans for M demonstration (reference 1b, paragraphs 7a, 7d, and 7e).

(2) Army procedures and techniques for quantifying M will be published (reference 1b, paragraph 4j).

b. The ability to quantify and to measure M is of fundamental importance. While a good deal of work has been done in this area with some measure of success, much remains to be done before we can specify and measure M with a high degree of confidence and with knowledge as to the precise meaning of what is being done.

9. Definition:

a. Maintainability (M) is a characteristic of design and installation which is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources (reference 1c).

b. Quantification of M is usually in the form of one or more of the following indices rather than a probability:

(1) Corrective Maintenance Downtime.

(a) Mean
(b) Median
(c) Maximum (95th percentile)

(2) Preventive Maintenance Downtime.

(a) Mean
(b) Median
(c) Maximum (95th percentile)

(3) Mean Maintenance Downtime (Corrective and Preventive).

(4) Maintenance man-hour /Operating hour.

(5) Maintenance costs per unit in a given time period.

c. M is sometimes expressed in terms of a weighted check list score as in reference 1d. However, many of the items on these lists are qualitative and do not relate to the probability of accomplishing maintenance in a given time period.

d. M is considered to be dependent on many variables. These may be generally lumped together as:

(1) Design features (including physical design, human engineering, and required support facilities).

(2) Personnel factors (including proficiency and motivational factors).

(3) Support factors (including supply, test equipment, and technical data factors).

10. Problem Areas: The present state-of-the-art includes certain soft areas which tend to detract from the ability to quantify maintainability (M). The net effect of these problem areas is to make it extremely difficult to predict or measure M with any accuracy or even with knowledge of the precise meaning of the figures we are using. Problems include the following:

a. It is difficult to evaluate how far to go in a M program, including how far to go in quantification, because the associated cost (i.e., added acquisition costs vs reduced support costs) are not well known for each of the various alternatives.

b. The number of factors or variables which are known to affect M, in some way, is very large. There may be unknown factors. The exact relationship of M to many of the known factors is unknown or else only grossly known. This is particularly true of the factors involving humans. In addition, the distribution associated with the variables may be unknown or have very wide variance (for example, the speed of maintenance personnel in accomplishing a specific task).

c. The pertinent variables may or may not be independent. Further, the relationship of M to these variables may be complex (i.e., non-linear), or certain variables may not lend themselves to expression in a mathematical sense at all.

d. Certain variables may be difficult to control or measure in specific test or use situations.

e. Available data on specific equipments are usually limited in quantity and not such that all the pertinent variables are well defined.

f. M associated with the system is a distinct dependent variable from M of subsystems or components (the relationship being shown by a mathematical model). The problem here usually is getting sufficient information from the user to know what he really wants and what tradeoffs are permissible.

g. Demonstration of M usually involves simulation rather than actual operating conditions.

h. Techniques for predicting and demonstrating logistic and administrative downtimes, which often constitute most of the total downtime under actual conditions, are essentially nonexistent.

i. Prediction and demonstration are further complicated if it is desired to separate maintenance echelons.

j. Prediction of M growth through development, test, and use phases presents further difficulties.

k. Certain inherently qualitative elements are difficult to avoid in the assessment of M.

11. Discussion Guide: Discussions are to consist mainly of uninhibited, informal conversations which will welcome ideas whether or not they conform to present policies or procedures, and will include the following:

a. Problem areas indicated above as well as others presented by participants.

b. Identification of any needed breakthroughs, studies or research with specific recommendations as to a course of action.

c. Specific recommendations as to needed policy or procedural changes.

d. Specific recommendations for procedures which should be followed by the Army (using and developing) field commands.

12. Tentative Agenda:

0845 - 0900	Registration.
0900 - 0910	Welcome by Chief, Research and Development.
0910 - 0915	Administrative remarks.
0915 - 1010	Presentations by Navy and Air Force Representatives.
1010 - 1020	Questions directed to Navy and Air Force speakers.
1020 - 1145	Presentations by Army Representatives.
1145 - 1245	Lunch.
1245 - 1400	Presentations by Army Representatives.
1400 - 1425	Questions directed to Army speakers.
1425 - 1445	Coffee Break.
1445 - 1545	Open Discussion moderated by Abraham S. Pollack, OCRD.
1545 - 1605	Summarization by Lt Colonel Gerald E. Ledford, OCRD.
1605 - 1615	Closing remarks.

13. Arrangements Committee: Mr. Abraham S. Pollack and Lt Colonel Gerald E. Ledford, Department of the Army, Office of the Chief of Research and Development (CRD/U2), Pentagon, Washington, D. C. 20310, OX 5-6533 or OX 7-8544.

AGENDA

ARMY TECHNICAL MEETING ON QUANTIFICATION OF MAINTAINABILITY DURING RESEARCH AND DEVELOPMENT OF MATERIEL

19 JULY 65

OSD AUDITORIUM, Rm 1E801, PENTAGON

0845 - 0900	REGISTRATION
0900 - 0910	WELCOME by Lt. Gen. William W. Dick, Chief of Research and Development, Department of the Army
0910 - 0915	Administrative Remarks
0915 - 0920	DOD MAINTAINABILITY PROGRAM Albert L. Jackson, Jr., Office of Asst Dir (Engr Mgmt), DDRE
0920 - 0945	MAINTAINABILITY MEASUREMENTS Cmdr. Keith N. Sargent, Systems Effectiveness Branch, Office of Naval Material
0945 - 1020	QUANTIFICATION OF MAINTAINABILITY Major Richard R. Stanton Systems Effectiveness Division, Systems Policy Directorate, Air Force Systems Command
1020 - 1040	INTRODUCTION OF SYSTEM EFFECTIVENESS PARAMETERS IN SYSTEM SPECIFICATIONS Leonard Weingarten, Research Analysis Corporation
1040 - 1100	TEN NEW CONCEPTS FOR ELECTRONIC MAINTENANCE Dr. E. L. Shriver, Human Resources Research Office, George Washington University
1100 - 1120	COFFEE
1120 - 1135	EFFECT OF MAINTAINABILITY ON MAINTENANCE & LOGISTICS SUPPORT PLANNING AND HOW TO MEASURE THIS EFFECT Colonel Elwin T. Knight, Maintenance Readiness Division, U. S. Army Supply & Maintenance Command
1135 - 1150	THE ARMY'S MAINTAINABILITY DILEMMA - COMMUNICATION Charles D. Cox, Research & Development Directorate, U. S. Army Missile Command

1150 - 1210	SOME PROBLEMS IN DEFINING MAINTAINABILITY & ASSOCIATED TERMS H. Walter Price, Reliability Branch, Harry Diamond Laboratories
1210 - 1225	APPLICATIONS OF MIL-M-55214(EL), MAINTAINABILITY REQUIREMENTS FOR ELECTRONIC EQUIPMENT Michael I. Bonosevich, Materiel Readiness Directorate, U. S. Army Electronics Command
1225 - 1240	OPERATION WOODPILE - DEVELOPMENT OF TECHNIQUES FOR MAINTAINABILITY DEMONSTRATION Michael Bialkowski, U. S. Army Electronics R&D Activity, Fort Huachuca
1240 - 1300	HUMAN ENGINEERING RELATIONSHIPS TO MAINTAINABILITY MEASUREMENT B. L. Sova, Systems Research Laboratory, Human Engineering Laboratories
1300 - 1400	LUNCH - EXECUTIVE DINING ROOM/GENERAL & FLAG OFFICERS' LOUNGE Room 3C1063/3C1065
1400 - 1415	USING MAINTENANCE FLOAT TO MEASURE MONEY VALUE OF MAINTAINABILITY Boris Levine, Troops and Material Branch, Military Engineering Division, Office, Chief of Engineers
1415 - 1430	SCIENTIFIC AND TECHNICAL APPLICATIONS FORECAST ON RESEARCH ON MATERIEL FAILURES Sumner Meiselman, Research Plans Office, Army Research Office
1430 - 1600	DISCUSSION: QUESTIONS, PROBLEMS, CHALLENGES AND RECOMMENDATIONS Moderator - Abraham S. Pollack, Review and Analysis Division, Office of the Chief of Research and Development
1600 - 1615	SUMMARIZATION AND CONCLUDING REMARKS Lt Colonel Gerald E. Ledford, Review and Analysis Division, Office of the Chief of Research and Development

A T T E N D A N C E

Army Technical Meeting on Quantification of Maintainability

During Research and Development of Materiel

NAME	AGENCY
Andrew, Robert T.	USAMC
Antetomaso, Leroy F.	Edgewood Arsenal
Bialkowski, Michael	USAEL R&D Activity
Bona, Arthur B.	USAMC
Bonosevich, Michael I.	USAECOM
Bruno, O. P.	BRL
Burchfield, D. D.	USA AVCOM
Burke, Gerald D.	USAMC
Burnett, W. P.	USA MICOM
Byrne, Robert J.	Natick Laboratories
Carthage, W.	USA MUCOM
Christianson, C. J.	RAC
Clarkson, Richard L., Lt Col	OCRD
Cole, Myron C.	ERDL
Courtney, Robert L.	WSMR
Cox, Charles D.	USAMICOM
Daniel, J. Nelson	AV LABS
Diamantes, Thomas, Lt Col	USACDC
Erickson, J. D., Col	OCRD
Frishman, Fred	ARO
Gardner, Edson	USAMC
Golub, Abraham	OASA(FM)
Harboe, Mr.	ERDL
Jackson, Albert L.	DDRE
Kaufman, Joseph	USAMC
Kicak, John	USAMC
Knight, Elwin T., Col	USA SMC (AMSSM-MR-M)
Krause, Norman C.	USAMC (QA)
Kulp, Richard	HUMRRO
Ledford, G. E., Lt Col	OCRD
Levine, Boris	OCE
Lewett, G. P.	USACDC/CORG
Marlin, R. B., Brig Gen	OCRD
McMenamin, E. P.	Frankford Arsenal
Meiselman, Sumner	ARO
Myron, Paul	ATAC
Norton, John V.	USAMB
Nucci, E. J.	DDRE
Olsen, C. L.	ERDL
Pile, Benjamin D.	Med Equip R&D Lab, Ft. Totten, N.Y.

NAME	AGENCY
Pollack, Abraham S.	OCRD
Price, H. Walter	HDL
Rhodes, Joseph F.	USAMC
Richardson, Orrie H.	USA TECOM
Riegle, C. A., Col	OCRD
Sands, Spencer C.	USAMEC (SMOME-M)
Sammet, George Jr., Col	OCRD
Sargent, Keith N., Cmdr.	Office Naval Materiel
Sasmor, Robert, Dr.	APRO
Schroeder, R. L., Major	OCSA
Shriver, E. L., Dr.	HUMRRO
Sibthorp, George	DCSLOG
Sova, B. Lawrence	HEL
Stanton, R. R., Major	USAF (SCSVE)
Suarez, John	ASA
Sweet, Ernest	USA MOCOM (AMSMO-RD-DS)
Tate, Perry L.	USAMC
Uhrig, P. K.	ATAC
Uzzo, Sal I.	USA WECOM
Weingarten, Leonard	RAC
Wilder, A. D., Col	DCSLOG
Wilson, T. L.	USA SMC
Woodside, Chas. R.	OASA(R&D)
Yeargin, B. A.	ACSFOR
Ziegenhorn, Orville E.	USA WECOM

PURPOSE

In addition to reporting on the indicated meeting, it is hoped that the material contained herein will prove useful to future Army efforts in the area of Maintainability including management of specific Department of the Army projects, and technical meetings related to this subject. This report is addressed both to those individuals concerned with planning, management and implementation of materiel development projects and those concerned with logistics/personnel support of this materiel in the field.

The purpose of the meeting is indicated in the 19 June 1965, letter of invitation from the Chief of Research and Development which initiated the meeting (and which is included in this report).

PROCEEDINGS AND REFERENCES

a. Presentations:

The agenda, which is included herein, indicates generally how the meeting proceeded. Each speaker submitted a paper which is included herein (see contents) and which contains substantially what he presented as well as some additional material in some cases.

b. Other Discussions:

Lt General William W. Dick, Jr., opened the meeting by welcoming the attendees. His remarks included emphasis on the importance of materiel readiness to the Army. Mr. Albert L. Jackson gave a short summary of the Department of Defense Maintainability Program, noting that a package of two MIL-STD's and one MIL HDBK on M should be completed before the end of this year.

A usable tape recording was available only for the discussion and summarization periods at the end of the meeting, which are transcribed herein. An incomplete list of points made at the meeting during other question, answer, and discussion intervals follows:

1. Maintainability requirements must be tailored to the specific procurement.

2. Demonstration tests can be used as the start of a data pool and point of departure for data from actual field operations.

3. Required field data should be realistic in terms of what data will likely be filled in at all as well as what is needed for retrofit, logistics and design.

4. Full life cycle costs need to be recognized.

5. A non-compartmentalized overall systems approach must be used rather than attempting to optimize based on individual disciplines such as Maintainability by itself.

6. Maintainability verification should be integrated with other tests including flight tests, etc.

7. Further research is needed to develop a reasonably useful ability to quantify Maintainability.

8. A better data base is required.

9. Setting realistic operational requirements do not just involve CDC but rather an iterative dialogue between CDC and AMC. They also reflect consideration of available dollars.

c. Other Reference Publications:

Certain other publications not included herein were available for distribution to the attendees at the meeting or were mentioned at the meeting as being of interest to the attendees. In addition some other related material has been distributed by mail to the attendees. These other reference publications are as follows:

1. "System Effectiveness," January 1965. Address inquiries as to availability to Office of Naval Materiel, Systems Effectiveness Branch, Washington, D. C. (Telephone Number: Area Code 202, Oxford 6-5120 or 6-5110).

2. "Maintainability Study; Tractor, Universal, Engineer, Rubber-tired; (UET-RT) Model III, Diesel Driven, w/Scraper Center Section," February 1963. (Uses technique based on that developed by National Security Industrial Association, Maintenance Advisory Committee, Maintenance Reliabilt y and Maintainability Panel). Address inquiries as to availability to U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, ATTN: (OMEFB-KI) Mr. C. L. Olson. (Telephone Number: Area Code 70_, 781-8500 Extension 64128).

3. Military Specification MIL-M-55214(EL), 8 February 1963, "Maintainability Requirements, General; for Electronic Equipment.

4. "Maintainability Engineering Guide," 1 May 1964, Report No. RC-S-64-1. Address inquiries as to availability to Defense Documentation Center or to U. S. Army Missile Command, Redstone Arsenal, Alabama 35809 ATTN: (AMSMI-RCR) Mr. Charles D. Cox. (Telephone Number: 876-2835).

5. "Maintenance Participation through the Development Phase" by Mr. William J. Donnelly prepared for the Army Maintenance Seminar, St. Louis, Missouri, 13-14 April 1965. Address inquiries as to availability to U. S. Army Munitions Command, Dover, New Jersey, ATTN: AMSMU-SM-MC.

6. "Development of an Index of Electronic Maintainability" by Manus R. Munger and M. Paul Willis of Human Factors Office, American Institute for Research, Pittsburgh, Pennsylvania, 1959. Address inquiries

as to availability to U. S. Army Electronics Command, Fort Monmouth, New Jersey, ATTN: (AMSEL-MR-NMP) Mr. M. Bonosevich.

7. "Maintainability: A Major Element of System Effectiveness" by A. S. Goldman and T. B. Slattery, p/o University of California Engineering and Physical Sciences Extension Series. Copyright 1964 by John Wiley and Sons.

MAINTAINABILITY MEASUREMENTS

REMARKS BY

CDR KEITH N. SARGENT, USN

HEAD, SYSTEMS EFFECTIVENESS BRANCH

OFFICE OF THE CHIEF OF NAVAL MATERIAL

PRESENTED AT THE U.S. ARMY TECHNICAL MEETING

ON QUANTIFICATION OF MAINTAINABILITY ON 19 JULY 1965

IN WASHINGTON, D.C.

MAINTAINABILITY MEASUREMENT

Before launching into a discussion of Maintainability Measurement, one should first establish the terms of reference to be used and the total context within which these terms are to be used. This can be a tedious process which tends to demean the listener who is an expert in the area. However, one real lesson which this author has learned is that in any analytical area, failure to carefully define results in confusion and misunderstandings and upon occasion, can lead to fatal defects in analytical approaches.

To avoid this type of difficulty, we have developed a triad model as a means for keeping our analyses in context and as a base for our specific definitions. The model takes two forms, the conceptual and the functional. The conceptual triad has been presented in a number of papers by Stone, Rohe, Jayne, and others as well as this author.

(SLIDE #1)

This is the basic expression for Systems Effectiveness which, in itself, is a triad:

$$E_s = PAU$$

Where: E_s = Systems Effectiveness Index

P = Index of Performance

A = Index of Availability

U = Index of Utilization

(SLIDE #2)

The second expression of the triad is that for Cost Effectiveness:

$$E_c = \frac{PAU}{C_a + C_u}$$

Where: E_c = Cost Effectiveness Index

C_a = Cost of Acquisition

C_u = Cost of Utilization - and -

P, A, & U are as indicated in the basic expression.

(SLIDE #3)

The third expression is for the concept of Defense Effectiveness:

$$E_d = \frac{W}{E_t} \left(\frac{PAU}{C_a + C_u} \right)$$

Where: E_d = Defense Effectiveness Index

W = Index of Military Worth

E_t = Index of degradation of military worth as a function of time - and - the remaining terms are as previously described

Implicit in the consideration of this triad is a fundamental axiom, "The sole philosophical end of any given military system is mission accomplishment". This becomes explicit through the use of the indices. In P, A & U the base for their indices is absolute mission accomplishment of the system. The term W likewise is an index of mission accomplishment but to the somewhat broader base of service mission.

To give somewhat more substance to the conceptual model, we have developed the functional model triad.

(SLIDE #4)

Here is shown the functional equivalent to the basic expression $E_s = PAU$. We will come back to this model in a moment.

(FLIP #1)

To the basic functional model, we have added the cost factors. In the end analysis the cost factors are taken in aggregate. Nevertheless, there are associative relationships between costs and the individual elements of our basic model structure. In earlier papers the term W, or Military Worth was included in the Cost Effectiveness expression. In this model, military worth is not addressed. This then is the functional equivalent of the conceptual model $E_c = \frac{PAU}{C_a + C_u}$ shown earlier. From an analytical standpoint, this is a cleaner approach [illegible] problem is that in top defense management circles, we find the term Cost Effectiveness being used to include considerations of military worth. It is therefore, necessary to include these considerations in the model at [illegible] until such time as we can gain acceptance of the notion of defense effectiveness.

(FLIP #2)

The choice between the two expressions will be discussed a bit later.

Completing our triad is the functional model for Defense Effectiveness. The considerations of military worth to the service or DoD mission accomplishment and its degradation as a function of time are introduced. This time degradation can stem from any phase in the life cycle of the system and is not limited to R&D schedule considerations.

(REMOVE FLIPS 1 & 2)

Returning to the basic functional model, we find the term A as the center of the structure. This substructure has two main stems, machine modules and man modules. These are held together by a characteristic called compatibility. You will note that maintainability is an element of both stems. For the purposes of this presentation, we will acknowledge that maintainability of man module functions is an element to be considered. However, the remainder of our time will be addressed to the maintainability of the machine module(s) and measurement thereof.

In this model structure, maintainability has been separated into two major areas, (SLIDE #5) repairability and serviceability.

In an attempt to reduce, if not eliminate, misunderstandings, definitions of these terms are postulated.

(SLIDE #6)

Maintainability - A measure of the extent to which a system can be expected to remain in service or be restored to service through maintenance action.

(SLIDE #7)

Repairability - A measure of the extent to which a system, which is down, can be restored to service through maintenance action.

(SLIDE #8)

Serviceability - A measure of the extent to which a system can be expected to remain in service through maintenance action.

(SLIDE #8 off)

From the foregoing definitions three things become quite clear. First, we are addressing the capability for maintenance action. Second, we must be able to measure this capability. Third - and of primary significance - The focus of both is minimizing downtime. It follows then that we must address maintenance in terms of time.

In order to attack the problem one must separate the various time factors. Let us look at repairability first.

While repair action can be discretely measured after the fact, repair prediction or repairability must be expressed in parametric terms with associated distributions. This then leads to a probability approach to measurement. Thus repairability can be expressed as

(SLIDE #9) $$P(t \leq T) \int_0^T f(t)dt$$

What we wish to do is minimize the downtime or find

(SLIDE #10) $$\text{Min } t_D = t_A + t_W$$

Where

t_D is the downtime,

t_A = active downtime, and

t_W = waiting time

(SLIDE #11) In turn, both t_A and t_W may be further subdivided as follows:

1. Active Downtime

$$t_A = t_{det} + t_{diag} + t_{corr} + t_{verif}$$

Where

t_{det} = detection time (recognized)

t_{diag} = diagnostic time (localize and isolate)

t_{corr} = corrective time (disassemble, remove, replace, reassemble)

t_{verif} = verification time (alignment and checkout)

(SLIDE #12) 2. Delay Time

$$t_W = t_u + t_m + t_p + t_l + t_a$$

Where

t_u = undetected failure delay time

t_m = maintenance technician delay time

t_p = preparation delay time

t_l = logistics delay time

t_a = administrative delay time

The undetected failure delay time includes the time that the system is in a failed state and is not noticed either because it is not monitored or not indicated, or is between system checks.

The maintenance technician delay time includes time to notify technician and for him to become available to start a maintenance action.

The preparation delay time includes time for technician to gather tools, test equipment, manuals, etc., to start the repair sequence.

The logistics delay time includes the time required to obtain spare parts either on board or from an external source.

The administrative delay time includes any other delay times which might prevent repair action from being performed.

The foregoing makes a neat approach to the measurement of repairability. Each of the contributing elements can be discretely measured and quite logically add up. While they add up in logic, they do not always add up in fact.

(SLIDE #13)

In those instances where the measured events are exclusive there is no problem as illustrated in the top half of the figure. However, when the measured events are not exclusive, as shown in the bottom half of the figure, actual down time will be less than predicted. Since the introduced error is in the conservative direction, this need not be viewed with great alarm. Nevertheless, it is an area which requires additional examination and analysis.

(SLIDE #13 off)

While we do have the foregoing tools with which to analyze problems and reinforce or support experience based intuitive judgement, a great deal of theoretical work remains to be done before repairability prediction becomes a scientific tool.

In the area of serviceability our approach is even less scientific. While the mechanics of designing a system with serviceability in terms of accessibility, test points, monitoring, etc. are fairly well understood, the degree to which this contributes to maintainability is not. Much of the highly touted preventive maintenance approach is being questioned and re-examined. As with repairability, we are lacking in an understanding of generalizations of functions of a rather well appreciated concept.

Any experienced maintainer can provide an opinion on the repairability, serviceability and resultant maintainability of a system. As a matter of fact, he usually is not too far wrong in his assessment when compared with subsequent experience in his own organization. Frequently, one can obtain fairly general agreement among the maintainers' assessments. However, one seldom finds agreement among the rationales supporting these assessments.

This is the enigma facing the maintainability theorist. At the present stage of development of maintainability theory, it is not yet clear what distribution (if any single distribution will suffice) is proper for describing maintenance actions which would be performed where chance failures occur. There is much evidence to indicate that the lognormal distribution is suitable or fits many cases and that the exponential distribution is suitable in only a few. But there are various versions of the lognormal distribution depending upon how many parameters are used to characterize the distribution. Much work is going on at the present time in this area. Whereas the exponential distribution makes use of an arithmetic meantime of the parameter, the lognormal distribution makes use of a geometric meantime of the parameter or an arithmetic meantime of the log of the parameter. Assuming that the lognormal distribution is a proper one, then the expression for maintainability assumes a more complex form.

From the foregoing, one might conclude that we are in pretty poor shape. Please disabuse your minds of that idea. Certainly we have much to do to refine the tools for measuring maintainability with exactitude. But - the American Indian built canoes with the crudest of implements that functioned for their purposes as well as any built today. We, too, can build systems, using relatively crude tools, which have maintainability at acceptable levels. That we don't always do it is more attributable to the user of the tool than the tool - or perhaps more to the point - attributable to the designer who doesn't even bother to use the tools that are available.

We do know how to measure maintenance and from this can extrapolate to similar situations by way of predicting maintainability. While this is not exact, it does provide coarse guidance. Parenthetically you can spell it COARSE or COURSE as you will. Our current press for Systems Effectiveness effort in the Navy has as one of its objectives the structuring of a discipline which requires use of the tools for maintainability prediction. Crude as these indices may be, their use will insure that we are in the right ball park at least. As we become more adept in their use, we'll find ways to sharpen their edges.

This, in brief, is how we are approaching maintainability in the Navy. While we are attempting to develop an acceptable theory of maintainability, we are placing great emphasis on the use of the analytical tools we do have available. Our principal concern is to keep our maintainability work in context with our end objective of mission accomplishment. We recognize that maintainability for maintainability's sake is not justified. Although a very important area, maintainability is but one element of our systems effectiveness effort.

In conslusion I feel that I should make our position clear with regard to this meeting. In my shop NIH has but one meaning, National Institute of Health. My principal purpose here is not to blind you with the Navy's brilliance in the field of maintainability quantification. Rather, I intend to learn all I can about your achievements in the Army. We will have no compunction whatsoever in appropriating your successes for our own use. I just hope we're smart enough to recognize a success when we see it.

$E_s = PAU$

E_s IS SYSTEMS EFFECTIVENESS

P - PERFORMANCE

A - AVAILABILITY

U - UTILIZATION

$$E_c = \frac{PAU}{C_a + C_u}$$

E_c – COST EFFECTIVENESS

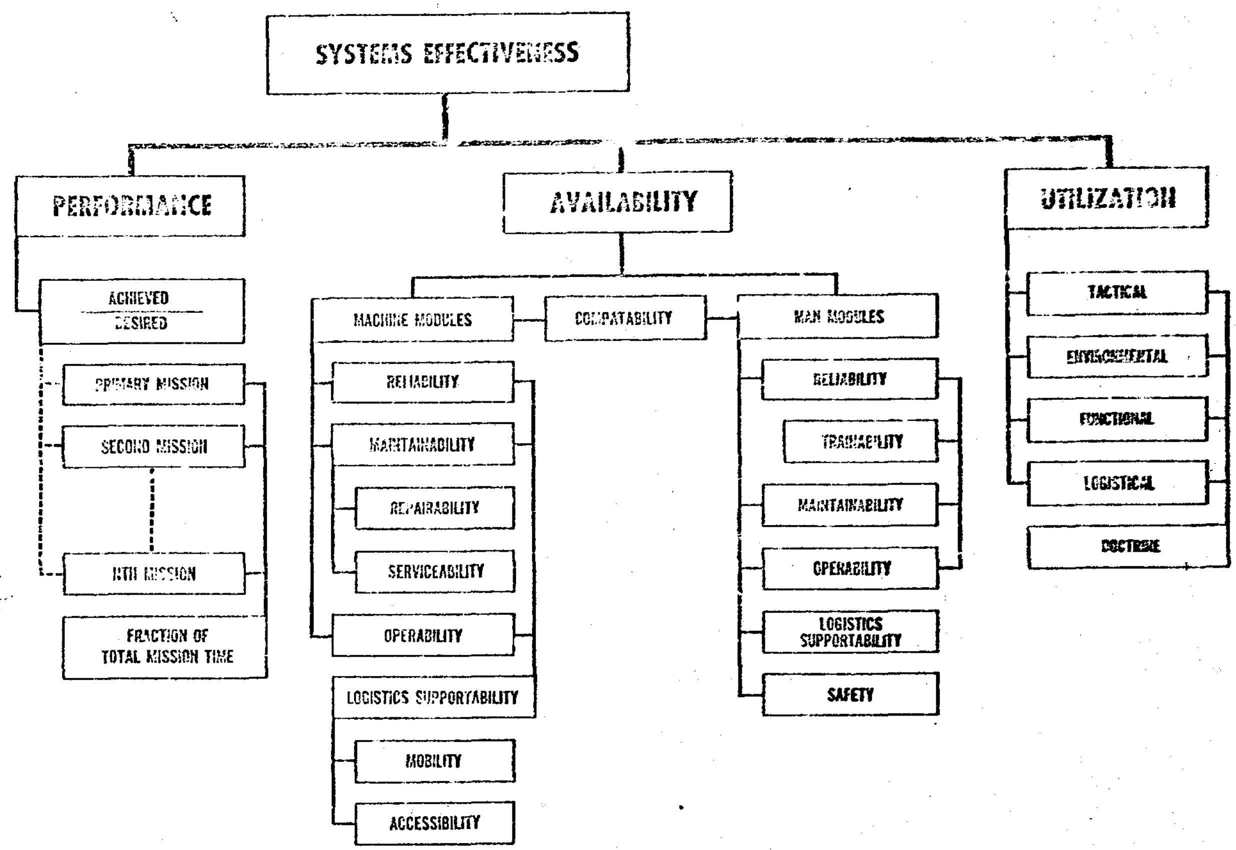
C_a – COST OF ACQUISITION

C_u – COST OF UTILZATION

SLIDE 2

$$Ed = \frac{W}{E_t}\left(\frac{PAU}{C_a + C_u}\right)$$

LIDE 3


SYSTEMS EFFECTIVENESS
PERFORMANCE
ACHIEVED
DESIRED
PRIMARY MISSION
SECOND MISSION
NTH MISSION
FRACTION OF TOTAL MISSION TIME
AVAILABILITY
MACHINE MODULES
RELIABILITY
MAINTAINABILITY
REPAIRABILITY
SERVICEABILITY
OPERABILITY
LOGISTICS SUPPORTABILITY
MOBILITY
ACCESSIBILITY
COMPATABILITY
MAN MODULES
RELIABILITY
TRAINABILITY
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SAFETY
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TACTICAL
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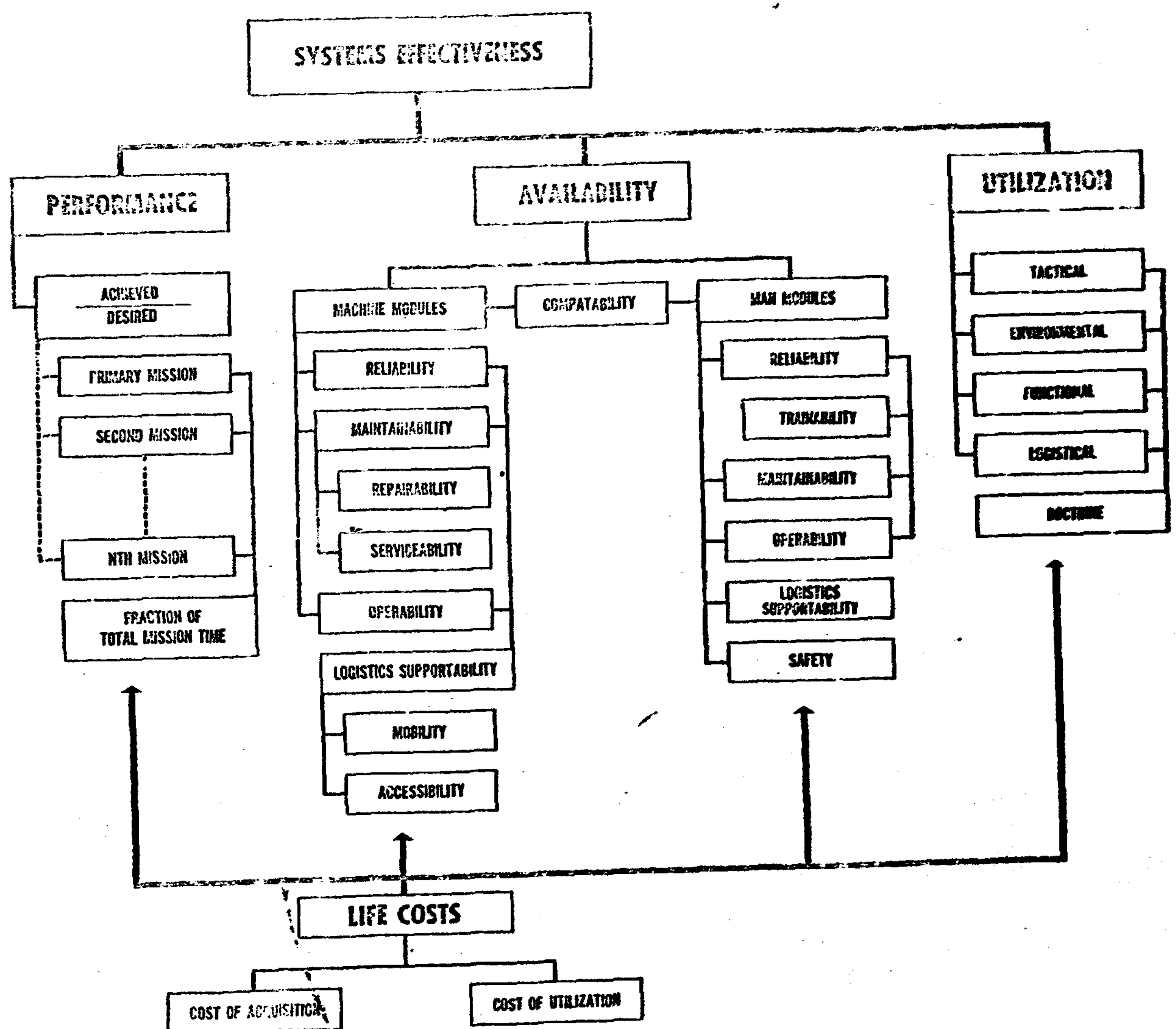
DOCTRINE

SLIDE 4


SYSTEMS EFFECTIVENESS
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COMPATABILITY
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OPERABILITY
LOGISTICS SUPPORTABILITY
SAFETY
UTILIZATION
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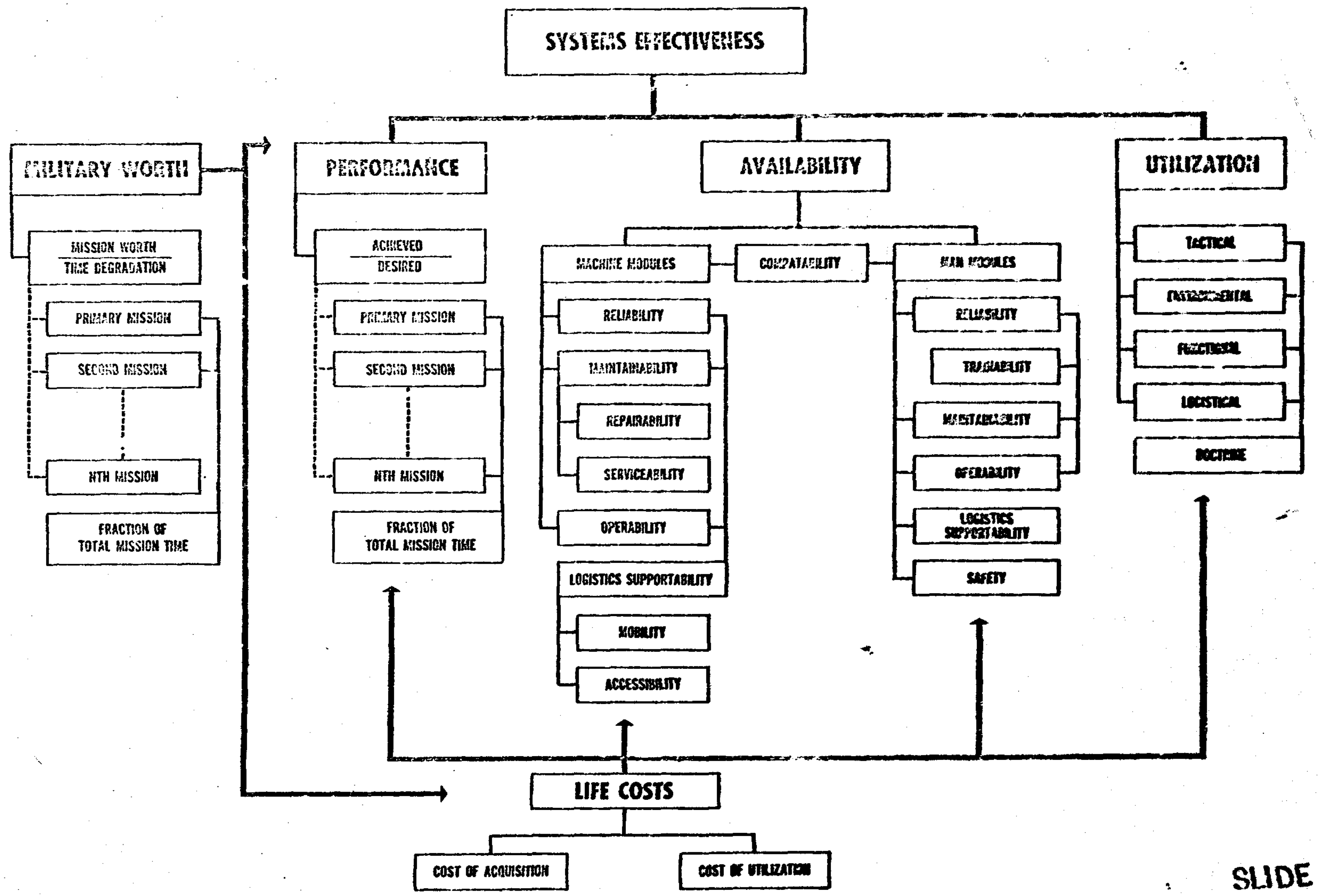
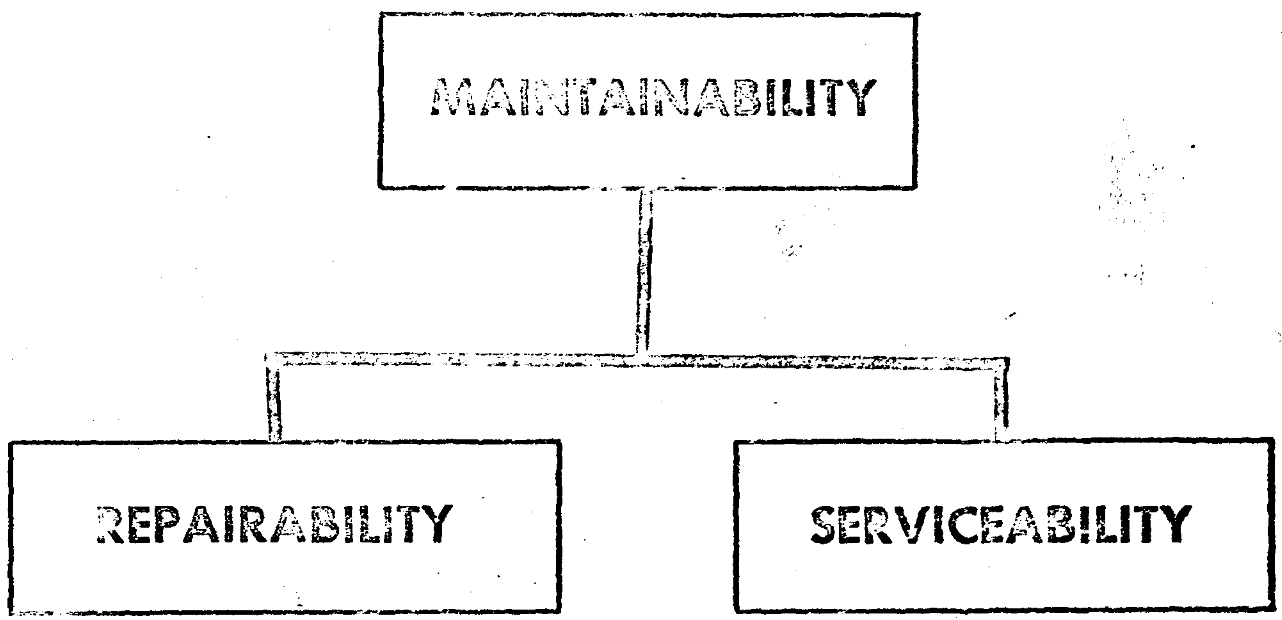
DOCTRINE
LIFE COSTS
COST OF ACQUISITION
COST OF UTILIZATION

SLIDE
FLIP



SLIDE 4
FLIP 2



SLIDE 5

MAINTAINABILITY - A MEASURE OF THE EXTENT TO WHICH A SYSTEM CAN BE EXPECTED TO REMAIN IN SERVICE OR BE RESTORED TO SERVICE THROUGH MAINTENANCE ACTION.

SLIDE 6

REPAIRABILITY - A MEASURE OF THE EXTENT TO WHICH A SYSTEM, WHICH IS DOWN, CAN BE RESTORED TO SERVICE THROUGH MAINTENANCE ACTION.

SLIDE 7

SERVICEABILITY - A MEASURE OF THE EXTENT TO WHICH A SYSTEM CAN BE EXPECTED TO REMAIN IN SERVICE THROUGH MAINTENANCE ACTION.

SLIDE 2

$$P(t \leq T) \int_0^T f(t)\,dt$$

SLIDE 9

$$\text{Min } t_D = t_A + t_W$$

Where

t_D is the downtime,

t_A = active downtime, and

t_W = waiting time

SLIDE 10

$$t_A = t_{det} + t_{diag} + t_{corr} + t_{verif}$$

Where

t_{det} = detection time (recognized)

t_{diag} = diagnostic time (localize and isolate)

t_{corr} = corrective time (disassemble, remove, replace, reassemble)

t_{verif} = verification time (alignment and checkout)

SLIDE 11

$$t_W = t_u + t_m + t_p + t_l + t_a$$

Where

t_u = undetected failure delay time

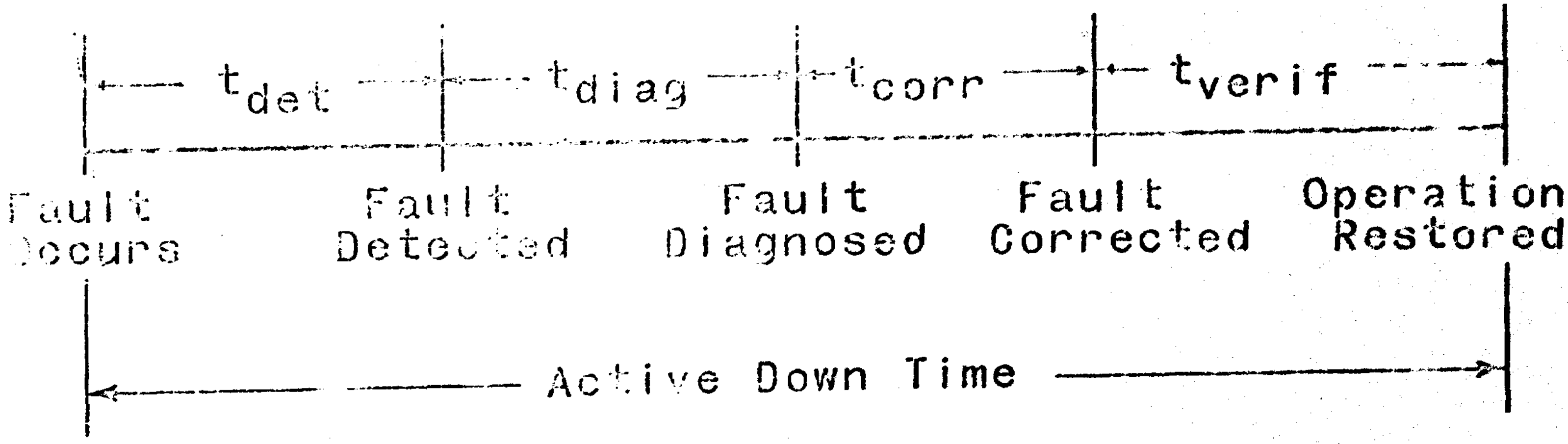
t_m = maintenance technician delay time

t_p = preparation delay time

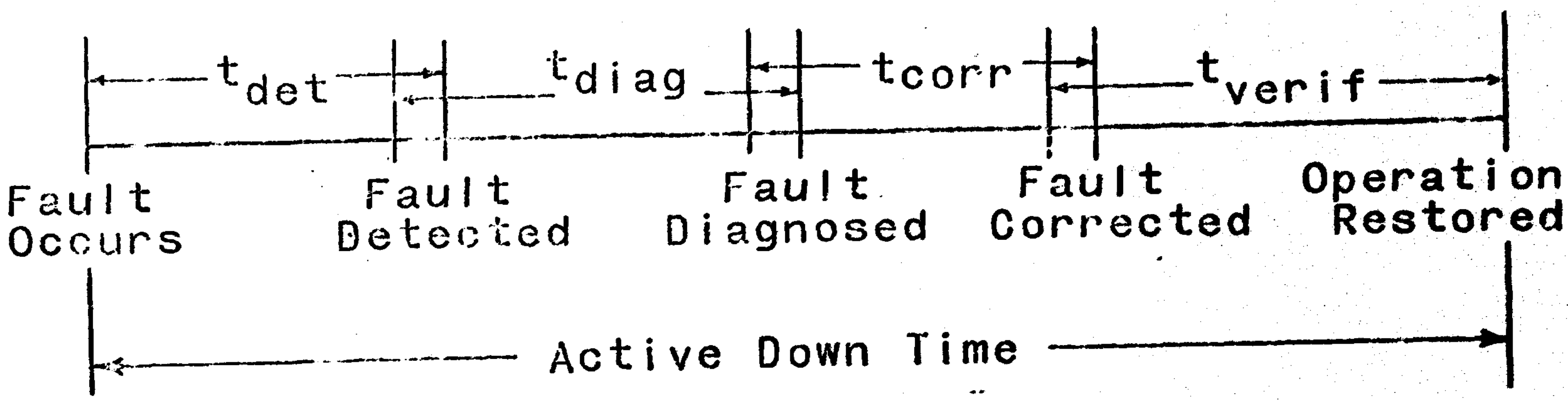
t_l = logistics delay time

t_a = administrative delay time

SLIDE 12



Exclusive Events



Overlapping Events

SLIDE 13

"QUANTIFICATION OF MAINTAINABILITY"

by

Majors Frank H. Moxley, Jr.

and Richard R. Stanton

19 July 1965

Headquarters Air Force Systems Command

Systems Effectiveness Division

Deputy Chief of Staff/Systems

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TABLE OF CONTENTS

QUANTIFICATION OF MAINTAINABILITY

I. INTRODUCTION

The purpose of this presentation is to give to you some of the current Air Force thinking on the subject, "Quantification of Maintainability." But before the question, "How to Quantify Maintainability"?, can be answered, the term Maintainability (M) must be rigorously defined. In 1964 the Air Force, other services, and the Department of Defense defined and published a M definition, along with other terms relating to M in MIL-STD-778, "Maintainability Terms and Definitions."

The Air Force has found this to be an acceptable and useful definition, although there have been many misconceptions and perhaps some changes are needed to clarify the definition. Let us look at the definition very closely since all quantification of M must stem from the definition itself.

II. THE MAINTAINABILITY DEFINITION

The current definition of M in MIL-STD-778 is: "Maintainability is a characteristic of design and installation which is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources." Many people have misunderstood the portions "item will conform" and "given time period" and the rigorous probablistic concept which stems from the definition. (Chart 1). Therefore we recommend the following definition, which has slight changes for clarity, be adopted: "Maintainability is a characteristic of design and installation which is expressed as the probability that the maintenance action to restore an item to specified conditions or to verify that an item conforms to specified conditions can be completed within a specified time period when maintenance is performed in accordance with prescribed procedures and resources."

III. EXAMINATION OF RECOMMENDED DEFINITION

Let's concentrate on the proposed definition briefly and segmentally examine it in detail. (Chart 2). "M is a characteristic of design and installation"...is the first segment. M is a design parameter that can be specified and measured, and for which the customer is willing to pay. The purpose of M engineers is to influence design to achieve M requirements and thus M is now an acceptable engineering function.

(Chart 3). Now looking at the next segment..."which is expressed as a probability...", this connotes dependence upon probability and related statistical theory. You cannot avoid the question, "How are the values of repair times distributed?", particularly if you are initially trying to answer the question, "How long on the average does it take to repair the equipment once it fails?" Note the generalized term "average" itself has numerous statistical meanings; e.g., arithmetic mean, geometric mean, median, and mode. So to determine how repair times are distributed we need to plot and examine empirical data, and use curve fitting techniques to gain insight into the probability density function and associated cumulative distribution function. Then, once the type of distribution of repair times is known, we also have knowledge of its shaping and location parameters. Assigning values to these distribution shaping and location parameters becomes the basis of specifying quantitative maintainability requirements. Thus, we see that statistical knowledge and and ability are essential to M.

(Chart 4). Looking at the following segment of the proposed definition... "that the maintenance action to restore an item to specified conditions or to verify that an item conforms to specified conditions....", we see that the definition includes both preventive and corrective maintenance actions, as it should, and that the conditions must be specified. That is, the functional operating conditions which establish acceptable or non-failed operation must be identified in order to judge conformance. Also peculiar or special conditions such as contamination limits, for example, as in the case of servicing a hydraulic system, should be specified to judge conformance.

(Chart 5). The next segment of the definition is..."can be completed within a specified time period..." M basically concerns time as an element for specification, prediction and demonstration. Time as a measure of maintenance action is still the foundation of M data, and other methods of quantitatively specifying M will be shown to emanate from time measurement a bit later. Also referring to the probability aspects of the definition discussed earlier, it is obvious that "time-to-repair" logically fits the "random variable" statistical requirement. Maintenance times are distributed according to a probability distribution.

(Chart 6). Now we turn to the final segment of the definition which is... "when maintenance is performed in accordance with prescribed procedures and resources." The term "resources" include tools, data, equipment, training, facilities, spares, manpower, and possibly others. The term "procedures" involves the maintenance concept and environment and policy as they affect formal documentation of maintenance techniques and procedures in technical data such as tech orders. The term "prescribed" is a key term. It is this part of the definition that makes it incumbent upon the procuring activity to unequivocally stipulate contractually any constraints imposed upon the design in terms of limitations on resources and to insure that the maintenance concept and maintenance environment are clearly identified for the contractor.

IV. TIME AS BASIS FOR QUANTIFICATION

There was one point in the discussion of the definition I indicated I would return to. Undoubtedly many of you are concerned that the definition of M is concerned with time as a basis of specification, prediction and demonstration. (Chart 7). Secondly you will maintain that our current service specifications, in fact, the current draft of tri-service MIL-STD, "Requirements for a Maintainability Program" contains examples of quantitative terms categorized as to time, rate, maintenance complexity, maintenance costs and accuracy. We maintain that with the exception of "accuracy" the lower hierarchy data base is "time" as a measure. The hierarchy of system models alluded to is as follows: (Chart 8) As you can see there is a natural ordering of mathematical models used in the systems engineering process in which system reliability and maintainability models' outputs provide input data to higher order models for logistical and sytem/cost effectiveness decisions, and these R and M models are time-base oriented. This then is the realm of the M engineer. In his efforts to influence design to control maintenance time requirements, he also is affecting maintenance rate, complexity, and cost considerations which may be derived from higher order models. However, he cannot affect them autonomously.

V. AVAILABILITY AS A QUANTITATIVE MEASURE

Perhaps we should take time also to recognize that specifying an "availability" requirement is an indirect way of also specifying M as seen from the formula: $A_i = \frac{MTBF}{MTBF \& MTTR}$ However, logic and experience tell us in this regard, also, that it is judicious to specify a minimum acceptable mean time between failures and a maximum acceptable mean time to repair. The contractor may meet the availability requirement with such a relatively low value of MTBF (compensated for by a low MTTR) as to cause logistics and stock level problems. Also it should be clearly stated whether the numerical requirements pertain to intrinsic parameters (values to be realized under laboratory conditions) or operational parameters (values to be realized in the field and taking into account administrative and logistics delays).

VI. SUMMARY

Although there are many more facets to "Quantification of M" which I have not even touched upon; e.g., statistical distributions and their associated parameters is a subject of considerable magnitude. However, in closing I would like to summarize the main points of the presentation and perhaps offer a few cautionary considerations for thought.

1. Although the Air Force has found the definition of MIL-STD-778 to be acceptable, misconceptions based on semantics or limitations of the communicative arts justify minor changes for clarity.

2. The M definition is important and must be virorously defined since all quantification of M must stem from the definition itself.

3. The procuring activity must recognize and master the statistical skills involved in the probabilistic aspects of M. Too frequently preconceived notions and ease of mathematical computation have served as decision criteria in selecting governing statistical distributions reather than a combination of goodness of fit to empirical data, theoretical significance and tractability.

4. M basically concerns "TIME" as a basis for quantification, specification, prediction, demonstration, and data collection. Maintenance times are the real

realm of the M engineer. Other M quantitative terms, not directly expressed as time, are directly affected by time and emanate from higher order models to which time is a basic data input.

5. The use of MIL-STD-778 or its successor as a contract specification and the DOD/Tri-Service effort to standardize M specifications should significantly reduce inter-service communction problems and the similar dilemma that industry has in producing for more than one service.

6. However, standardization in no way reduces the responsibility of the procuring agency to explicitly state the contractual M quantitative requirements tailored to that specific procurement based upon proper definitions of terms. Coupled with this the procuring agency must clearly state the maintenance concept, maintenance environment, and any constraints imposed upon design.

7. As a final thought, although the primary subject of today's technical meeting is M quantification, unless the same emphasis and skills are applied to the contractual responsibilities for demonstration of M requirements the effort applied to quantification will be negated.

CHART 1

RECOMMEND M DEFINITION

"M IS A CHARACTERISTIC OF DESIGN AND INSTALLATION WHICH IS EXPRESSED AS THE PROBABILITY THAT THE MAINTENANCE ACTION TO RESTORE AN ITEM TO SPECIFIED CONDITIONS OR TO VERIFY THAT AN ITEM CONFORMS TO SPECIFIED CONDITIONS CAN BE COMPLETED WITHIN A SPECIFIED TIME PERIOD WHEN MAINTENANCE IS PERFORMED IN ACCORDANCE WITH PRESCRIBED PROCEDURES AND RESOURCES."

CHART 2

"M IS A CHARACTERISTIC OF DESIGN AND INSTALLATION

CHART 3

WHICH

IS EXPRESSED AS THE PROBABILITY

CHART 4

THAT THE MAINTENANCE ACTION TO

RESTORE AN ITEM TO SPECIFIED CONDITIONS OR TO VERIFY THAT AN

ITEM CONFORMS TO SPECIFIED CONDITIONS

CHART 5

CAN BE COMPLETED WITHIN

A SPECIFIED TIME PERIOD

CHART 6

WHEN MAINTENANCE IS PERFORMED IN ACCORDANCE

WITH PRESCRIBED PROCEDURES AND RESOURCES."

CHART 7

M QUANTITATIVE TERMS

TIME (MEAN AND MAXIMUM MAINTENANCE DOWNTIME, MEAN AND MAXIMUM TIMES TO REPAIR, MEAN TIME BETWEEN MAINTENANCE ACTION).

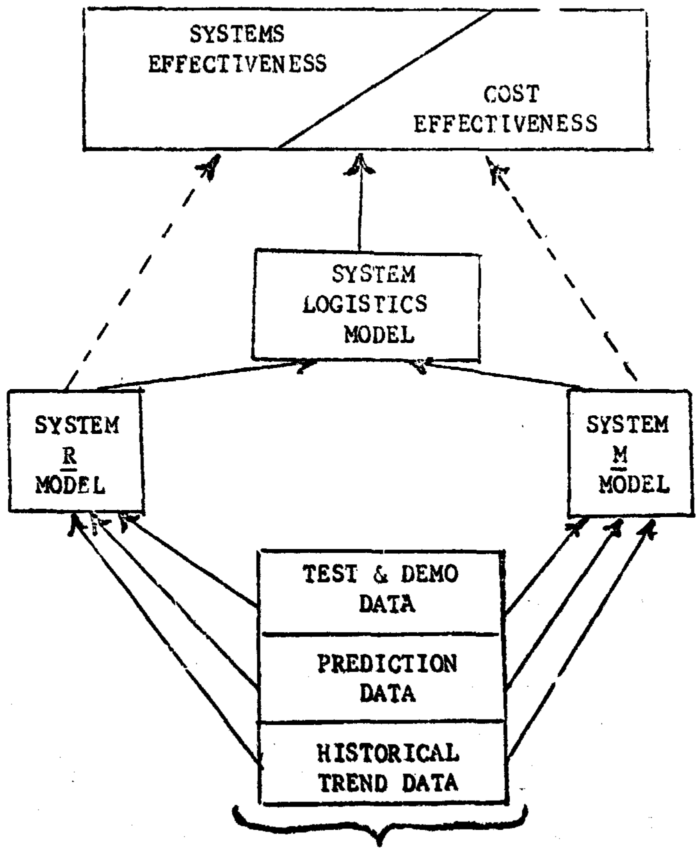
RATE (MAINTENANCE MANHOURS/FLYING OR OPERATION HOUR, MAINTENANCE MANHOURS/MISSILE ALERT HOUR, MAXIMUM MAINTENANCE TIME/DAY IN ORBIT).

MAINTENANCE COMPLEXITY (NUMBER AND SKILL LEVELS OF MAINTENANCE PERSONNEL, VARIETY OF SUPPORT EQUIPMENT).

MAINTENANCE COSTS (MAINTENANCE COSTS PER OPERATING HOUR, MANHOUR COST PER OVERHAUL).

ACCURACY (TOLERANCES OF PERFORMANCE, TOLERABLE ERRORS, EFFICIENCY OF REPAIR).

CHART 8



* TIME BASE ORIENTED *

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SYSTEM EFFECTIVENESS PARAMETERS

in SYSTEM DESIGN:

SOME TOOLS, APPROACHES, AND PROBLEMS

AUTHOR: Lennard B. Weingarten

Research Analysis Corporation

FOREWORD

This paper deals with problems and techniques dealing with system effectiveness in the system design process. The paper represents research supported by USAF-AFSC(SSD), USN BUSHIPS, and USN BUWEPS and performed by the author, generally in collaboration with Mr. R. A. Westland, while both were employed by Dunlap and Associates, Inc.

Chapter I

INTRODUCTION

The increasing severity of system effectiveness requirements and increasing specificity as to means of their achievement and demonstration has necessitated the development and application of a variety of Operations Research techniques to the design of complex systems. While OR techniques have been employed in system design problems for a considerable period of time, it has only been in the last few years that specific attention has been given to the introduction of system effectiveness parameters into the system optimization process, particularly reliability and maintainability parameters. Systems effectiveness, or the probability of a system successfully performing the mission for which it is designed, is determined as shown in Figure I-1, by the relation between: (1) the probability of operation with respect to engineering standards--performance; and (2) the probability of operation with respect to time--availability (or alternative "life" measures such as dependability). Availability, in turn, is determined by the relation between reliability and maintainability, which ultimately are functions of a number of design and support factors.

Historically, primary attention has been given the performance aspects of effectiveness. In recent years, however, the observed effectiveness of our complex systems--particularly military systems--has been well below that predicted. System reliability and maintainability were identified as obvious contributing factors. During the 1950's emphasis was given to finding means of improving reliability, collecting and analyzing failure data, and developing prediction and other tools to permit the quantitative specification of this key design variable. During the late 1950's and early 1960's, the same approach is being taken in design for maintainability. The broad areas of application of OR techniques to reliability and maintainability design which have been under study during this period include:

- effectiveness requirements determination,
- redundant and multimode availability analysis,
- availability, reliability, and maintainability goal allocation techniques,
- design optimization, and
- complex system reliability and maintainability prediction methodology.

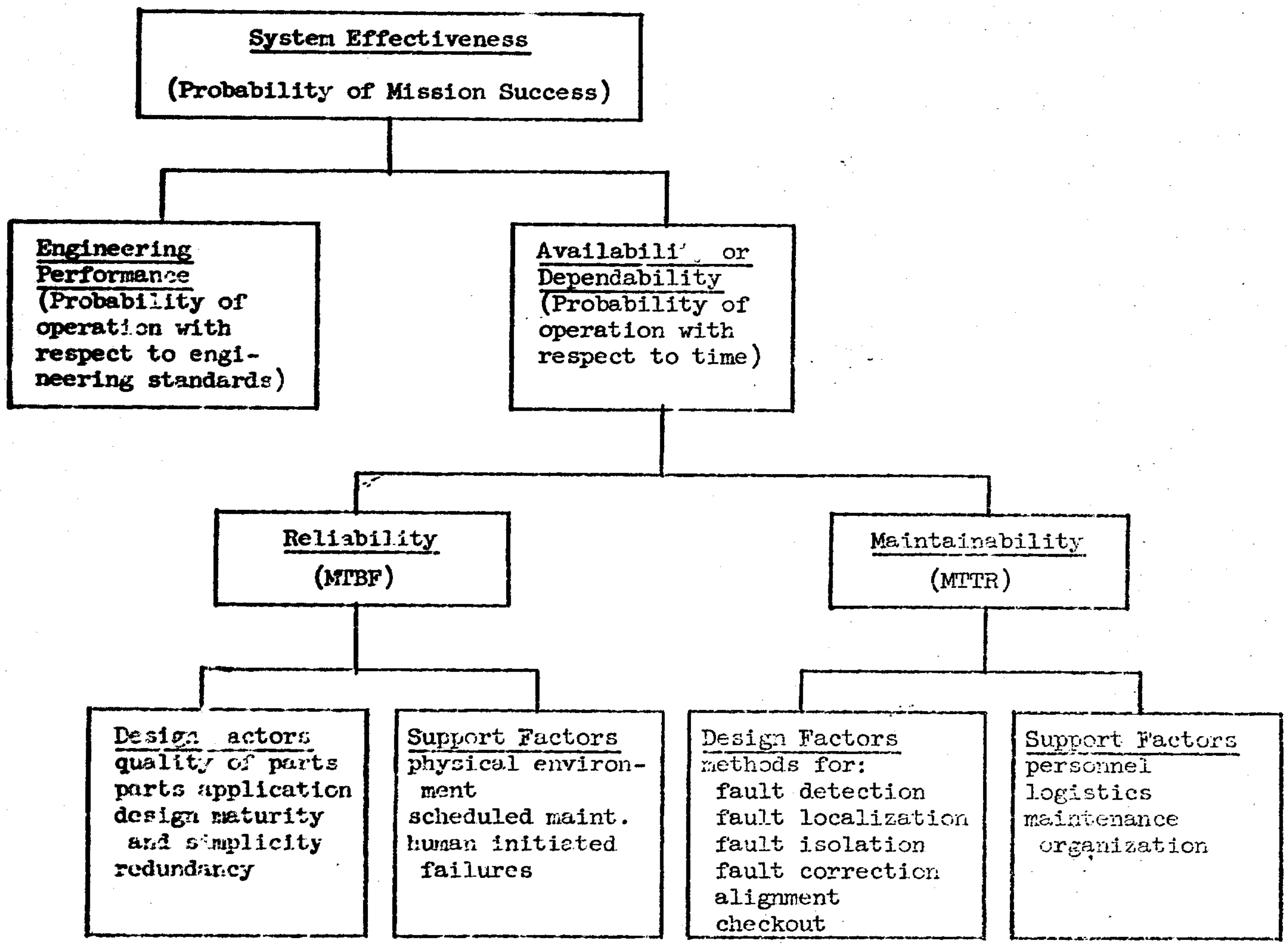

Figure I-1. Hierarchy of factors affecting mission success.

A variety of mathematical tools have been employed including as shown in Figure I-2, analytic, probabilistic, and simulation. The analytical models for availability and dependability include a host of simplifying assumptions including time independence and exponential distributions for failure and restore rates, but have been extensively utilized in military specifications and much of the early maintainability literature. Currently, probabilistic modeling is more extensively utilized, particularly in the analysis of complex, multimode systems. The problems of mathematically treating a large number of variables and taking into account the variety of distributions involved, has more recently lead to the use of simulation techniques in the analysis of aircraft and missile systems. Suffice it to say that these tools and more can be used for specifying required life characteristics.

It is the purpose of this paper to illustrate some of the approaches and tools of introducing effectiveness parameters into the system optimization process with the objective of perhaps furthering interest in some of the yet unresolved problem areas. Additionally, the approaches described represent extensions of material presented in previous papers on operations research aspects of systems effectiveness, reliability and maintainability in references 12 and 13. The major topics covered are: a representative modeling approach, design trade-off tools, restore time statistical distributions, and aspects of test and evaluation.

Analytic

Continuous Operation--Point Availability

$$A_p = \frac{MTBF}{MTBF + MTTR} = \mu/\mu+\lambda$$

where: MTBF = mean time between failures ($\lambda = \frac{1}{MTBF}$)

MTTR = mean time to restore ($\mu = \frac{1}{MTTR}$)

Stated Mission Duration--Mission Availability

$$A_m = A_p P_s = \frac{MTBF}{MTBF + MTTR} \exp(-t_1/MTBF)$$

Allowable Downtime--Dependability

$$D = P_s + (1-P_s)P_r = 1 + \exp\{-(\lambda t_1 + \mu t_2)\} - \exp\{-(\mu t_2)\}$$

where: $P_r = 1 - \exp(-t_2/MTTR)$

D = dependability

t_1 = mission duration

t_2 = allowable downtime

Probabilistic

$$P(S) = P(I)\, P(O)\, P(L_j)\, P(C/L_j)$$

where:

P(S) = probability of mission success
P(I) = probability that system input exists
P(O) = probability that the mission will terminate in a satisfactory output, given a useable input
$P(L_j)$ = probability that the system will assume one of n "life" states (i.e., various combinations of system availability at the start of the mission and failure during the mission)
$P(C/L_j)$ = probability that the mission will be completed within specific time bounds, given that the system has assumed one of the "life" states

Figure I-2 Mathematical Tools for Expressing and Determining Life Characteristics

Chapter II

OVERALL MODELING APPROACH

A procedural model for system effectiveness requirements determination, analysis and design is briefly outlined in Figures II-1 and II-2, and Table II-1. The procedure uses as inputs a tactical requirement and imposed constraints; takes cognizance of related military missions, operating environment and structure; establishes effectiveness measures and functional requirements; assesses possible modes of operation; evaluates alternatives of equipment choices; and provides criteria for the selection of appropriate design, maintenance, and support concepts. The general process and input-output relationships for which the methodology is applicable is shown in Figure I-1. The general approach is principally characterized as a multi-stage decision process with each stage consisting of generation and evaluation of alternatives at successively more detailed levels of analysis with feedback to preceding steps.

As shown in Table II-1, probabilistic modeling can be employed extensively in the mission requirements determination step. As can be noted, the approach is to establish effectiveness in two different but related fashions: one in a mission context, and the other in a system specific context. In the first case, the effectiveness of the system is treated in relation to both the threat which it is meant to counter and the environment in which it is meant to function. This approach permits evaluation of changes in each of the three variables. In the second case, the treatment of the effectiveness of a system in terms of its component aspects permits evaluation of changes in various system effectiveness parameters and selection of an optimum configuration.

The system requirements determination step constitutes a structured process for examining mission requirements and constraints, military structure and related missions, and detailed budgetary constraints on the one hand, and alternative system concepts and cost on the other to arrive at a specific set of quantitative design and support approaches which supplement previously established mission requirements and constraints.

The systems engineering step is a systematic procedure for translating mission requirements and specified design and support appraoches into design specifications. The design and development step includes resolution of detailed design problems, design of the personnel subsystem, and generation of detailed information to improve or modify the established requirements and design approaches. The test and evaluation step consists of determining if the designed system satisfies all imposed requirements and constraints and arriving at decisions concerning specific corrective actions if required.

The establishing of availability requirements should be the result of detailed analysis of overall system requirements rather than a sterile establishing of a "number requirement."

Table II-1

Mission Requirements Determination

- Objective: Define functional parameter requirements which optimize mission effectiveness.

Define mission effectiveness:

$$P(ME) = P(T)P(ENV)P(SE)$$
$$P(SE) = P(D/T)P(E/D)P(S/D,E)$$

where

$P(ME)$	=	mission effectiveness
$P(T)$	=	probability that a target level is present
$P(ENV)$	=	probability of a given environmental state
$P(SE)$	=	system effectiveness
$P(D/T)$	=	f_1 = target detection probability
$P(E/D)$	=	f_2 = target engagement probability
$P(S/D,E)$	=	f_3 = successful target kill probability

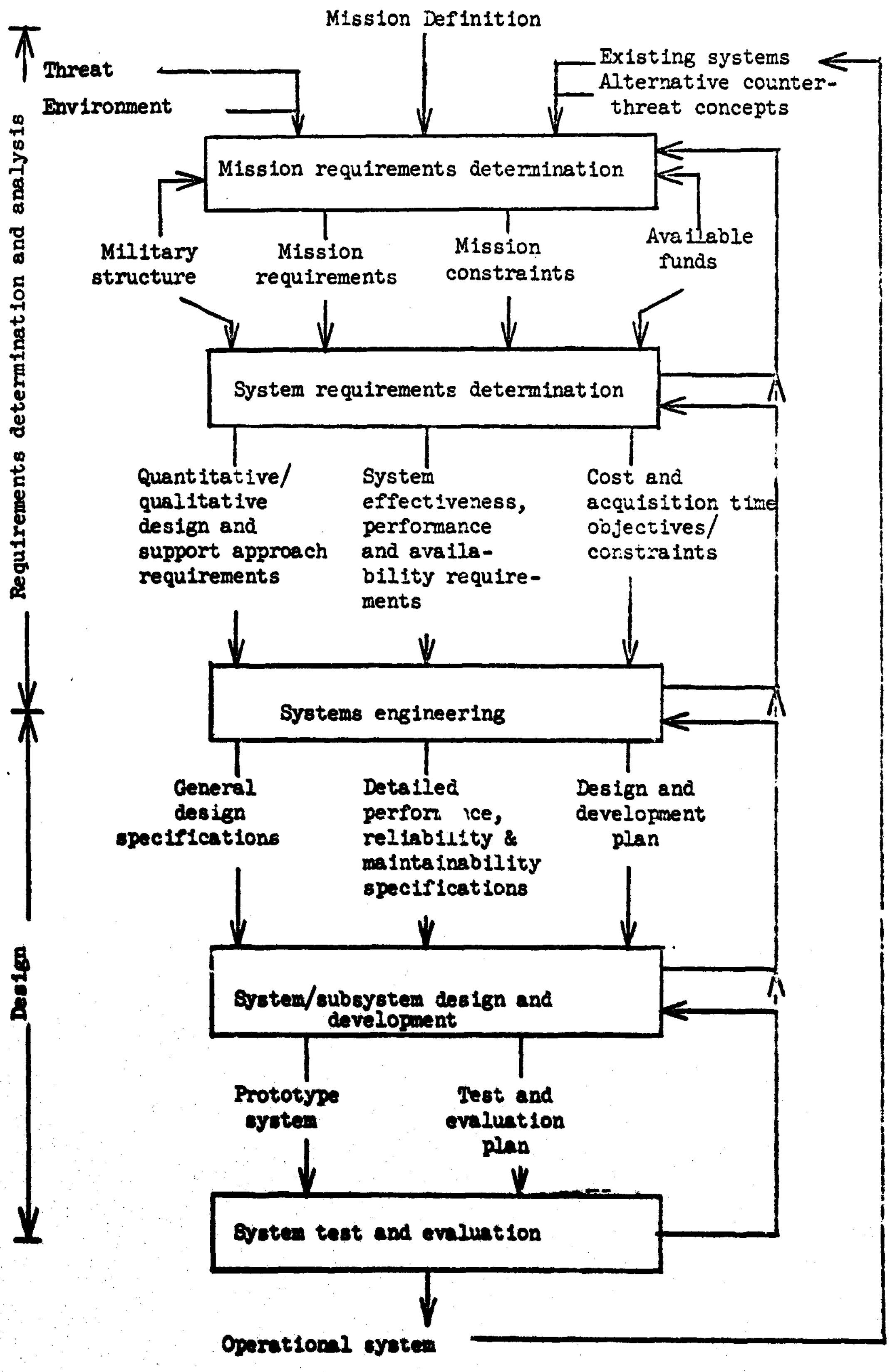

Figure II-1 System Effectiveness Requirements Determination, Analysis and Design

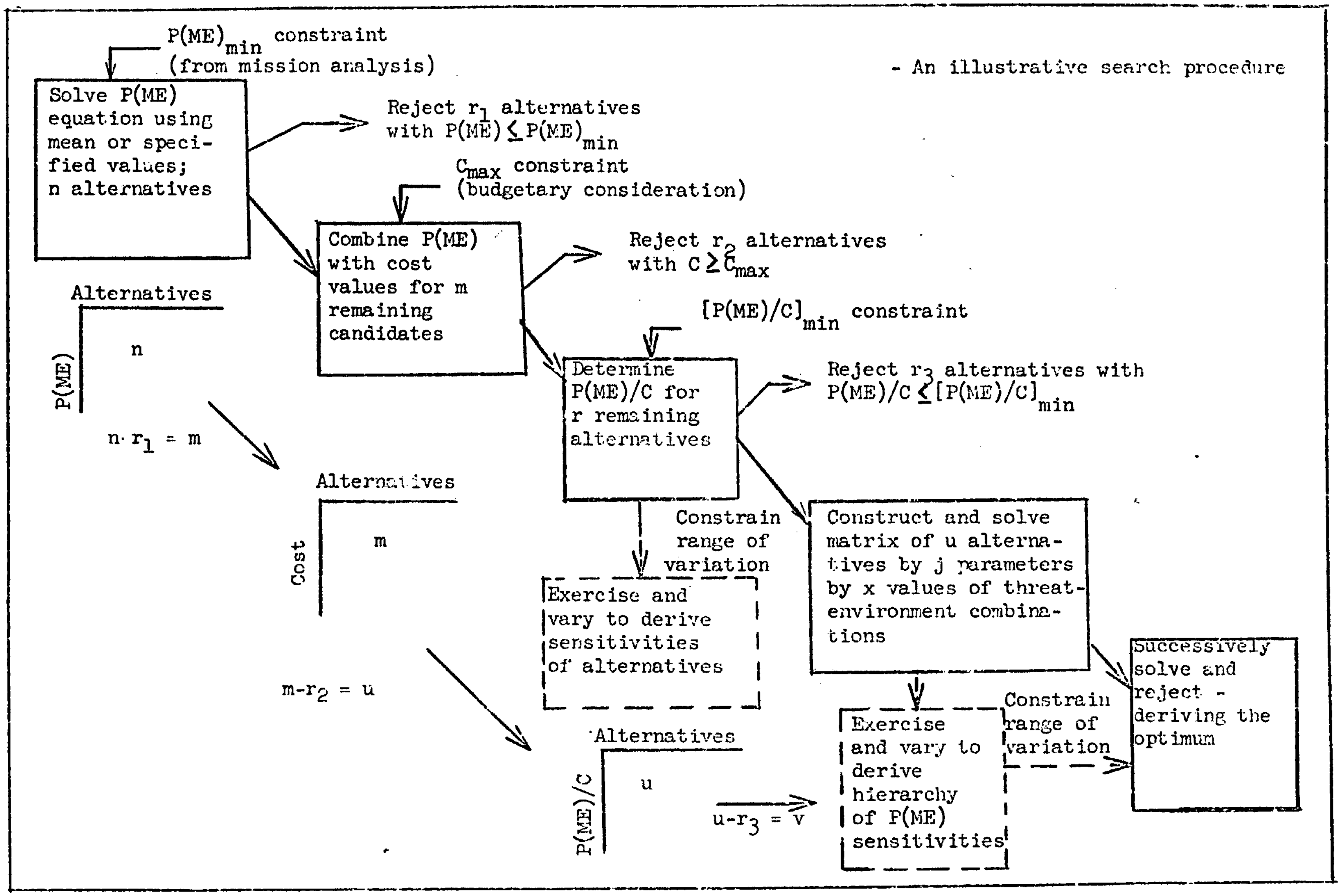

Figure II-2 Mission Requirements Determination

Table II-2

System Requirements Determination

Criticality code: H high, M medium

Availability code: H high, M medium, L low

Data requirements — CATEGORY	Criticality	Availability	SOURCE: Higher echelon	SOURCE: Other systems	SOURCE: Military data	SOURCE: Mfg. data	SOURCE: Literature	SOURCE: Requires gen.	FORM: Observation	FORM: Expt. study	FORM: Projection	FORM: Assumption	FORM: Useable form	FORM: Requires process.
Performance Design Information														
Subsystem design criteria data	H	M		X		X	X	X						X
Man-machine function allocation data	H	L		X		X	X	X	X	X				X
Automation criteria data	H	L		X		X	X	X						X
Molecular electronics data	H	M		X		X	X	X		X	X		X	X
System degradation criteria	H	L		X	X	X		[illegible]						X
Reliability and Maintainability Data														
Reliability prediction data: std. designs	H	H		X	X	X	X			X			X	X
Reliability prediction data: new designs	H	M		X	X	X	X	X			X	X		X
Maintainability " " std. designs	H	M		X	X	X	X	X		X			X	X
Maintainability " " new designs	H	L		X	X	X		X			X	X		X
Checkout and test criteria data	H	L					X	X			X			X
Modular design criteria data	H	M				X	X	X			X			X
Availability/readiness model data	H	M					X	X			X			X
Support System Data														
Manpower availability (no. and skill)	H	M	X		X			X			X	X	X	X
Logistics channel capacities/capabilities	M	L	X		X			X			X	X	X	X
Repair facility capacities/capabilities	M	L	X		X			X			X	X	X	X
Cost Data														
Cost forecasting data	H	M			X	X	X	X		X			X	X
Make-buy decision data	M	M		X		X	X	X		X	X		X	X
Performance design and prod. costs	H	M		X	X	X		X			X	X		X
Reliability design and prod. costs	H	M		X	X	X		X			X	X		X
Maintainability design and prod. costs	H	M		X	X	X		X			X	X		X
Logistics costs	H	M		X	X			X			X	X		X
Facilities costs	H	L		X	X			X			X	X		X
Manpower costs	H	H		X	X			X			X	X		X

REPRESENTATIVE SYSTEM EFFECTIVENESS REQUIREMENTS

One of the most recent avionics system readiness specifications has been issued by the Bureau of Naval Weapons; it is "General Specification for Avionics System Design; System Readiness/Maintainability" and bears the number MIL-S-23603(WEP). The specification deals with the establishment of time goals (see Figure II-1) for the performance of maintenance tasks, the methods of attaining these goals, and the means of proving their attainment. The specification deals with all levels of system design and does treat both corrective and preventive maintenance.

One of the specified items is for M_{max}--the time by which 95% of the corrective maintenance tasks will have been performed--and it is specified at 30 minutes. This formulation

$$\log M_{max} = \log \overline{M_{ct}} + 1.65 \sqrt{\frac{\sum_{1}^{N} (\log M_{ct})^2 - \frac{\left(\sum_{1}^{N} \log M_{ct}\right)^2}{N}}{N-1}}$$

automatically assumes the distribution of active restore task times will be lognormally distributed (i.e., the logarithms of the restore task time will distribute themselves normally). There are at least two questions concerning this rationale. Firstly, the formulation as shown uses the arithmetic means of the distribution when the geometric is the more accurate measure and the following formulation should be substituted

$$\log M_{max} = \overline{\log M_{ct}} + 1.65 \sqrt{\frac{\sum_{1}^{N} (\log M_{ct})^2 - \frac{\left(\sum_{1}^{N} \log M_{ct}\right)^2}{N}}{N-1}}.$$

Secondly, although the lognormal distribution seems to fit a good amount of the historical data, other distributions (exponential, Weibull, Erlang, Gaussian, etc.) better fit certain kinds of data. The changes in distribution form are functions of the level of automatic fault isolation, the basic equipment type, whether it is airborne or surface, etc. It is not the intent of this paper to establish the correct distribution (or, indeed, whether there is one general distribution which will be universally applicable), so suffice it to say that there is sufficient question that automatically assuming lognormality is not warranted. See section IV of this paper for a discussion of distributions.

Whatever the form of the distribution(s) for the various subsystems, there exists the question of the relationship of the subsystem means. One method of allocating subsystem goals would be to take the system goal, assume it to be the arithmetic mean of the geometric means of the several subsystems and thus allocate. This has the basic disadvantage that it makes no proviso for varying complexity, criticality, and such system characteristics. A second means would be to assume the system goal as the geometric mean of the various subsystem geometric means and allocate accordingly. This has the same disadvantage as the means above but does present a more stable measure. Still a third means would be to assume the system goal to be the geometric mean of the weighted geometric means of the subsystems. The fourth method is based on the assumption that the system goal is the arithmetic mean of the weighted geometric means of the subsystems comprising the total system.

$$\frac{1}{n} \sum_{i=1}^{n} \overline{M_{ct_i}}^{G} \qquad (1)$$

$$\sqrt[n]{\prod_{i=1}^{n} \overline{M_{ct_i}}^{G}} \qquad (2)$$

$$\sqrt[n]{\prod_{i=1}^{n} a_i \overline{M_{ct_i}}^{G}} \quad \text{where a is a weighting factor} \qquad (3)$$

$$\sum_{i=1}^{n} a_i \overline{M_{ct_i}}^{G} \qquad (4)$$

The weighting factor mentioned is developed from relative complexity, failure rate, criticality, use factor, etc., and is meant to reflect the fact that items which fail most often, or are most complex and/or important for system operation should be fixed most rapidly for achieving least total system downtime.

None of the techniques mentioned has been definitively established as the correct method; in fact, there exists the possibility that system type or configuration may require selection from the list above. When there is a system comprised basically of greatly similar equipment, the problem tends to be minimized, but when there is a diversity of equipment types, functions, etc., in the system the problem becomes more complex. One of the requirements for future study is to resolve this question.

Chapter III

RELIABILITY-MAINTAINABILITY TRADE-OFF PROCEDURES

As part of the design selection process, various trade-off procedures are required to select an optimum design. One trade-off procedure which has received considerable attention, at least in terms of methodological development, is that between reliability and maintainability to arrive at maximum availability for a specified total cost or minimum total cost for a specified availability. The procedure is based upon the systematic generation of alternative design approaches for reliability and maintainability and determination of a variety of parameters for each approach, including MTBF, MTTR, design time, design and manufacturing cost, size, weight, number and skill level requirements for personnel, maintenance costs, logistics costs and the like. The steps of the procedure are:

1. A preliminary step to define the trade-off measure and criterion, and the level of effort to be applied to the trade-off procedure;

2. An initial design analysis step to establish a framework of mission and design goals and constraints forming the boundaries within which design alternatives are to be considered;

3. Determination of the design and support parameters associated with a "standard design" or a starting point design assumption including MTBF, MTTR, design, production and support costs, and physical parameters;

4. Determination of trade-off requirements through comparison of the standard design parameters with specified goals;

5. A trade-off analysis step consisting of generation and evaluation of alternative reliability and maintainability design approaches to determine a set of approaches which optimally satisfy the mission availability (or dependability) goal;

6. A final step consisting of reiteration of the trade-off procedure based upon additional or modified design information, to refine successively the selection of design approaches.

To illustrate the steps of the trade-off procedure, their application to a hypothetical design problem is briefly outlined:

- A requirement exists to design a transmitter which will satisfy an availability requirement of 0.990 and a minimum MTBF requirement of 150 hours.
- The "standard design," based upon the use of military standard components and a minimum prescribed maintainability design approach, will result in a MTBF of 125 hours, a MTTR of approximately 2.75 hours, and an availability of 0.978.
- The design is found inadequate with respect to availability and minimum MTBF requirements, and the selected course of action is to trade-off improvements in reliability and maintainability in such a manner that the required availability goal is achieved at minimum cost.
- Generation of alternate design approaches within the trade-off procedure framework results in the following combined sets of reliability and maintainability design approaches (RDA's and MDA's respectively) which will satisfy the availability and minimum MTBF requirements, and weight and design time constraints:

Set No.		MTBF	MTTR
1	RDA: Derating components in basic design MDA: Extensive modularization and automatic testing	125	1.25
2	RDA: Special design to accommodate high reliability circuitry MDA: Modularization and semi-automatic testing	150	1.50
3	RDA: Derating and partial redundancy MDA: Semi-automatic testing and only limited modularization	200	2.00
4	RDA: Use of special high reliability components MDA: Partial semi-automatic testing and only limited modularization	225	2.25

Cost data are developed for the alternate sets of approaches including those associated with the design and manufacture of the equipment, and those associated with the support of the equipment in the field--maintenance manpower, test equipment, logistics, and repair facilities, as required. The optimum approach is identified as the one resulting in minimum total cost.

The three more significant problems associated with carrying out the trade-out procedure are those of the actual design generation process--the creative engineering process, data collection and/or estimation, and the actual solution of the trade-off problem. Applicable tools to solve the latter problem are the calculus to find maxima and minima of functions when adequate data are available to describe analytical functions, and mathematical programming and related techniques in other instances. The analytical solution of the trade-off analysis can be illustrated by a trade-off for a point availability requirement and minimum design and production cost criterion. The method of analysis can readily be extrapolated to more complex problems, and to trade-offs for satisfying other criteria such as minimum total cost or weight. As integral steps of the trade-off procedure, the following cost functions are developed:

$$C_R = \frac{C_{DR}}{N} + C_{PR} = f(MTBF) \qquad (1)$$

$$C_M = \frac{C_{DM}}{N} + C_{PM} = f(MTTR) \qquad (2)$$

$$C_{T'} = C_R + C_M = f(MTBF, MTTR) \qquad (3)$$

where: C_R = the total per unit design and production cost increment resulting from an improvement in the reliability of the "standard design"

C_{DR} = incremental reliability design cost

C_{PR} = incremental reliability production cost

C_M = the total per unit design and production cost increment resulting from an improvement in the maintainability of the "standard design"

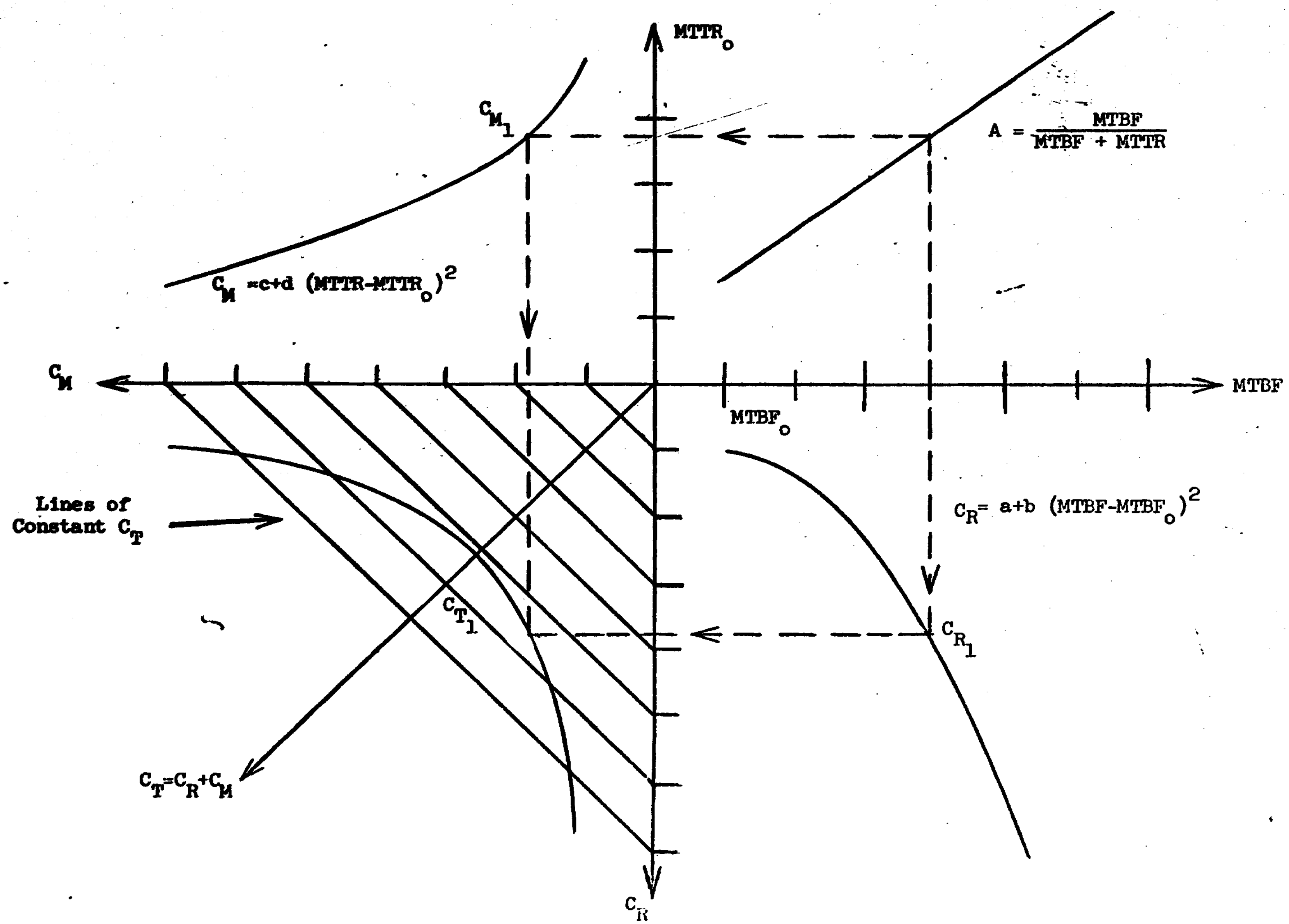

Figure III-1 Illustrative Cost Minimization Problem

$C_{T'}$ = the total incremental design and production cost increment resulting from an improvement in the reliability and maintainability of the "standard design"

A minimum value of $C_{T'}$ can be determined by differentiating the expression for $C_{T'}$ with respect to MTBF and MTTR, and evaluating the zero value of the resulting function. The total differential is:

$$dC_{T'} = \frac{\partial C_{T'}}{\partial(MTBF)} \; d(MTBF) + \frac{\partial C_{T'}}{\partial(MTTR)} \; d(MTTR) \qquad (4)$$

Setting the differential equal to zero, the following solution is obtained:

$$\frac{\partial C_{T'}}{\partial(MTBF)} = \frac{d(MTTR)}{d(MTBF)} \; \frac{\partial C_{T'}}{\partial(MTTR)} \qquad (5)$$

For a fixed availability relationship

$$MTTR = K_A MTBF \qquad (6)$$

where: $K_A = (1-A)/A$

and

$$d(MTTR) = K_A \; d(MTBF) \qquad (7)$$

Simplifying Equation (5) with the use of Equation (7), the total cost will be a minimum when

$$\frac{\partial C_{T'}}{\partial(MTBF)} = - \frac{MTTR}{MTBF} \; \frac{\partial C_{T'}}{\partial(MTTR)} \qquad (8)$$

The optimization of $C_{T'}$ can also be performed by a graphic procedure. Referring to Figure III-1, the first step is to plot the line for the required availability. This is shown in the upper right quadrant. Next the C_R versus MTBF and C_M versus MTTR functions are plotted in the lower right and upper left quadrants, respectively.

To find the total cost function, a series of projections is necessary; the first is from the availability line down to the C_R curve which defines a point, C_{R_1}. The second projection is to the left to the C_M curve which defines a point, C_{M_1}. From C_{R_1}, a horizontal projection is made into the lower left quadrant, and from C_{M_1}, a vertical projection is also made into the lower left quadrant. The intersection of the two projections defines a point, $C_{T'_1}$, representing the total cost for a particular set of design approaches. Other points in the lower left quadrant may be similarly constructed, and a curve plotted. The axis of $C_{T'}$ as indicated, is 45° counterclockwise from the C_M axis, and increasing $C_{T'}$, is outward from the origin. The minimum value of $C_{T'}$ is that point on the curve which is tangent to the minimum constant $C_{T'}$ line.

Frequently the process of generating and evaluating alternative design approaches will not yield adequate data to permit development of approximate analytical functions to represent the relations between C_M and MTTR, and between C_R and MTBF. However, in instances when that is possible, an analytical solution can readily be carried out as outlined above.

Comparative MTBF and cost data representative of that developed during the reliability design approach generation process are illustrated in Figure III-2. The curves which treat only parts costs for a hypothetical transistor logic circuit indicate the relative economy of the derating approach over a reasonably wide range of MTBF. For the example considered, derating would represent the preferable appraoch; if derating cannot provide the total increase required in MTBF, special parts and/or sequential redundancy (standby elements not operating) can be applied selectively. Support ccsts (manpower, logistics, test equipment, and repair facilities) may be treated in the same manner as outlined above by expressing them as functions of MTTR and MTBF.

Total reliability and maintainability cost minimization may be carried out in the same manner as outlined above. The total cost expression is given:

$$C_T = C_R + C_M + K_D (C_L + C_F + C_H) \qquad (9)$$

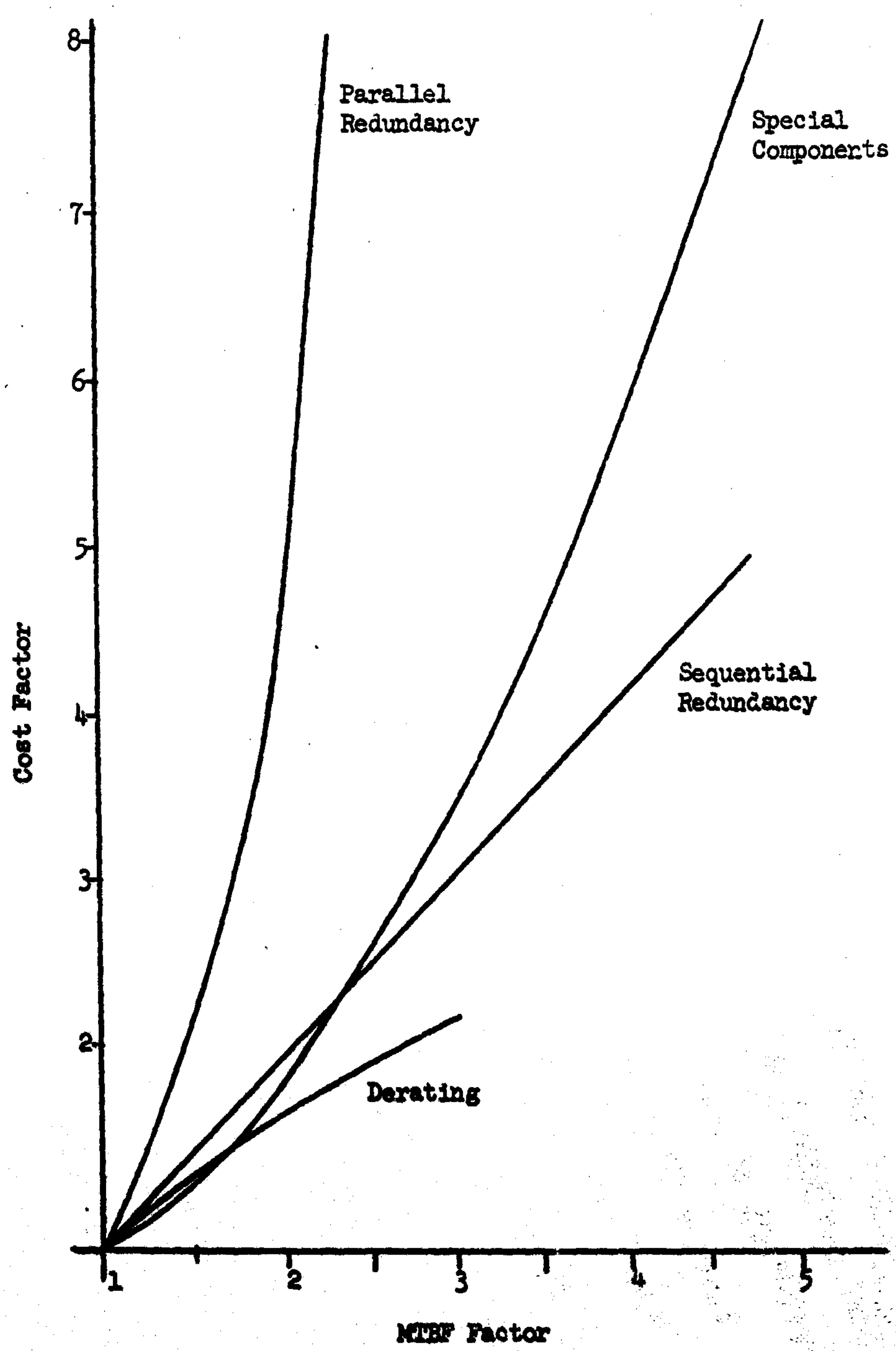

Figure III-2. Cost versus MTBF for various reliability design approaches.

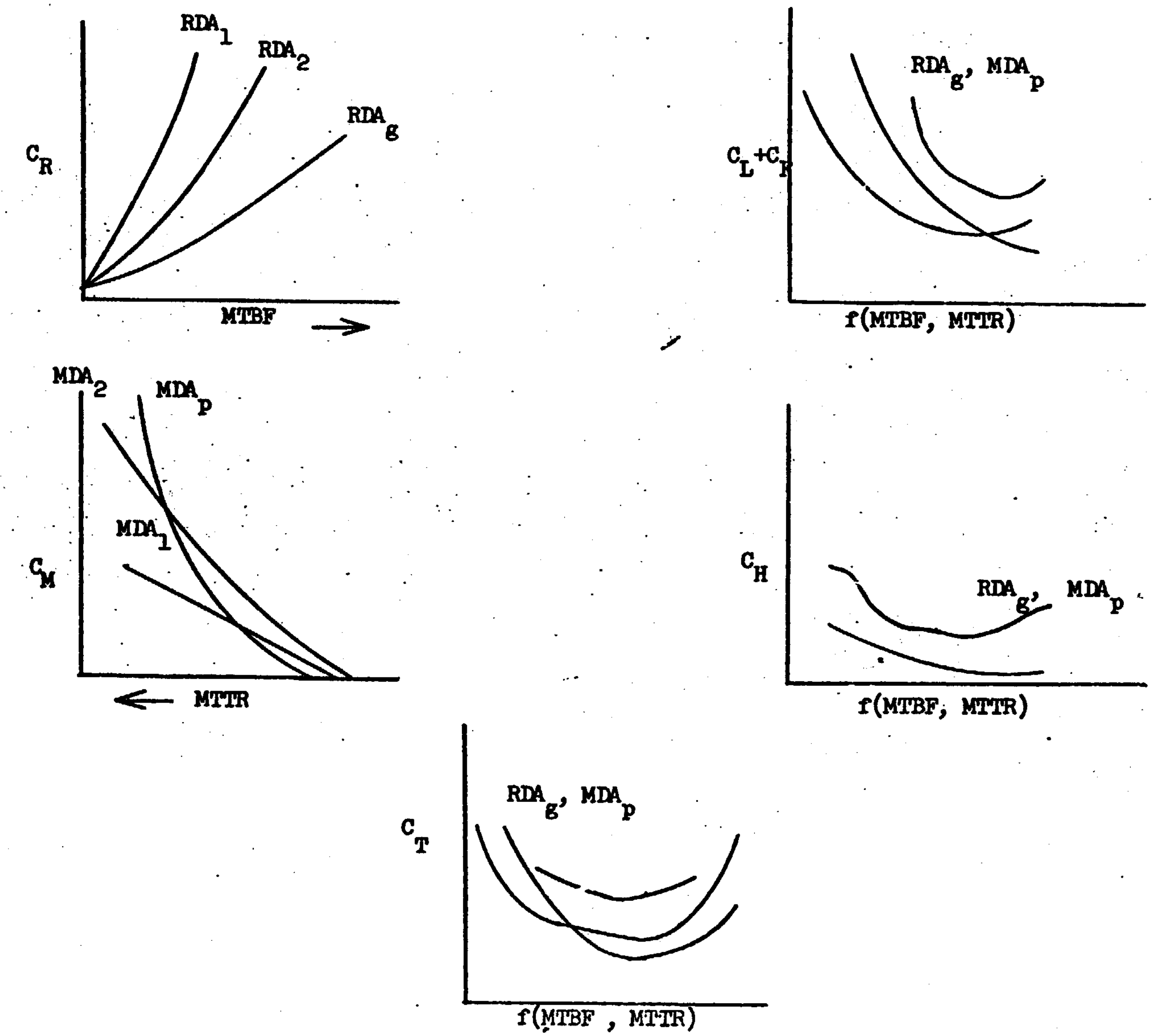

Figure III-3 Illustrative Total Reliability-Maintainability Cost Minimization Problem where:

K_D = discounting factor applied to establish the present value of annual support expenditures throughout the life of the system,

C_L = annual logistics cost,

C_F = annual depot repair facilities cost, and

C_H = annual manpower cost

Illustrative cost relationships for design, production, logistics, repair facilities and manpower are shown in Figure III-3. The C_R and C_M cost functions are similar to those shown in Figure III-2:

$$C_R = f(RDA_g) \; ; \; C_M = f(MDA_p)$$

$$MTBF = f(RDA_g) \; ; \; MTTR = f(MDA_p)$$

$$C_R = f(MTBF) \; ; \; C_M = f(MTTR)$$

Since the availability or other measures of probability of operation with respect to time, fixes the relationship between MTBF and MTTR, costs can be expressed:

$$C_R + C_M = f(MTBF, MTTR)$$

Similarly, logistics repair facilities, and manpower costs can be expressed as functions of MTBF and MTTR:

$$C_L + C_F = f\{RDA_g, MDA_p, L_i\} = f(MTTR, MTBF)$$

$$C_H = f\{RDA_g, MDA_p, H_i\} = f(MTTR, MTBF)$$

where:

$\{RDA_g, MDA_p, L_i\}$ represents a compatible set of RDA's, MDA's (i.e., having MTBF's and MTTR's which satisfy or exceed the stated availability requirement), and logistics policies, L_i.

$\{RDA_g, MDA_p, H_j\}$ represents a compatible set of RDA's, MDA's and manning policies, H_j.

The most commonly encountered logistics policies include:

L_1 = piece parts, associated with MDA's involving: (1) on-line restoration to the piece part level, or (2) on-line restoration through the substitution of spare equipments or units (by switching or physical replacement) with off-line repair to the piece part level;

L_2 = piece parts and modules to replace wear outs, associated with MDA's involving on-line replacement to the module level, and higher echelon repair to the piece part level;

L_3 = modules to replace disposables and piece parts not contained on modules, associated with MDA's involving on-line replacement to the module level and higher echelon disposal of modules;

L_4 = resupply of depot repaired modules and piece parts not contained on modules, associated with MDA's involving on-line replacement to the module level, and rotation of the failed modules to a Com Z repair facility.

The most commonly encountered manning policies include:

H_1 = maintenance performed by an operator who is not assigned to other equipment in the event of a failure

H_2 = full time assignment of m maintenance technicians to the equipment

H_3 = maintenance by a pool of electronic technicians who maintain a variety of equipments.

The optimizing task consists of examining the compatible sets:

$$C_m = \{RDA_g, MDA_p, L_i, H_j\} \qquad (10)$$

to determine the set which result in the total minimum reliability and maintainability cost. Frequently it will not be possible to develop the continuous cost functions depicted in Figures III-2 and III-3, and it becomes necessary to evaluate discrete design approach and associated logistics and manpower cost data. Although a large number of variables must be treated, in most practical system design problems, constraints significantly limit the number of alternatives to be examined. Mathematical programming algorithms can then be employed to determine the optimum solution.

Considerable advances are required before the trade-off procedure of this type can be used in a routine manner, not only in terms of the establishment of standard data pools to facilitate carrying out the trade-off analysis, but also in prediction techniques which are sensitive to the key design and support features which should be subject to trade-off, and the further development of mathematical trade-off techniques, particularly those which take various decision data deficiencies into account.

Chapter IV

STATISTICAL DISTRIBUTIONS

A number of distributions have been proposed as being descriptive of active maintenance actions. The two most often mentioned are the two-parameter lognormal and the exponential with the former generally preferred; the normal (Gaussian) distribution is also apparently applicable in some instances. A fourth which has been proposed is the Weibull; a fifth which may also be descriptive of the active restore functions is the Erlang. Each of the distributions which may have application to maintainability programs are outlined below.

A. Normal

The normal is a two parameter distribution. Once the mean and the standard deviation are known, the distribution is completely defined.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp - \frac{(x-\bar{x})^2}{2\sigma^2}$$

mean = $\bar{x}$

variance = σ^2

B. Lognormal

The usually specified distribution, the lognormal, is a two-parameter distribution: any two of the mean, the median (geometric mean), and the dispersion. There exists a good body of data which shows that the logarithms of active restore times will distribute themselves normally. In this case, the arithmetic mean has a definable relationship to the median. That relationship, when described, gives the dispersion parameter:

$$f(t; m, \sigma) = 1/t\,\sigma\sqrt{2\pi}\ \exp - \{\frac{1}{2\sigma^2} \ln^2 (t-\bar{t})\}$$

mean = m exp $(\sigma^2/2)$

where: median = m

mean = $\bar{t}$

ln = natural logarithm

Thus, with any combination of two of the mean, the median, and the standard deviation (dispersion parameter) of the logarithms the distribution is described. There exist a three- and a four-parameter log-normal for use when the distribution does not start at zero and/or when the distribution is truncated. (See reference 7.)

C. Exponential

The exponential distribution is a one-parameter distribution; the descriptive parameter is the mean.

$$f(t) = \lambda \exp - (\lambda t)$$

where:

λ = a positive parameter

$$F(t) = 1 - \{\exp - (\lambda t)\}$$

$$\text{mean} = 1/\lambda$$

$$\text{standard deviation} = 1/\lambda$$

Therefore, knowing only the mean restore time it is simple to construct the distribution. That leads to the further statement that it is an easy matter to specify the quantitative maintainability requirements of a system if one assumes an exponential distribution; if one specifies the required MTTR, one has specified the maximum as well.

The drawback to the use of the exponential revolves about the fact that the distribution may well be too insensitive. Since the mean is the only descriptor of the distribution, fluctuations in the data will tend to be lost if the means does not vary with them directly.

D. Weibull

The Weibull distribution takes its name from the man who developed it. It is an exponential function described by the three parameters: shape, scale, and location.

$$f(t) = \beta/\alpha(t-\gamma)^{\beta-1} \quad \exp - \{t-\gamma)^{\beta}/\alpha\}$$

$$\text{mean} = \gamma+\alpha^{1/\beta}\Gamma\ (1+\beta/\beta)$$

$$\text{var} = \alpha^{2/\beta}\ \{\Gamma\ (2+\beta)/\beta-\Gamma^{2}\ (1+\beta)/\beta\}$$

where:

α = scale parameter

β = shape parameter

γ = location parameter

In order to establish this distribution it is required to determine the values of each of the three descriptors; however, in using it for describing active maintenance actions, the location parameter is zero since the distribution itself starts at zero, thus the distribution is, for practical purposes, describable with only two parameters, shape and scale. When the shape parameter, β, equals one, the Weibull becomes a special case of the exponential distribution.

E. Erlang

The Erlang distribution, like the Weibull, takes its name from its developer. It is described in terms of the mean or the mode and a measure, k, of skewness.

$$g(t;\ \mu k) = C_k t^{k-1} \exp - (k\mu t)$$

$$\text{mean} = 1/\mu$$

$$\text{mode} = \frac{k-1}{\mu k}$$

$$\text{var} = \sigma^2 = \frac{1}{k\mu^2}$$

where:

$$C_k = \frac{(\mu k)^k}{\Gamma(k)}$$

k = skewness parameter

The constant, C_k, is assigned so that the integral of the corresponding function over its range equals unity. With any two of the three descriptors of the distribution (mean, mode, variance, or "k") the distribution is described.

F. Comparison

Much of the empirical data compiled on active restore times seems to fit the lognormal distribution and it could logically be the correct describer of the real world, because it tends to diminish the impact of a small number of extreme time data points. The drawbacks to this distribution revolve about the difficulties in working with it. Since it is a distribution of a transformed function, care must be exercised in separating what describes the distribution and what describes the data. As the distribution comes into general use most of the difficulty should disappear; the fact that there is a commercially available lognormal graph paper should help in this regard. (A cumulative lognormal distribution forms a straight line on such paper.)

The exponential distribution seems to fit some of the data currently available but no better than and generally not as well as the lognormal distribution. It is an extremely easy distribution to work with but it tends to be too insensitive for the data.

The Weibull distribution on the other hand, appears to be too sensitive for the data. When fitting it to the actual data and satisfying the mean, the value of β tends toward unity, in which case it is merely a special case of the exponential. Further, it is not a tractable distribution but the appearance of Weibull graph paper should obviate part of the difficulty in establishing values of α and β.

The Erlang, too, may be too sensitive for the data but it does hold promise as being worthy of further investigation over a broad range of maintainability data. The difficulty in using it lies between that of the exponential and that of the lognormal. The former being the easiest with which to levy requirements and the latter less difficult only than the Weibull.

The distributions listed here are those most commonly encountered but by no means is definitive. There may well be other distributions of applicability, especially for describing maintenance actions on the evolving microintegrated circuits. Systems which are diverse in nature may be describable only by composites of two or more distributions. Not only the shape of a given distribution but also changes in distribution may be encountered with differing maintenance policies on a given system. Other features (use, environment, etc.) may well influence the distributive characteristics of restore times and these will be discovered only after future study and research.

Chapter V

TEST AND EVALUATION

One of the major steps in the overall maintainability program is the determination of whether or not the established requirements have been met. The three referenced specifications approach the same problem in both similar and different fashions, but one thing remains true--an estimate of the mean and maximum maintenance times is required.

A. Specifications

1. MIL-M-26512C(USAF)

One method proposed is as follows:

A sample based on the failure rate of each replaceable item, its estimated mean time to repair, and the number of these in the system over the total number of replaceable items multiplied by the failure rate times the density establishes the percent of total test to be allocated to that item.

$$\text{Percent of sample} = \frac{n_i \lambda_i MTTR_i}{\sum_{i=1}^{n} n_i \lambda_i MTTR_i} \times 100$$

Then, using a table of random numbers, the specific items to be faulted are chosen.

The sample size required is estimated from the following relationship:

$$N = \frac{\Phi\sigma'}{K\bar{X}'}$$

where:

N = sample size

Φ = desired confidence level coefficient

σ = estimated standard deviation of maintenance downtime population being sampled

$\bar{x}'$ = estimated mean of sample population

k = desired accuracy level coefficient (1-accuracy level)

After the first ten samples have been run, compare the resultant $\frac{\sigma'}{\bar{x}'}$ ratio with that estimated and if different revise the sample size.

A second method suggested is that of sequential testing but with no further specification. Other methods which can be developed can be submitted for acceptance.

2. MIL-S-23603(WEP)

The technique for establishing mean and maximum times is essentially identical to the preferred method in MIL-M-26512C(USAF) save that it is used at a number of system levels: SRA, WRA, System, and Weapon. Further, the sample size is based on the percentage of total failure of a category multiplied by 50 and rounding off to the nearest whole number. (Checking specified indices is straightforward and can be accomplished basically by examination of equipment specifications and drawings.)

3. MIL-M-23313A(SHIPS)

This specification is based on proportioning a fixed sample of 20 failures according to the percent of total failure rate of each part category.

4. Comparison

As stated previously, the intent of all of the specifications is basically the same--proof of the predictions or establishment of the facts with certain statistical descriptors.

The first two specifications mentioned follow basically the same approach but there are certain differences.

The intent of MIL-M-26512C in establishing a sample size as it does is to determine a desired confidence level and an accuracy level to mate these with estimates of the mean and standard deviation and thus to sample no more than is required.

Unfortunately, the sample size is based on estimating σ and $\bar{x}$. The more advanced the system, the higher is the likelihood that the errors in estimating those parameters will be large. The specification makes allowance for this fact by showing a method for changing the original sample size as a function of evolving data in the form of a $\sigma/\bar{x}$ ratio. Depending on the sequence of testing, it becomes possible to bias that ratio and thus to develop an improper sample size. The means of obviating this potential problem are fairly straightforward; assign the first ten samples on a random sample basis and/or periodically during the testing period re-examine the ratio and adjust the sample size accordingly (i.e., if large changes are evidenced).

MIL-M-23603 follows the same sampling plan as does MIL-M-26512, but calls for its use at each of four levels. The amount of testing required can thus become inordinately large. The more complex the system, the greater the sample size and the more time required. Thus we arrive at a sort of inequity: the more complex a system about which data must be gathered, the greater the number of samples required to satisfy the specification in a crowded system test calendar. That is, in terms of total program sequencing, it is highly likely that a large block of time for maintainability testing will not be available. Schemes to utilize the repair efforts during other kinds of testing are largely unsuccessful because the failures which occur are of the "birth" type and are not necessarily representative of those which will occur during system normal operation. Also, the conditions under which the repairs are made will generally not represent those expected in normal use for such reasons as:

- The level of repair will be different (probably not remove and replace);
- The personnel making the repairs will usually be of much higher skill than can be expected in use; and
- Such documentation as will be available at test time will not be representative of what will be available.

Methods can be developed to meet the spirit if not the letter of the specification. One such would be to use a sample at the WRA level (giving a reasonable sample size) apportioning to system and weapon level, and derive the basic faults to be inserted using the specification:

	TO CHECK	INSERT FAULT IN	
	Weapon	System	
Sample Size →	System	WRA	
	WRA	SRA	
	SRA	Piece Parts	← Actual failure selection

A second method would follow a sequential testing procedure based on the sample selected as above.

MIL-M-23313A technique is somewhat different than the two preceding in two basic ways:

- the sample to be selected is fixed at 20,
- the sample is based on the proportion of failure rate of any category to the total failure rate.

Using only failure rate to allocate, changes the allocation basis from downtime contribution to frequency of occurrence. Since the measurement is of downtime, it is generally preferable to choose a sample based on the former rather than the latter.

Further, since confidence varies as n^{-2}, the confidence interval will normally be quite large or the confidence level quite low.

$$C_1 = \tilde{x}_1 - \lambda_\beta \, \sigma/\sqrt{n}$$

$$C_2 = \tilde{x}_1 + \lambda_\beta \, \sigma/\sqrt{n}$$

where:

C_1 = lower confidence limit

C_2 = upper confidence limit

$\tilde{x}_1$ = population mean

σ = standard deviation

λ = number of sigma to percent deviation

β = confidence coefficient

n = sample size

B. Sequential Analysis

A basic tool which can be used most effectively in a test plan is the sequential method of analyzing hypotheses, which may be described as follows (see Figure V-1). A rule is given for making one of the following three decisions at any stage of the experiment:

(a) to accept the hypothesis, (b) to reject the hypothesis, (c) to continue the experiment by making an additional observation. Thus, a test procedure is carried out sequentially as illustrated below. On the basis of the first observation, one of the aforementioned three decisions is made. If the first or second decision is made, the procedure is terminated. If the third decision is made, a second trial is performed. The number "N" of observations required by such a test procedure is a random variable since it is directly dependent upon the outcome of the preceding observations. The sequential test method normally required substantially fewer observations than conventional statistical test methods (9). In addition, the decision to accept or reject may become obvious after the first few observations, and no additional sampling need be done.

Given the hypothesis, H_1, that the restore time is less than or equal a given value (in this case the design goal), observations of restore times made. Based upon statistical analysis, the indivisual restore times are classed as "acceptable" or "non-acceptable." An accumulation of results when plotted within the framework of the specified parameters, will lead the decision to accept or reject the given hypothesis, as determined when the plotted path intercepts the respective limit line.

The general procedure for the experimental evaluation plan would be as follows:

a. Specify the test constraints for the experiment: tools, test equipment, spare parts, skill levels, etc.

b. Specify the appropriate "time to restore" requirement; this constitutes the hypothesis H_1.

c. Establish "acceptable" and "non-acceptable" criteria for individual restore times, based upon statistical analysis.

d. Select P_1, the proportion of "non-acceptable restore times" so small that a total number of observations having this proportion is considered acceptable. Select P_2, the proportion of "non-acceptable restore times," greater than P_1, of such magnitude that a total number of observations having this proportion is considered unacceptable.

e. Select α, the risk of rejecting a total number of observations in which P_1 is valid. Select β, the risk of accepting a total number of observations in which P_2, is valid.

f. Construct the sequential test graph, with Accept Hypothesis and Reject Hypothesis levels as defined via P_1, P_2, α, and β.

g. Perform the restore time test observations until the decision to accept or reject is determined by the sequential analysis.

h. Repeat the test for various combinations of failures, test conditions, and other variables as required to simulate operational conditions.

The specifications of the sequential test parameters described above require mutual agreement between the procuring agency and contractor, inasmuch as these parameters are direct functions of the desired level of maintainability.

The successful execution of the sequential tests and analyses will constitute proof that the maintainability goals have been achieved within the specified level of certainty. Any deficiencies will automatically call for corrective action, such as design revision, system MTTR reapportionment, or relaxation.

The quality of the test plan, of course, is dependent upon the quality of the sample selection, the detailed analysis of the implications of the test conditions, and the careful definition of what constitutes a maintenance observation or sample point (a given observation might constitute the mean restore or repair time for 1, 2, or 3 distinct failures). Through the use of the sequential test procedure, efficiency of method is achieved, but the development of a manageable test program requires careful attention both in experimental design, and in the selection of actual experiments to be performed.

In the unlikely eventuality that no clear decision can be made at the end of the sampling, the two avenues of approach left open are: (1) to continue until the specified risk levels are satisfied or (2) to cease testing and ascertain the risk level at which a judgment <u>can</u> be made and use it for reporting purposes.

1. <u>CPIF Contract Implication.</u>

It is worthy of noting at this point that the selection of the α and β values can be used most effectively in determining fee spread in CPIF contracts. The incentive portion of the fee can be made to reflect not only MTTR and MMAX but also the "faith" that the value is [illegible] greater than the value reported.

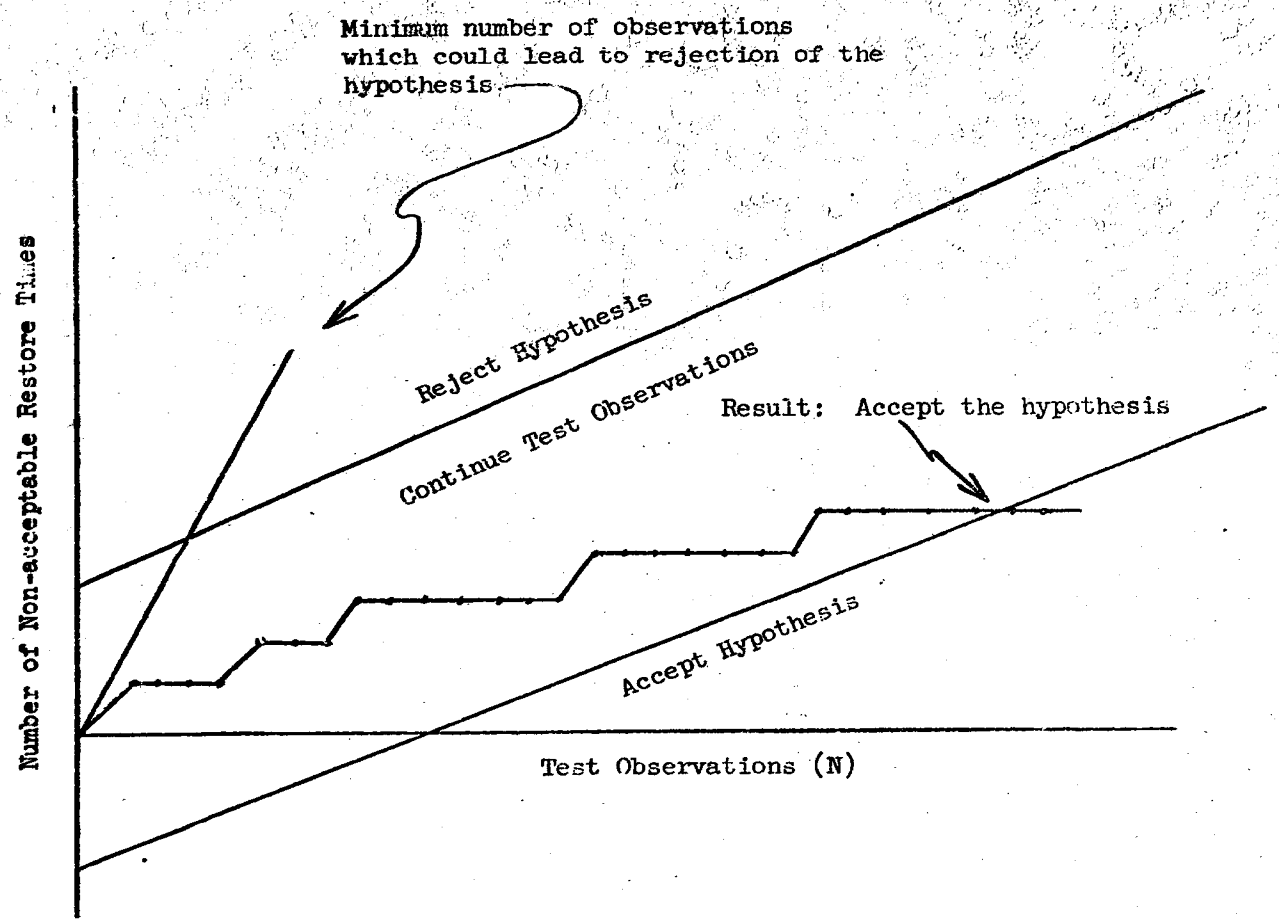

Figure V-1 Sequential Analysis Model

C. Testing

The goal of the previous discussion is to derive a set of faults to be inserted into the system and to time their removal. For that reason, if no other, a few words about the testing itself are in order.

The choice of simulated failures provides availability predictions which, in turn, presupposes a knowledge of all the types of potential failures, their consequences to the function of the system, their frequency of occurrence, and what is the approach for restoring the system to operational status. At a minimum, the first two of these (types and consequences of failures) must be known in detail if the probable maintenance task is to be analyzed to the degree required for preliminary MTTR estimates. The frequency of occurring failures may, of necessity, be based on preliminary reliability estimates since tests are generally conducted before adequate field data can be accumulated. The approaches which can be taken in restoring the system to operational status should be available in detail form.

The overriding criterion is that a true prediction of availability be achieved. Thus, MTBF and MTTR, the two independent variables, assume equal importance. At the time of testing, the predicted MTBF should be available for all system levels, thus aiding in the test plan development to the establishment of MTTR and, thus, availability. In addition to the criterion of deriving a true prediction of availability, however, it should be remembered that the system is far more than merely a vehicle for the maintainability engineer to apply his talents. The testing which is of such importance to him requires time that is being called for by other people with equally pressing problems. Further, the system design engineers should not be expected to allow their as-yet unproved system to have faults inserted without some guarantees that the system will not be harmed. That is indicative of another level of criteria which can, if not met, prevent the attainment of the overriding criterion.

Some of these physical or engineering criteria which are important to the sampling procedure are as follows:

1. It must be possible to simulate the failures without permanent or expensive damage to the system. Complete absence of damage should be the goal to the extent feasible.

2. The maintenance tasks associated with correcting the simulated failures must be identical to the tasks required for correcting the actual failures.

3. Indicator states and signals or voltages at test points and other monitoring points must be the same for both simulated and actual failures.

Ordinarily it is possible to simulate failures without damage to the system. Such techniques as blocking inputs or outputs of plug-in modules at the connectors, or unobtrusively disconnecting leads from terminals are used where the fault to be simulated is characterized by the absence of a signal. In other cases, the super-imposing of an externally generated signal on a normal internal signal simulates a fault. Rarely will a part actually need to be failed, although using previously failed parts allows realistic simulation. The possibility of associated failures is excluded by prior circuit analysis. Both choice of failures simulated, and simulation methods are accomplished so as to minimize the possibility of unpredictable effects and/or system damage.

The requirement that test point and display information be precisely simulated places further restrictions on the simulation techniques which can be used in any given instance. In some cases, it may prove advisable to re-select a failure in favor of one which may be more adequately or safely simulated.

D. Uses of Data

The data gathered are useable in a number of fashions, largely dependent upon the phase of the overall program when they are developed.

1. Early Program

As the conceptual system progresses, some preliminary estimates of time will generally be made by the maintainability analysts. This may be in the vein of evaluating different candidates. On the basis of some preliminary model testing and/or previous experience with similar equipment, the designers and packagers can be advised concerning suggested design approach changes or at least probable areas of difficulty. Simulations can be run at this stage to derive predicted spares requirements, shop requirements, and so on. Further, the MTTR estimates are used (save for MIL-M-23313) to develop the sample for the formal test and demonstration.

2. Formal Test and Demonstration

The data developed here are in one sense the most important, since there will generally be contractual decisions made on the basis of their output. In addition, they are useable as the start of a data pool on the system and as a sort of base measure for use in evaluating field usage data. They have one additional value: a limited value in planning system retrofit.

3. Field Usage Data

These are the most real measures of the level of maintainability. Whatever the potential proved during the Test and Demonstration, these measure the fact directly. Unfortunately, they are the most difficult to gather in terms both of getting them at all and getting them accurately (cluster analysis will often show the tendency for "neat" times). The traditional problems associated with getting the data forms filled out for all occurrences and filled out accurately are applicable here. The easier the form that is supplied, the more likely it is to be completed; The more strictly formatted the form, the more likely that the data will be on the same base. The final form should reflect trade-offs among the probabilities of getting them filled out properly, getting correct information, being able to handle the data simply, and so on.

The data derived can be used for retrofit and logistics information but equally important, they form part of the pool of data which will help in the predicting for future systems. This point is especially important at this time because of the evolution of micro-integrated circuitry systems about which virtually no data are currently available.

One further point is that the comparison of these data with those of the Test and Demonstration can produce an indirect measure of the maintenance process and can be used to keynote problem areas requiring attention.

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TEN NEW CONCEPTS FOR MAINTAINING ELECTRONIC SYSTEMS

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TEN NEW CONCEPTS FOR MAINTAINING ELECTRONIC SYSTEMS

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Introduction

By way of introduction I would like to comment on how we think this paper is related to MAINTAINABILITY. It is concerned with ten new concepts for structuring the trouble shooting process to achieve better maintenance.

This structuring is achieved in several ways: changing the documentation, the training, and the equipment; and all three should be brought into congruence. Traditionally these three areas are under separate responsibilities in the services and in industry. We feel they should be brought together more forcibly than they have in the past. We believe that the really important advances in maintainability will be made through changing the personnel subsystem. The highest costs are in the personnel subsystem, by a factor of 2 to 1 over the other costs, for an assumed system life of ten years.

The point is simply that these ten concepts approach maintainability by modifying the personnel subsystem and also have direct implications for structuring the hardware, but that because of compartmentalization of responsibility implementation of any of these concepts has been difficult to achieve on a system basis.

Ten Concepts

The ten concepts discussed here were developed in Government agencies and in private industry. They all stem from a perceived need for change in the conventional approach to electronics maintenance which has prevailed since World War II, when major items of electronic equipment first made their appearance.

The appearance of these new concepts does not mean that the people who are responsible for training and technical manuals and design have not been doing their job -- and doing it well. They do represent a view, however, that major changes in approach to electronic maintenance can now be made which would alleviate many problems and result in better maintenance at lower cost. Each concept represents a different plan for accomplishing major changes but all have a common approach.

They all share the view that some type of equipment analysis, accomplished by electronic experts (in advance even of the training of men to maintain the equipment) can result in a trouble shooting strategy (and specific information to support that strategy) for the analyzed equipment which, when appropriately presented to the maintenance man (via manuals, training, or special display equipment) will result in better maintenance at less cost. These concepts differ from the conventional approach in that they call for making an equipment analysis for trouble shooting once, by experts, and transmitting this to the repairman along with appropriate supporting data so that the repairman does not have to make analyses for himself, repeatedly, while he is trouble shooting. This also implies bringing the equipment into congruence with the strategy which means test point identification and location, as well as configuration of parts into trouble shooting packages.

Having the analysis made once by experts results in reduced trouble shooting time. The experts must spend sizeable amounts of time making analyses of each circuit. It is easy to see how much this adds to trouble shooting time when it is done over and over again by each man on the job -- while the system is inoperative. The effectiveness of one concept (FORECAST) has been experimentally compared to the conventional approach in three major studies. The tested effectiveness of this new concept ranged from 40% to 200%. Equal proficiency was found when training time was reduced by 60%. The JOBTRAIN concept was also given a major test in which equal proficiency was obtained with a training time reduction of 50%. In tests on minor items of equipment, the MAINTRAIN, ATOMS, BAMAGAT, and SIMM concepts also showed some gains over conventional approaches.

Because of the relatively high cost of the personnel subsystem, the largest potential for savings resides in increasing personnel effectiveness so that fewer men can achieve the same or greater effectiveness. In every concept the trouble shooting strategy is worked out in terms of "dependencies." This means what portions of the equipment are dependent on what other portions for their inputs.

The trouble shooting strategy for an electronic system requires expert analysts to lay out the system dependencies. A block diagram is one format for showing the flow of inputs and outputs (FORECAST). The diagrams may be reduced to a dependency chart giving the same information (SIMS, BAMAGAT, IBM). Functional loops are another name for dependencies (ATOMS). Still another format is to list the checks to be made according to the order established by the dependencies (JOBTRAIN). These checks can be color-coded to relate to equipment areas having the same color code (MAINTRAIN). The order in which the tests are to be performed can also be indicated by having them physically arranged on an equipment panel in that order (FIST). They can also be read out on a card reader (MEMRI, ADMIRE).

Every dependency chain starts at the power supply and input stimuli and ends at a system display or output response. The trouble shooter's job is to start at an out-of-tolerance display indication or output and check the other display or output indications along the single dependency chain (functional loop). This is called symptom collection or loop checkout. If he gets off this chain, he is lost. All concepts make this chain clear in one way or another. The trouble shooter is not required to figure out the chain or the checks to be made on it from schematic diagrams and a knowledge of theory. Experts have already done this and recorded the information in one format or another.

Symptom information will, on the average, localize the site of the trouble to an area which is approximately 5% of the system. This is about the size of a chassis or module. But it will not be a module unless the equipment is configured to conform to the trouble shooting strategy. With today's typical hardware configurations, the trouble may be localized to an area the size of a chassis but the parts in this area may be spread over several chassis.

This 5% area is approximately equivalent to five stages. Portable test equipment can be employed to further localize the trouble to a stage by measuring the outputs of one stage to the next. Some concepts provide guidance in selecting these measurements; others do not; any of them could provide it. Some formats bring the trouble shooter to this point without seeing the overall picture of the dependencies or loops.

Others use overall pictures of the loops to guide him. The important point seems to be that they all get him to this point without requiring him to work out the dependencies for himself. The FIST concept goes one step further and employs transformation networks built into the points to be measured on the dependency chain in order that one simple but specially designed test instrument is used for all measurements. This test instrument is the size of a man's hat and gives a Go, No-Go, or no test indication.

All concepts go this far. FORECAST goes one step further and organizes the stages into trouble shooting blocks. This means analyzing the stages to identify which parts will affect which test points, regardless of feelbacks, feedbacks and other oddball electronic exceptions to the simple logic of a good signal into a block,and a bad signal out of it means the trouble is in this block. This additional analysis further reduces the need for the trouble shooter to analyze the circuit and determine for himself what he has checked when he makes a check. It also makes possible the use of simple resistence checks within the trouble shooting block to find the malfunctioning piece-part. This within block trouble shooting procedure is common to all hardware systems. Once trained in the method, the man can use it on any system.

This ends the summary of the concepts. In a summary as brief as this, the details of each concept may not have received perfect justice but within the limits of a summary it is as accurate as we can make it at the present time -- and we feel the generalizations are essentially correct.

These new concepts for electronic maintenance have clear system-wide implications for training documentation, operations and equipment configuration. Clearly, for maximum effectiveness, training, documentation and equipment configuration must be brought into line. Guidance for bringing them into line can come from these concepts.

In order to compare the effectiveness of concepts, they must be converted to a common denominator. This means determining how much of the trouble shooting process each applies to. Formulas for making this conversion to common grounds have been worked out and will be published as part of our report on these ten concepts.

Evaluating the Concepts

To be of any real value to the Army, an evaluation of any of these concepts for electronic maintenance must be made in terms of the total man-machine system of which each concept is a part. Any other type of evaluation is worse than meaningless -- it can be outright misleading.

Evaluation on a systems basis is a relatively new approach and the methods and concepts for accomplishing it are not completely developed. However, overall system evaluation is clearly in the mainstream of all military (and civilian) decisions. It is no longer sufficient to consider the cost of a new item of hardware; hardware must be evaluated in terms of the cost/effectiveness of the system into which it fits. A low-cost hardware item may require high-cost training, while a high-cost manual may actually reduce training costs by far more than the differential cost of the manuals.

Sub-System Optimization

Policies for the entire electronic maintenance system including training, manuals, supply, job duties and operations were established when electronic equipment was relatively simple, scarce and much less important to the Army than it is today. There have been minor adjustments in job structure and unit operations resulting from changes in test equipment, logistics, etc. However, no major readjustment which responded to the interactions of all important factors has taken place. One reason for lack of major readjustment is that an initially established structure tends to perpetuate itself due to its compartmentalization.

There are eight Army agencies and commands which have a piece of the responsibility in the area of electronic maintenance. All of these agencies work toward the optimization of costs and effectiveness within the subsystem for which they are responsible, but at best even with coordination this tends toward subsystem optimization. It has become clear that the sum of optimized subsystems does not equal optimization of the total system. For instance, minimizing manual costs may cause the total system to tend toward maximum cost and minimum effectiveness.

The current policy for development of manuals is to provide the producer a relatively rigid set of specifications for their content and style. This policy is one which has been very successful for the procurement of standard items like clothing, food, nuts and bolts. The same degree of rigidity and specification of detail is not used for the procurement of items which require research and development, e.g., aircraft and radar systems.

The existence of numerous new concepts for manuals and electronic maintenance indicate evidence of research and development efforts in this area. It would appear that policies for the procurement of these products should now shift toward those used for R&D items. This would mean the relaxation of rigid specifications and the increased use of coordination between the procuring agency and the producer of manuals. This increased involvement of the procurement office will require a high degree of knowledge and competence regarding concepts on the part of the procurement office. A change in procurement policies along these lines might well produce increases in overall system effectiveness comparable to the improvements in successive major weapon systems which have occurred since World War II.

There are so many interlocking factors, currently compartmentalized into areas of responsibility that it will take time and experimentation to play them off against each other. An experimental approach will have to be handled in such a way as to provide adequate stability for our force readiness, yet give the necessary flexibility. The pressures for such an approach led to the initiation of Task MOSAIC, of which a summary of ten new concepts is one aspect.

We always hear it said with great force and sincerity, "We can't wait -- we need a solution now." Yet "locking on" what appears to be a solution now and codifying it in specifications can result in a new rigid structure which might "lock out" still greater advances.

The implication of this is that there should exist a state of flux for several years. During this period, changes should be adopted and their effects studied. But no attempt should be made to arrive at an "ultimate" solution which then becomes locked into new specifications for "all time." So this paper, rather than indicating which concept is best becomes a recommendation for further research -- but reaearch in which currently compartmentalized responsibilities are opened up so that a total systems approach to maintainability is possible.

THE EFFECT OF MAINTAINABILITY ON MAINTENANCE AND LOGISTIC SUPPORT PLANNING

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THE EFFECT OF MAINTAINABILITY ON MAINTENANCE AND LOGISTIC SUPPORT PLANNING

Gentlemen:

During this presentation I will make certain proposals which I hope will provide a base for further discussion and study. These proposals have not been staffed in AMC/SMC and are not to be considered as the official AMC/SMC position on the subject.

My assigned subject is "The Effect of Maintainability on Maintenance and Logistic Support Planning". To this subject I would like to add "and how to measure this effect." However, before we consider the results or effects of maintainability, or the lack thereof, and the measurement of these effects, we must examine the factors which give rise to the need for maintenance actions which, in turn, give rise to the need for maintainability.

CHART #1 ON

"Maintenance consists of those actions required to overcome or prevent a lack of reliability. This maintenance includes both servicing and repair operations, - the servicing to prevent or delay failure and repair to overcome failure. In both cases, failure = lack of reliability".

Why don't we have 100% reliability - and eliminate maintenance. In most cases, the state of the art or cost will not permit attainment of 100% reliability

CHART #1 OFF

Note that cost is a factor in achieving reliability. But maintenance actions also cost. Let's look at the maintenance costs generated by a lack of 100% reliability.

CHART #2 ON

"Maintenance costs are reflected in time, facilities, equipment, publications, supplies and personnel necessary to prevent, delay or overcome inherent unreliability." On the basis that a 100% reliable item would operate forever with no maintenance or servicing, all support costs are maintenance costs.

Can these maintenance actions be costed? They can. Our reliability engineers can predict from experience or theory, that a given part will require a specific amount of service during its life and will fail after a specific period of time or use. By computing the maintenance cost of servicing and replacement of each part with predicted unreliability, multiplied by the number of times a specific part will be replaced during the design life of the individual end item, and this figure multiplied by the total number of end items to be procured, the total maintenance cost of a specific part can be computed. If the maintenance cost of each part with predicted unreliability were computed and all of these sums added we would arrive at the total maintenance cost of the anticipated inventory of the end item in question. Such a figure, if ever computed for a complicated end item, would be staggering and the need for additional reliability or built-in maintainability, or both, would become a matter of urgency.

CHART #2 OFF

and so, finally, we come to maintainability. Let's look at the current Army definition of maintainability,

CHART #3 ON

as contained in MIL-STD 778, dated 22 April 1964, Maintainability Terms and Definitions. "Maintainability (M) is a characteristic of design and installation which is expressed as a probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources."

Frankly, the only thing this definition tells me is that if I can commit enough resources to meet a prescribed turn around time, I have maintainability. I will admit that an item may be maintainable under such conditions and when measured only against time. I submit, also, that under such a definition the most poorly designed piece of equipment in the Army inventory can have a higher degree of maintainability (probability of meeting a turn around time) than the best designed piece of equipment, depending on resources committed.

CHART #3 OFF

I do not believe that the definition is meaningful and I propose, in lieu thereof, a definition in substance as follows:

CHART #4 ON

"Maintainability is a design condition resulting from the incorporation of characteristics of design and installation which reduce the cost of maintenance actions to the lowest economically feasible level."

As a corollary we might define reliability as a design condition resulting from the incorporation of characteristics of design and materiels to insure maximum economically feasible trouble-free operations. Economically feasible means that the cost of further increases in trouble-free operations would be greater than the cost of the maintainability features and maintenance actions necessary to service or repair the equipment.

CHART #4 OFF

Please note that the entire cost of an end item, including design, procurement and support can be costed in three areas - Reliability - Maintainability - Maintenance.

CHART #5 ON

"Basic design reliability cost + maintainability design cost + maintenance action cost = total system cost". In some cases the design and procurement cost of maintainability features will be such that additional reliability may be bought at a lesser cost. In almost all cases the cost of maintenance actions (support) will warrant intensive action to build in either greater reliability or greater maintainability, or both. In all cases, the cost figures for reliability, maintainability and maintenance action should result in the lowest total system logistic cost figure.

CHART #5 OFF

I have indicated previously how maintainability affects maintenance requirements. Let's take a look now of the affect of these maintenance requirements on the maintenance support plan.

CHART #6 ON

The time requirement can affect the maintenance float, number of personnel, the training requirements of those personnel and total allocation in TOE. Skill requirements affect personnel authorization and training and special tools, and facilities. Tools affect the TOE, personnel and equipment, of the maintenance elements of all organizations concerned. Facility requirements to house and operate the maintenance equipment must be computed in the support plan.

Personnel requirements are reflected in training requirements and TOE authorization. Supply is reflected in the provisioning of all supplies consumed by the end item during its life cycle and by the personnel to handle these supplies. In effect, the support plan is based on maintenance actions required and these, in turn, are based on predicted or actual unreliability as modified by maintainability.

<u>CHART #6 OFF</u>

Gentlemen: The logistic cost of the inventory of a specific end item varies with the cost of reliability, maintainability and maintenance actions. The lowest possible logistic cost required to meet operational availability requirements is a national objective. Under these conditions the dollar cost of reliability, maintainability and maintenance actions is the only meaningful unit of measure as to how efficiently we do our job. REMEMBER

CHART #7 ON (Same as Chart 5)

The cost of RELIABILITY + MAINTAINABILITY + MAINTENANCE = LOGISTIC COST.

Not one of these elements can exist independant of the others and cost is our only common denominator. I propose that we quantify our requirements in these areas on a cost basis.

CHART 1 - MAINTENANCE

MAINTENANCE CONSISTS OF THOSE ACTIONS REQUIRED TO OVERCOME OR PREVENT A LACK OF RELIABILITY.

THIS MAINTENANCE INCLUDES BOTH SERVICING AND REPAIR OPERATIONS, THE SERVICING TO PREVENT OR DELAY FAILURE AND REPAIR TO OVERCOME FAILURE.

IN BOTH CASES, FAILURE = LACK OF RELIABILITY.

CHART 2

MAINTENANCE COSTS ARE REFLECTED IN:

TIME

FACILITIES

EQUIPMENT

PUBLICATIONS

SUPPLIES

PERSONNEL

NECESSARY TO:

PREVENT

DELAY, OR

OVERCOME INHERENT UNRELIABILITY.

CHART 3 - CURRENT DEFINITION OF M

MAINTAINABILITY (M) IS A CHARACTERISTIC OF DESIGN AND INSTALLATION WHICH IS EXPRESSED AS A PROBABILITY THAT AN ITEM WILL CONFORM TO SPECIFIED CONDITIONS WITHIN A GIVEN PERIOD OF TIME WHEN MAINTENANCE ACTION IS PERFORMED IN ACCORDANCE WITH PRESCRIBED PROCEDURES AND RESOURCES.

CHART 4 - PROPOSED DEFINITION OF M

MAINTAINABILITY IS A DESIGN CONDITION RESULTING FROM THE INCORPORATION OF CHARACTERISTICS OF DESIGN AND INSTALLATION WHICH REDUCE THE COST OF MAINTENANCE ACTIONS TO THE LOWEST ECONOMICALLY FEASIBLE LEVEL.

CHARTS 5 and 7.

BASIC DESIGN RELIABILITY COST

\+ MAINTAINABILITY DESIGN COST

\+ MAINTENANCE ACTION COST

= TOTAL SYSTEM COST

MAINTAINABILITY AFFECTS MAINTENANCE SUPPORT PLAN AS TO

MAINTENANCE FLOAT	PUBLICATIONS	EQUIPMENT & FACILITIES	SUPPLY	PERSONNEL
NUMBER	TECH MANUALS	FIELD	TOOLS	NUMBER
LOCATION	E. S. C.	DEPOT	CONSUMABLES	SKILLS
STORAGE	P. L. L.		REPLACEMENT PARTS-COMPONENTS	TRAINING
CRITERIA FOR USE	A. S. L.		STORAGE	
	CRITERIA		HANDLING	
	STANDARDS		SURVEILLANCE	
			TESTING FOR - SERVICEABILITY	
			TRANSPORTATION	

CHART #6

THE ARMY'S MAINTAINABILITY DILEMMA - COMMUNICATION

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U. S. ARMY MISSILE COMMAND

(PRESENTED AT THE ARMY TECHNICAL MEETING ON QUANTIFICATION OF MAINTAINABILITY DURING RESEARCH AND DEVELOPMENT OF MATERIEL, 19 JULY 1965, SPONSORED BY THE CHIEF OF RESEARCH & DEVELOPMENT, DEPARTMENT OF THE ARMY.)

THE PURPOSE OF THIS WORKSHOP IS TO EXPRESS INDIVIDUAL THOUGHTS, SO I WOULD LIKE TO TAKE THIS OPPORTUNITY TO EXPRESS MY CONCERN ABOUT THE WAY THE ARMY (MYSELF INCLUDED) HAS WONDERED INTO A STATE OF DILEMMA WITH RESPECT TO THE BUSINESS OF MAINTAINABILITY. I FIND IN MY ACTIVITIES IN AND AROUND THE ARMY, THAT THERE IS A CLOUD OF CONFUSION ABOUT THIS WHOLE SUBJECT, AND I FOR ONE FEEL THAT SOMETHING SHOULD BE DONE. DURING THIS SHORT PRESENTATION, I WISH TO HIT UPON ONLY ONE AREA OF CONCERN - THAT IS, THE INEFFICIENT AND INEFFECTIVE COMMUNICATION OF THOUGHTS AND IDEAS OF THIS THING CALLED MAINTAINABILITY.

I FEEL THAT THE MOST SERIOUS MAINTAINABILITY PROBLEM IN THE ARMY TODAY IS COMMUNICATION. BEFORE WE CAN EVER HOPE TO QUANTIFY MAINTAINABILITY, WE MUST BE ABLE TO TALK ABOUT IT INTELLIGENTLY. TODAY, IT IS HARD TO FIND TWO PEOPLE WHO CAN SIT DOWN TOGETHER AND DISCUSS MAINTAINABILITY AND FOR THEM BOTH TO BE TALKING ABOUT THE SAME THING, AND FOR THEM BOTH TO BE IN AGREEMENT WITH THE CURRENT DEFENSE DEPARTMENT'S AND THE ARMY'S PUBLISHED IDEAS ON THE SUBJECT.

BEFORE LOOKING INTO THE REASON WHY WE HAVE THIS PROBLEM, LET US IDENTIFY AS WELL AS WE CAN THAT WHICH I SAY IS BEING MISUNDERSTOOD.

IT STARTS WITH THE DEFINITION OF MAINTAINABILITY TAKEN FROM MIL-STD-778, WHICH STATES: "MAINTAINABILITY IS A CHARACTERISTIC OF DESIGN AND INSTALLATION WHICH IS EXPRESSED AS THE PROBABILITY THAT AN ITEM WILL CONFORM TO SPECIFIED CONDITIONS WITHIN A GIVEN PERIOD OF TIME WHEN MAINTENANCE ACTION IS PERFORMED IN ACCORDANCE WITH PRESCRIBED PROCEDURES AND RESOURCES."

I DON'T HAVE TO TELL THIS GROUP THAT THIS DEFINITION IS DECEPTIVE. WHAT ARE THE KEY WORDS IN THIS DEFINITION? WHAT DOES IT REALLY SAY? OR, POSSIBLY MORE IMPORTANT TO SOME......WHAT DOES IT NOT SAY? LET'S ANALYZE IT CLOSER.

FIRST, IT STATES THAT MAINTAINABILITY IS A CHARACTERISTIC OF DESIGN AND INSTALLATION. IT RECOGNIZES, THEREFORE, THAT ALL TRUE MAINTAINABILITY PROBLEMS ARE TRACEABLE BACK TO THE ORIGINAL DESIGN OR THE MANNER IN WHICH THE DESIGN WAS INCLUDED IN SOME HIGHER ASSEMBLY. IT NEXT STATES THAT MAINTAINABILITY IS EXPRESSED AS A PROBABILITY. THIS IS SUPPOSEDLY EXPRESSED AS THE PROBABILITY THAT AN ITEM WILL CONFORM TO "SPECIFIED CONDITIONS" WITHIN A GIVEN PERIOD OF TIME. "SPECIFIED CONDITIONS" ARE ASSUMED TO BE SOME MINIMUM OPERATIONAL STATE OF READINESS, BUT NOT NECESSARILY A PERFECT STATE OF REPAIR IN ALL CASES. THE GIVEN TIME ASPECT APPEARS AT FIRST TO PLACE A PREMIUM ON THE RAPIDITY OF REPAIR. A CLOSE LOOK, HOWEVER, WILL SHOW THAT THIS IS NOT SO. THE RAPIDITY OF REPAIR IS INVOLVED ONLY WHEN THIS SPECIFIED TIME IS SHORT OR IS BEING MINIMIZED. I THINK THE GRAYEST AREA IS HIDDEN IN THE LAST EXPRESSION -- WHEN MAINTENANCE IS PERFORMED IN ACCORDANCE WITH PRESCRIBED PROCEDURES AND RESOURCES.

THIS SAYS THAT YOU CANNOT EXPRESS MAINTAINABILITY UNLESS THE MAINTENANCE ENVIRONMENT HAS BEEN ESTABLISHED. IT IMPLIES THAT THE ESTABLISHMENT OF THIS MAINTENANCE ENVIRONMENT IS NECESSARY ONLY FOR THE QUANTITATIVE EXPRESSION OF MAINTAINABILITY. I REMIND YOU, THAT BY OUR OWN DEFINITION, MAINTAINABILITY IS A CHARACTERISTIC OF DESIGN AND INSTALLATION......NOT A CHARACTERISTIC OF THE MAINTENANCE ENVIRONMENT.

AS I MENTIONED EARLIER, THIS DEFINITION IS DECEPTIVE. SOME EVEN ARGUE THAT THE STATEMENT USED IN DEFINING MAINTAINABILITY ACTUALLY DEFINES SOMETHING ELSE ENTIRELY. SOME SIMPLY DISAGREE WITH IT. OTHERS NOT EVEN FAMILIAR WITH THIS DEFINITION PROFESS THEY UNDERSTAND MAINTAINABILITY ANYWAY. I FIRMLY BELIEVE THAT AS LONG AS PEOPLE THINK OF MAINTAINABILITY AS "THE ABILITY TO MAINTAIN" WHICH, UNFORTUNATELY, SOUNDS COMPLETELY LOGICAL......AS LONG AS THIS GOES ON, WE WILL CONTINUE TO HAVE OUR DILEMMA COMMUNICATING MAINTAINABILITY IDEAS AND THOUGHTS.

TO BETTER ILLUSTRATE THIS, I AM GOING TO GIVE EXAMPLES OF THIS CONFUSION BY DISCUSSING SOME OF OUR "SACRED COWS" OF MAINTENANCE IN THE LIGHT OF THE MAINTAINABILITY AS STRUCTURED BY THE MILITARY DEFINITION. PLEASE REMEMBER THAT MY USE OF THE WORD "MAINTAINABILITY" IS STRICTLY AS DEFINED EARLIER.

FIRST, ONE ALREADY MENTIONED, IS......MAINTAINABILITY IS NOT SIMPLY THE ABILITY TO MAINTAIN. THE ABILITY TO MAINTAIN INFERS SIMPLY A MAINTENANCE CAPABILITY. THIS IS THE REASON MANY PEOPLE WILL INTERCHANGE THE WORDS MAINTAINABILITY AND MAINTENANCE WITHOUT KNOWING THEIR DIFFERENCES.

SECOND. MAINTAINABILITY IS NOT DESIGNING FOR EASE OF MAINTENANCE. THE TERM "EASE OF MAINTENANCE" HAS COME TO BE A CLICHE' WE ALL LOVE TO USE. WHAT SOUNDS BETTER THAN TO HAVE EASE OF MAINTENANCE?

HOWEVER, ACCORDING TO THE DEFINITION, EASE OF MAINTENANCE IS NOT MENTIONED AS A MAINTAINABILITY CHARACTERISTIC. THE DESIGNER IS FREE TO DESIGN FOR EASE OF MAINTENANCE ONLY IF THE ALTERNATIVES BEING CONSIDERED ALL SATISFY THE MAINTAINABILITY CONSTRAINTS SPECIFIED. IT IS NOT, THEN, THE MAINTAINABILITY REQUIREMENT THAT STIPULATES DESIGNING FOR EASE OF MAINTENANCE.

THIRD. MAINTAINABILITY IS NOT DESIGNING FOR MAINTENANCE AT LEAST COSTS. ALTHOUGH WE ARE ALL OBLIGATED TO WATCH COSTS, NOT ONLY FROM THE ACQUISITION STANDPOINT, BUT FROM THE TOTAL LIFE COST STANDPOINT, THE ACT OF PROVIDING LESS COSTLY MAINTENANCE CANNOT BE CONSIDERED INTEGRAL TO THE MAINTAINABILITY FUNCTION. ACTUALLY, TO MEET THE TIME CONSTRAINT TO SATISFACTORILY MEET THE MAINTAINABILITY REPAIR TIME REQUIREMENT, WE MAY BE FORCED TO DEMAND A MORE EXPENSIVE DESIGN, A MORE COMPLICATED AND MORE COSTLY SUPPORT EQUIPMENT, AND A MORE EXTENSIVELY TRAINED TECHNICIAN. DESIGNING FOR A REASONABLY LOW COST OF MAINTENANCE IS A GOOD DESIGN GOAL AND A SERIOUS REQUIREMENT; HOWEVER, IT CAN BE READILY SEEN THAT IT IS NOT THE MAINTAINABILITY REQUIREMENT, PER SE, THAT REQUIRES THIS.

ANOTHER THING THAT MAINTAINABILITY IS NOT.....MAINTAINABILITY IS NOT DESIGNING FOR MINIMUM MANPOWER REQUIREMENTS. DESIGNING FOR A REQUIRED QUICK RESPONSE MAY VERY WELL INCREASE THE CREW SIZE.

THERE ARE OBVIOUSLY MORE OF THESE TYPES OF EXAMPLES; HOWEVER, THE POINT I WANT TO MAKE IS THAT MILITARY MAINTAINABILITY IS NOT A SUMMATION OF ALL THE THINGS THAT ARE GOOD FOR MAINTENANCE. MAINTAINABILITY IS NOT A CATCH PHRASE INTO WHICH ALL MAINTENANCE, MAINTENANCE ENGINEERING, AND OTHER SUPPORT JARGON CAN NOW BE CATALOGED.

MAINTAINABILITY IS A RATHER NEW FACET OF DESIGN. IT IS, IN FACT, A DESIGN PARAMETER. IT IS NOT JUST A NEW WORD FOR THE TRADITIONAL MAINTENANCE ENGINEERING CONSIDERATIONS. IT IS NOT A NEW WORD REPLACING THE TRIED AND TESTED TRUISMS CONCERNING THE BEST PHILOSOPHIES FOR GETTING THE MAINTENANCE FUNCTION PERFORMED UNDER FIELD OR COMBAT CONDITIONS.

THE FACT THAT THERE ARE SO MANY POINTS OF DISAGREEMENT AS TO JUST WHAT MAINTAINABILITY IS AND WHAT IT IS NOT, IN ITSELF SERVES TO ILLUSTRATE AND SUPPORT THE CLAIM THAT COMMUNICATION IS A SERIOUS PROBLEM WITH MAINTAINABILITY IN THE ARMY TODAY. THE FACT THAT THERE ARE PEOPLE SITTING TOGETHER TODAY IN THIS VERY ROOM WHO HAVE DIFFERENT INTERPRETATIONS OF THE BASIC DEFINITION OF MAINTAINABILITY ALSO SUPPORTS THIS CLAIM. AS LONG AS SUCH WIDELY DIFFERENT INTERPRETATIONS OF THE TERM CONTINUE, WE CAN EXPECT THE ACTIONS ACCOMPLISHED UNDER THE FUNCTIONAL HEADING OF MAINTAINABILITY TO BE JUST AS WIDELY DIVERSIFIED.

IF WE ACCEPT THE DEFINITION THAT THE MAINTAINABILITY OF AN ITEM IS A CHARACTERISTIC OF DESIGN AND INSTALLATION, REGARDLESS OF THE MANNER CHOSEN TO EXPRESS IT, THEN WE MUST REJECT THE HYPOTHESIS THAT THE PRESCRIBING OF THE GIVEN PROCEDURES AND RESOURCES FALLS WITHIN THE DOMAIN OF THE MAINTAINABILITY FUNCTION. IF WE ACCEPT THIS HYPOTHESIS, THEN WE MUST DISAGREE WITH THE BASIC DEFINITION WHICH MAKES MAINTAINABILITY THE PRIVATE AND UNDISPUTED POSSESSION OF DESIGN. IN THIS LATTER CASE, WE WOULD RE-DEFINE MAINTAINABILITY AS "A CHARACTERISTIC OF DESIGN, INSTALLATION, AND MAINTENANCE ENVIRONMENT." HOWEVER, IS THIS WHAT WE WANT? WE ALL RECOGNIZE THAT PROCEDURES AND RESOURCES HAVE LONG BEEN THE DOMAIN OF THE MAINTENANCE ENGINEER.

HIS INTEREST IN THE TECHNICAL PUBLICATIONS REPAIR PARTS, TOOLS, TEST EQUIPMENT, ETC., IS TRADITIONAL. THE MAINTENANCE ENGINEERING FUNCTION ESTABLISHES THE MAINTENANCE PHILOSOPHY AND ENVIRONMENT, OR IF YOU PREFER, THE MAINTENANCE PROCEDURES AND RESOURCES. MAINTENANCE ENGINEERING ESTABLISHES THE BASE LINE FROM WHICH THE DESIGNER MUST START IN ASSURING THAT HIS DESIGN PROPERLY CONSIDERS MAINTENANCE. IT ALSO ESTABLISHES THE BASE LINE FROM WHICH THE DESIGNER MUST START TO ASSURE THAT REPAIRS THAT MIGHT BE NECESSARY, CAN BE ACCOMPLISHED WITHIN THE TIME CONSTRAINT. THIS IS THE DESIGNER'S CONTRIBUTION TO MAINTAINABILITY. TRADE-OFFS BETWEEN MAINTENANCE REQUIREMENTS AND MAINTAINABILITY ARE COMMON. MAINTAINABILITY THEN IS MEASURED, BASED ON THE ORIGINAL BASE LINE ESTABLISHED BY THE MAINTENANCE ENGINEERS. THIS IS BASICALLY A COMMUNICATIONS PROBLEM. WHAT WE NEED IS A GOOD STATEMENT OF INTENT AS TO WHAT THE ARMY NOW CONSIDERS TO BE THE PRIMARY DOMAIN OF MAINTENANCE, THE PRIMARY DOMAIN OF MAINTENANCE ENGINEERING, AND THE PRIMARY DOMAIN OF MAINTAINABILITY. MOST IMPORTANT WOULD BE THE ESTABLISHMENT OF A CLEARLY DEFINED INTERFACE BETWEEN MAINTAINABILITY AND MAINTENANCE ENGINEERING. THIS WOULD SERVE TO CLARIFY THIS WHOLE PROBLEM, AND WOULD SERVE TO PLACE MAINTAINABILITY RESPONSIBILITIES MORE ON THE DESIGNER, WHILE REQUIRING HIM TO REALIZE AND UNDERSTAND HIS INTERFACE WITH THE MAINTENANCE ENGINEERS.

DO WE, AS THE ARMY'S MAINTAINABILITY WORK FORCE, CONDUCT OUR MAINTAINABILITY PROGRAMS STRICTLY IN ACCORDANCE WITH THE DEFINITIONS OF MIL-STD-778 AND AR 705-26? OR......DO WE ALTER THEM A LITTLE AND CONSIDER MAINTAINABILITY LESS OF A DESIGN PARAMETER AND MORE OF AN OPTIMIZATION OF THE MAINTENANCE PROCEDURES AND RESOURCES, THE JOB THAT MAINTENANCE ENGINEERING HAS BEEN DOING FOR YEARS?

I SUBMIT THAT, UNLESS A CLEAR-CUT DISTINCTION IS MADE BETWEEN MAINTAINABILITY AS A DESIGN CHARACTERISTIC, AND MAINTAINABILITY AS A FUNCTION OF THE MAINTENANCE ENVIRONMENT, AND PROPERLY RECOGNIZED AT ALL LEVELS, MAINTAINABILITY WILL BECOME MORE OBSCURE RATHER THAN MORE PROGRESSIVE, AND QUANTIFICATION FACTORS WILL BECOME MEANINGLESS.

WE CAN REMOVE THIS SERIOUS DILEMMA THROUGH IMPROVED COMMUNICATIONS. IMPROVED COMMUNICATIONS, HOWEVER, MUST BEGIN WITH A VOCABULARY WITH WORDS MEANING THE SAME TO ALL USERS.

AS A STARTER, I WOULD LIKE TO PROPOSE THE FOLLOWING:

1. THAT THE GENERAL TERM "MAINTAINABILITY" BE CONSIDERED BY THE ARMY TO RECOGNIZE NOT ONLY THE CHARACTERISTICS OF DESIGN AND INSTALLATION, BUT ALSO TO RECOGNIZE THE INFLUENCE OF THE MAINTENANCE ENVIRONMENT.

2. THAT THE GENERAL TERM "MAINTAINABILITY" BE CONSIDERED AS CONSISTING OF TWO MAJOR FIELDS OF INTEREST: MAINTAINABILITY ENGINEERING AND MAINTENANCE ENGINEERING.

3. MAINTAINABILITY ENGINEERING WOULD ENCOMPASS ALL MAINTAINABILITY CONSIDERATIONS ASSOCIATED WITH DESIGN CONFIGURATION, RELIABILITY ENGINEERING, HUMAN FACTOR ENGINEERING, STANDARDIZATION ENGINEERING, AND OTHER USUAL CONSIDERATIONS ASSOCIATED WITH DESIGN DURING DEVELOPMENT.

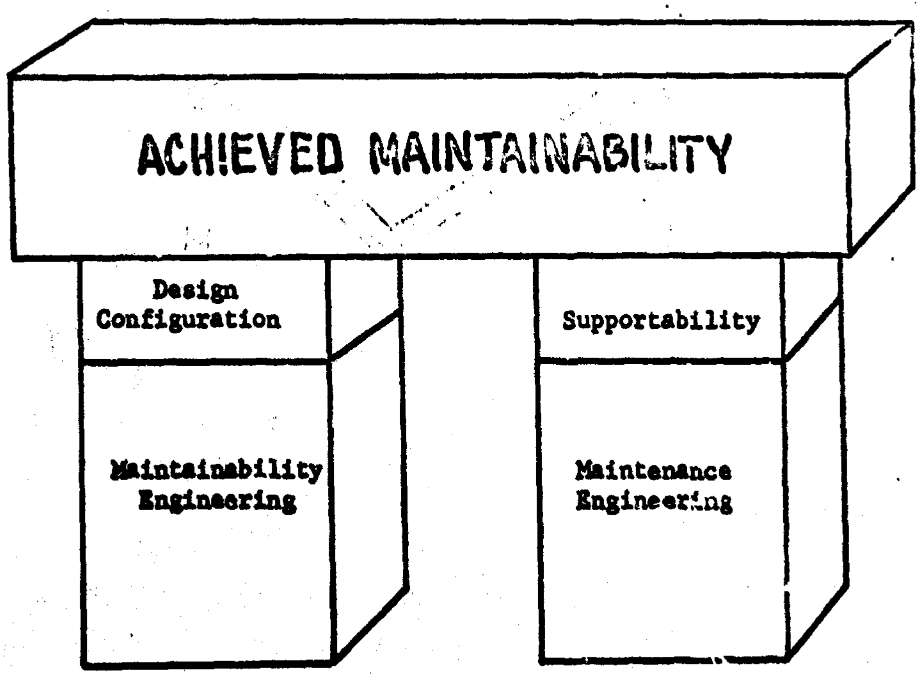
4. MAINTENANCE ENGINEERING WOULD ENCOMPASS ALL MAINTAINABILITY CONSIDERATIONS ASSOCIATED WITH MAINTENANCE PHILOSOPHY, MAINTENANCE PROCEDURES, MAINTENANCE RESOURCES, SUPPORT ENVIRONMENT, SKILLS, AND SUPPORT PLANNING IN GENERAL.

5. FORMAL CHANNELS OF COMMUNICATION MUST BE ESTABLISHED BETWEEN THE MAINTAINABILITY ENGINEERS CONCERNED WITH THE DESIGN AND THE MAINTENANCE ENGINEERS CONCERNED WITH THE SUPPORT REQUIREMENTS.

DATA EXCHANGE IN BOTH DIRECTIONS IS A MUST IF MAINTAINABILITY IS TO BE ACHIEVED TO SATISFY BOTH DESIGN AND SUPPORT.

IF THIS GROUP LEAVES THIS MEETING THIS AFTERNOON WITHOUT A COMMON UNDERSTANDING OF THE DEFINITION OF MAINTAINABILITY, THEN I FEEL THAT MUCH OF THE TIME AND EFFORT EXPENDED IN HOLDING THIS MEETING HAS BEEN WASTED. IF, ON THE OTHER HAND, WE CAN AT LEAST ACCEPT THE FACT THAT THE DEFINITION DOES EXIST, AND ACCEPT WHAT THE DEFINITION SAYS AS BEING WHAT WE CALL MAINTAINABILITY, THE MEETING HAS BEEN WORTHWHILE.

I SERIOUSLY FEEL THAT WE MUST IMPROVE OUR MAINTAINABILITY COMMUNICATIONS BEFORE ANY QUANTIFICATION NUMERICS WILL BE MEANINGFUL. I DON'T HAVE THE FULL ANSWER TO THIS DILEMMA. I WILL, HOWEVER, DO WHATEVER I CAN TO HELP THE ARMY GET THE ANSWER.



SOME PROBLEMS IN DEFINING MAINTAINABILITY AND ASSOCIATED TERMS

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SOME PROBLEMS IN DEFINING MAINTAINABILITY AND ASSOCIATED TERMS

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INTRODUCTION

Maintainability, in a sense, is like workmanship. That is, each term denotes an area which is undeniably important and which requires a term to specifically define and delineate that area. Yet, in both cases, attempts at precise, quantitative definition have not, in general, yielded results which are in any way satisfactory neither from an academic nor a practical standpoint.

There is considerable evidence that this difficulty exists and that it is not easily disposed of. For example, the document[1] which established this meeting exhibits a rather comprehensive awareness of this difficulty.

Unfortunately, this difficulty is not restricted to the word "maintainability" itself but extends to many terms which are a necessary part of that area which is connoted by the term "maintainability".

REFERENCE DOCUMENT

A "Proposed Military Standard for Definitions of Terms on System Effectiveness" has been recently circulated for comment.[2] Since frequent reference is made to this proposed standard it will be convenient to refer to it as the "reference document" herein.

DEFINITION VERSUS "QUANTIFICATION"

Definitions of technical terms are almost always quantitative definitions. In many cases the definitions are exclusively quantitative (i.e., the definition of a dyne). In other cases, the definition

1. Army Technical Meeting on Quantification of Maintainability (U) During Research and Development of Material (Anonymous and undated - Received June 1965)

2. Pertinent excerpts of the writer's comments on this proposed standard are being circulated as a separate document.

may not, in fact, delineate quantitative values, but imply that measurement is possible and that truly quantitative terms are available or can be easily defined as needed. For example, the definition of mass implies that it can be measured and that suitable units for such a measurement either exist or are definable.

To paraphrase Lord Kelvin, a non-quantitative definition is almost useless in any technology. In the field of maintainability this statement is no less true. The word "maintainability" and a host of terms which are needed within the field require quantitative definitions if anything meaningful is to be made part of the requirements for an item and if something constructive is thereby achieved. Otherwise, the situation - "- the contractor shall use the best workmanship -" will prevail.

The need is clear. Unfortunately, there are some grave difficulties in achieving these definitions.

DUALITY IN MEANING OF MAINTAINABILITY

Maintainability is a term which has at least two entirely distinct meanings. First, it denotes the area or technical field which is being discussed. Second, it denotes some (hopefully) quantitative attribute of an equipment or a man-machine complex. In this respect, the term "statistics" denotes both the technical field and some specific concepts or items within that field. Such a duality of meaning, in general, causes no serious ambiguity and, at worst, is an occasional mild annoyance. Hence, the writer in no way objects to this duality. However, it is important that this duality be recognized and that separate definitions be accorded to each sense. It is not the purpose of this paper to present solutions to these difficulties but to delineate them to facilitate and stimulate discussion.

MAINTAINABILITY IN THE FIRST SENSE

Defining maintainability in the first sense presents no difficulties which are not inherent in defining any field. The writer does not wish to minimize these difficulties, he simply wants to distinguish this type of difficulty from the type of difficulty which is encountered in attempting to define maintainability in the second sense.

The difficulties in defining a field are centered around the basic inability to delineate a complex situation in concise terms. This has long been recognized and various expediencies have been used. In general, the layman has some vague (usually erroneous) notion of what the field is (does the layman really understand what is meant by the term "mathematics"?) and the professional is so immersed in the fi ld that he doesn't need a formal definition of the field

It has been said that the term "physics" is best defined as "- that which a physicist does." which seems circumlocutious but it does illustrate the frustration in attempting to define such a term.

Thus, as far as the first sense is concerned, one is left with the need for a definition to satisfy the layman which need only be acceptable to, and not necessarily satisfying to, the professional.

PROPOSED DEFINITION (*First Sense*)

Maintainability is that technical field which is concerned with the relative ease of actions which correct malfunctions or which reduce the incidence of future malfunctions. These actions are called "corrective maintenance" and "preventive maintenance" respectively.

MAINTAINABILITY IN THE SECOND SENSE

It is the definition of maintainability in the second sense that really formidable problems arise. For this is the professional's term. This is the term with which he must work. The layman's need has (presumably) been satisfied with the definition in the first sense and, hence, his need and his views will not be considered further.

From the professional's viewpoint, the second sense definition must, perforce, be quantitative. More than this, it must be meaningful, clear, concise, unambiguous, satisfying, and useful. This is quite a requirement. It is doubtful that it can be attained completely. Any definition must, at best, be a compromise of these requirements.

It might be useful to attempt a ranking of the importance of these requirements. To do this requires an establishment of a criterion for such a ranking. One criterion could be that of desirability. Another criterion could be that of estimated ease of achievement. A third ranking could then be made which represented some compromise of the two criteria.

Any such ranking is, of course, a matter of opinion and, therefore, a subject of controversy. It is characteristic of such controversy that the further one proceeds down such a list - the greater the likelihood of controversy.

From a desirability standpoint, one might list

Meaningful
Satisfying
Useful
Quantitative
Unambiguous
Clear
Concise

From an estimated ease of achievement, one might list

Clear
Concise
Unambiguous
Meaningful
Quantitative
Useful
Satisfying

Unfortunately, these two lists are almost exact opposites in order. Therefore, making a compromise list can be extremely difficult (and extremely controversial).

Two Customers

There are at least two distinctly different types of persons who have a legitimate need for a second-sense definition of reliability. For convenience, one type will be designated the "practical" type and the second will be designated the "theoretical" type. Without question, each type's need for a definition is real and is important. Can a single definition serve both customers? This question merits further consideration.

The practical type includes all persons who are concerned with the direct performance of maintenance, or in designing equipment to facilitate such maintenance. Thus, this type includes design engineers, process engineers, maintenance superintendents, mechanics, etc.

The theoretical type includes all persons who are concerned with studies to minimize costs or to maximize effectiveness with respect to maintenance. Thus, this type includes mathematicians, economists, operations research workers, etc.

In these categories, the obvious categories of persons have been explicitly included. There are other categories of persons where the correct type designation is not nearly so obvious. To which type, for example, does the contract writer belong?

What Does Maintainability Include ?

It is pertinent to inquire: What does maintainability include? Is it

1. An attribute of the equipment only?
2. An attribute of the maintenance crew?
3. An attribute of the maintenance policy?
4. An attribute of the maintenance organization?
5. An attribute of the supply system?
6. A combination of some of these elements?
7. A combination of all of these elements?

This is not a trivial question. Although, number seven is frequently avowed, efforts seem limited to number one. Again, there is a conflict between what is desired and what can be achieved. The reference document contains terms which ostensibly cover all of these alternatives, but all thirteen of the terms which contain the word "maintainability" limit (implicitly or explicitly) their coverage to number one.

There are a number of reasons why there is a strong pressure away from number seven towards number one. First, consider the word itself. If reliability is an attribute of an equipment which is concerned with its ability to be relied upon, then it would be legitimate to interpret the word maintainability as an attribute of the equipment which is concerned with its ability to be maintained. But is it as legitimate to interpret the word maintainability as the ability of a maintenance crew to perform maintenance, or the ability of the supply system to allow maintenance to be performed? Such interpretations are at variance with the usual interpretations of words with the suffix "- able". Thus, trainability is the ability of a person to be trained - not his ability to teach others. Likewise, reasonability is the ability of a person to be reasoned with - not his ability to reason. So, linguistically speaking, the right is on the side of the number one advocates. However, one can always use the argument, like Lewis Carroll's caterpillar, that a word means only what one wants it to mean. Such an attitude is not conducive to unambiguity and concordance.

Second, consider a contractor's role in maintainability. Hopefully, he can exercise some control in area number one. He has no control over numbers 2, 4, and 5. And, he has only an advisory role, at best, in number 3. Of a necessity, then, the contractor (and the contracting officer is only interested in number 1. If anything other than number one is to be implemented it must be by the using organization. For some reason the using organizations have been singularly lacking in action in these other areas.

Third, the elements other than number one are concerned with matters far less tangible and less tractable than does number one. Number two, for example, deals directly with the great intangible and intractable factor called the human factor.

Hence, one can conclude that it has been expedient to ignore all but number one element in attempting to apply the concept of maintainability. The question at the moment is whether to continue to restrict maintainability to this area or to make an attempt at number seven. (It should be remembered that the rate of progress in applying and obtaining results from number one has not been significant.)

Is Maintainability a Probability?

Attempts have been made to define "maintainability" as a probability. This attempt probably arises tharough a combination of the influence of the theoretical type plus the success which has been achieved in defining "reliability" as a probability. However, as will be seen, the two concepts of reliability and maintainability are sufficiently different, that the approach which was (more or less) successful in the reliability field is not necessarily a fruitful approach in the maintainability field.

Although of potential usefulness to the theoretical type of maintainability practioner a probability definition is unlikely to be of much utility to the practical type. This is perhaps reflected in the reference document wherein the basic term "maintainability" is defined as a probability. But, in every one of the 13 expanded maintainability terms (such as Achieved Maintainability) the entire concept of maintainability is dropped. This same pattern can be observed in the allied term "Availability" where the basic term is defined as a probability, but the qualified terms do not include the probability to any phenomena.

The concept of probability is use ful in any situation wherein the phenomena exhibits a random variation in value and such variation is of such size relative to the average value as to be significant. In the usual statistical symbols, the concept of probability is useful when σ is comparable to μ. If the variation is quite small compared to the average it usually suffices to consider the phenomena to be deterministic. Thus, if an object is dropped it usually suffices to say that the greatest variation is in the human element. Consider, first, preventive maintenance. As far as a given piece of equipment is concerned, it should require a certain amount of time to perform a given preventive maintenance task. Any variation in this time would be due, almost entirely, to the human and other non-equipment sources, not to the equipment itself.

Even for corrective maintenance, the largest variation is due to humans. Thus, it should take a given time to diagnose and repair a given fault. Any variation in this time is almost entirely due to such factors as human intelligence, skill, dexterity, experience, education, health, motivation, interest, and other intangible factors.

The reliability case, often used as a parallel for maintainability, is quite different in this respect. Reliability is concerned with the occurrence of failures which is properly treated as a probability and which is a proper attribute of the equipment.

It would seem logical, then, to consider the equipment aspects of maintainability as deterministic and restrict the probabilistic treatment to the non-equipment aspects.

But there are still further difficulties in treating maintainability as a probability. These difficulties center around the types of distributions which may logically describe the phenomena. In the field of reliability, a majority of the applications have involved the exponential distribution. Much of the success achieved in these applications is due to the tractability of the expressions which involve the exponential distribution. In general, grave difficulties face the user of any other distribution. The use of the exponential can be justified on the basis of the rationality of the constant failure rate.

How rational is it to apply the exponential distribution to the maintainability case? Consider a maintenance crew performing a preventive maintenance task. Is it rational that the probability of completing the task is independent of how long they have been working? Rather it would seem that the probability of completion should increase with the length of time that the operation has been underway. A similar argument seems rational for the supply delay. Such a pattern requires the use of a distribution which is known as a "wear-out" distribution in the reliability field or an "old-age" distribution in the acturial field.

Consider the case of a crew performing the diagnosis portion of a corrective maintenance task. Unless the crew is performing like the proverbial monkeys punching typewriter keys, again it is not rational that the probability of completion is independent of how long the crew has been diagnosing. For any organized policy of trouble-shooting which can be imagined, the probability of diagnosis should increase with this length of time.

Thus, it is perhaps understandable why there is considerable confusion in the attempts to define maintainability and variations thereof in the reference document (and elsewhere, for that matter). It is also likely that these same difficulties will continue to plague future attempts at definition and application.

SOME OTHER MAINTAINABILITY TERMS

It would indeed be fortunate if the difficulties were limited to the term "maintainability" itself. Unfortunately many of the other terms used (or usable) in the field of maintainability are likewise beset by difficulties. A perusal of the reference document will reveal a considerable amount of confusion, duplication, and generally fuzzy thinking.

Consider, for example, the term "availability". Again the attempt is made to define the term as a probability. But the definer gets himself into several types of difficulty such that he defines a probability which is quite different than the probability he started out to define.* Moreover, the quantitative term which is given, is not apparently a probability but a ratio of mean times. And again, in the qualified availability terms there is a running confusion as to whether availability is an attribute of the machine, the other less tangible factors, or some (unknown) combination of these elements.

There are a proliferation of terms, which overlap or duplicate either in intent, in content, or in both in a general confusion. These include:

Availability
Dependability

Item, Interchangeable
Item, Replaceable

Maintainability
Maintenance Ability
Maintenance Capability

Maintainability
Repairability
Serviceability

Repair
Servicing

Maintainability
Supportability

and many others.

The writer suspects that the reference document contains more terms than can be usefully defined as unique terms. That is, a considerable number of these terms should be dropped (thereby made available for vernacular use) and efforts concentrated upon attempting to define the remaining terms as well as possible. Again, the writer suspects that the proliferation of terms is a smoke-screen to hide the confusion of the originators of the reference document. It would seem advisable to strip away the screens, recognize the problems, make the best definition possible, admit the shortcomings, and apologize to no-one.

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* See the excerpts of the writer's comments in the separate document.

APPENDIX

EXCERPTS* FROM "COMMENTS ON 'PROPOSED MILITARY STANDARD FOR DEFINITIONS OF TERMS ON SYSTEM EFFECTIVENESS' (1 April 65)" (July 65)

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INTRODUCTION

A document entitled "Proposed Military Standard for Definitions of Terms on System Effectiveness" dated 1 April 65 was recently circulated for comments. The writer responded with extensive comments through the appropriate channels. Since many of the included terms are relevant to maintainability, the writer thought it appropriate to make the excerpts which are included herein.

FORMAT

The format of those excerpts consists of the proposed definition followed by the writer's comments and suggested revisions. Each item is coded in accordance with the following scheme:

PD - Proposed Definition
C - Comment by the writer
R - Recommended amendment/revision/alternative by the writer

EXCERPTS

ACCESSIBILITY

PD: Existing Definition: A design feature which affects the ease of admission to an area for the performance of visual and manipulative maintenance.

PD: Proposed Definition: A design feature which affects the ease of admission to an area within an item for the performance of maintenance.

C: It is probably not good usage to equate the abstract noun "accessibility" to the concrete noun "feature". A design feature might be a removable cover — but the cover is not

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*Excerpts consist of those items which are believed to be significantly relevant to maintainability.

accessibility. Therefore --- it is illogical to say that accessibility is a "--- design feature ---".

R: *A characteristic of an item which relates to the relative ease of admission to various areas of the item required for the operation or the maintenance of that item.*

AVAILABILITY - -

PD: Existing Definition: The fraction of the total desired operating time that the item is actually operable; a measure of the system condition at the start of the mission, when the mission is called for at an unknown (random) point in time.

PD: Proposed Definition: The probability that at any point in time the system is either operating satisfactorily or ready to be placed in operation on demand when used under stated conditions.

C1: There are apparently a number of different (some decidedly so) definitions of "availability" which have been advocated and which are in more or less use.

One definition is used in the queueing theory area where it pertains to the idleness of a server(s). In this meaning it is implied that the server is operable. Thus, if one needs a haircut, a barber is available if he is healthy and does not, in fact, have a customer in his chair.

The other definitions are presumably due to the maintainability practioners. Here there seems to be a variety of conflicting meanings as indicated by two distinct definitions in the "Existing Definition", a third distinct definition in the "Proposed Definition", and yet other definitions are implied in the various availability entries with adjective app[illegible]ages.

C2: Existing Definition (First sense) - The first clause in this definition seems to come the closest to being somewhat consistent with those definitions that follow availability-plus-a-qualifying-adjective. In fact, in the maintainability area (as opposed to the queueing area) this definition is probably the least objectionable. It makes no pretence about being a probability but is content with just being a fraction.

C3: Existing Definition (Second sense) - The second clause in this definition does not automatically follow from the first clause. Therefore, it may or may not be consistent with the first clause. The second clause is certainly imprecisely stated. What is the basis of this "measure"?

C4: <u>Proposed Definition</u>: This definition seems to denote the same meaning as the second clause of the existing definition. However, the word "probability" has been added. Now, it is not at all evident (or proved) that the "fraction" mentioned in the existing definition (and indeed used in all of the following adjective modified definitions of availability) is in fact, a probability. It seems to be a ratio of mean times. Probabilities, in general, are derived by integrating a density function; or, by combining combinations of joint, disjoint, and conditional relationships of other probabilities. Since no distribution or density function is in any way evident in connection with this definition of availability, the approach of combining probabilities will be taken.

Suppose

$$A = P(B)P(C) + P(B)[1 - P(C)]^{*}$$

where

A = availability

B = state of being operable

C = state of being operated (i.e. processing a work load)

Then

$$A = P(B)[P(C) + 1 - P(C)]$$
$$= P(B)$$

Thus availability turns out to be the probability of being operable and the rest of the statement about "being operated or ready for operation" is so much (misleading) surplus baggage. If this is the case, it would seem logical to call the probability of being operable, "operability". This would free the term "available" to be used exclusively in the queueing theory sense.

C5: <u>Proposed Definition</u>: The placement of the word "that" is important. The proposed definition implies that availability is invariant in time when, like failure rate, it may be in fact, a function of time.

C6: <u>Queueing Theory Definition</u>: A term to denote availability in the queueing theory sense is essential to a System Effectiveness language. For example, in considering a fire control sytem wherein there are a number of tracking radar sets for tracking a number of different targets simultaneously, it is

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* This is the mathematical statement of "- is either operating satisfactorily or ready to be placed in operation -".

important to know the availability (i.e. the probability that there is an operable, idle tracking set) of the system should an additional target appear. Such situations are certainly not unusual and there are many cases of system effectiveness analyses which involve multi-server queueing line models. Hence, the necessity of having such a term as "availability" (in the queueing sense) in the System Effectiveness language.

C7: It is strongly recommended that the terms "available" and "availability" be reserved for meanings in the queueing theory sense. The terms "operable" and "operability" can then be used in the "Proposed Definition" sense. To designate the fraction of mean times in the "adjective-modified" sense the term "Vitality" can be used.

R1: *AVAILABLE - The state of being operable (q.v.) and idle (i.e., there is no current workload).*

R2: *AVAILABILITY - The probability at any point in time that one or mroe systems (sub-systems) are available.*

R3: *OPERABLE - The state of being capable of being operated.*

R4: *OPERABILITY - The probability at any point in time that the system (sub-system, component) is operable.*

R5: *VITALITY - A ratio of mean times which expresses the average portion of the time which the equipment is operable when preventive and/or remedial maintenance is a part of the policy. (See specific adjective-modified definitions below.)*

AVAILABILITY, ACHIEVED - -

PD: The probability that a system or equipment when used under stated conditions in an ideal support environment (i.e., available tools, parts manpower, manuals, etc.) shall operate satisfactorily at any given time. Achieved Availability excluded Supply Downtime and Waiting Administrative Downtime. It may be expressed as:

$$\text{Achieved Availability} = \frac{MTBM}{MTBM + \bar{M}}$$

where

MTBM = Mean time between maintenance and ready time during the same time interval, and

$\bar{M}$ = Mean Active Maintenance Downtime resulting from both preventive and corrective maintenance actions.

Also defined as a statistical estimate of availability based on actual demonstration under specified conditions. The specified conditions may be test conditions or operational conditions, but the conditions must be clearly stated.

C1: Pursuant to the extensive discussion under the "Availability" entry, the word "Availability" should be changed to "Vitality".

C2: The word "achieved" here seems quite contrived. The natural connotation would seem to be synonomous with the definition given under Availability, Operational: Therefore, it would seem quite desirable to replace the word "achieved" with a less ambiguous word, perhaps the word "ideal" or the set of words "ideally supported".

C3: The definition of MTBM as presently stated is not unambiguous.

C4: It seems basically incorrect to define a term to be an estimate, per se. It is doubly incorrect to assign an estimate meaning to a term which also means the true value. The ambiguity (and consequent lawsuits) can be formidable.

C5: "M" by itself does not seem a consitent designator.

R1: *VITALITY, IDEALLY SUPPORTED - The vitality of the equipment in an ideal support environment (i.e., available tools and parts, available and competent manpower, available and adequate manuals, etc.) Supply Downtime and Waiting Administrative Time are specifically excluded. It may be expressed as:*

$$\text{IDEALLY SUPPORTED VITALITY} = \frac{MTBM}{MTBM + MAMT}$$

where

MTBM = Mean time between maintenance actions.

MAMT = Mean active maintenance time (during which the equipment is not operable) including both preventive and corrective maintenance actions.

R2: *VITALITY, IDEALLY SUPPORTED, ESTIMATED - An estimate of Ideally Supported Vitality based upon the results of a statistically valid and relevant test. The conditions of the test must be explicitly stated since different conditions may produce different estimates.*

AVAILABILITY, INHERENT - -

PD: The probability that a system or equipment when used under stated conditions, without consideration for any scheduled or preventive maintenance, in an ideal support environment (i.e., available tools, parts, manpower, manuals, etc.) shall operate satisfactorily at any given time. Inherent Availability excludes Ready Time, Preventive Maintenance Downtime, Supply Downtime, and Waiting or Administrative Downtime. It may be expressed as:

$$\text{Inherent Availability} = \frac{MTBF}{MTBF + MTTR}$$

where

MTBF = Mean Time Between Failure, and
MTTR = Mean Time to Repair.

Also defined as the theoretical maximum availability of a design, assuming no design changes, and operation in an ideal, standard or theoretical environment (a Standard Summer Day, or an ideal supply environment). The details of the ideal, standard, or theoretical environment must be clearly stated.

(First Meaning)

C1: Pursuant to the extensive discussion under the "Availability" entry, the word "Availability" should be changed to "Vitality".

C2: Again a word is used ("inherent") which naturally connotes a meaning which is not intended in this particular usage. And again, it should be desirable to preclude misunderstanding by using another word (or set of words). For example, "without preventive maintenance" would seem to unambiguously denote the intended meaning.

C3: "Ready Time" should not be excluded since the equipment is operable during this time.

R: *VITALITY WITHOUT PREVENTIVE MAINTENANCE - The availability of the equipment in an ideal support environment (i.e., available tools and parts, available and competent manpower, available and adequate manuals, etc.) wherein no preventive maintenance is performed. Preventive Maintenance Downtime, Supply Downtime and Waiting Administrative Downtime are specifically excluded. In may be espressed as:*

$$\text{VITALITY WITHOUT PREVENTIVE MAINTENANCE} = \frac{MTBF}{MTBF + MTTR}$$

where

MTBF = Mean Time Between Failure.

MTTR - Mean Time To Repair.

(Second Meaning)

C1: This definition is so general as to be almost useless. What is the mathematical expression? What is the relevance of "no design changes"?

C2: Until this meaning is made more definitive, it should be deleted.

AVAILABILITY, MINIMUM ACCEPTABLE - -

PD: An availability below which the item is considered unacceptable; also a contractual requirement used as a condition for acceptance.

C1: As before, change "Availability" to "Vitality".

C2: This definition should indicate that the words "minimum acceptable" can be affixed to all other varieties of vitality such as "Minimum Acceptable Operational Vitality", etc.

R: *VITALITY, __________, MINIMUM ACCEPTABLE - A combining form as in "Minimum Acceptable Operational Vitality" to indicate the minimum tolerable value, often used as a contractual requirement for acceptance.*

AVAILABILITY, OPERATIONAL - -

PD: The probability that a system or equipment when used under stated conditions and in an actual supply environment shall operate satisfactorily at any given time. It may be expressed as:

$$\text{Operational Availability} = \frac{MTBM}{MTBM + MDT}$$

where

MTBM = Mean time between maintenance and ready time during the same time interval, and

MDT = Mean Downtime including Supply Downtime and Administrative Downtime during the same time interval.

When Preventive Maintenance Downtime is zero or not considered, MTBM becomes MTBF.

It is also defined as the availability of an item when operating and being maintained in a specific operational environment, usually by military personnel.

C1: As before, change 'Availability" to "Vitality".

C2: The definition of MTBM is not unambiguous.

C3: The last prargraph seems at best, redundant; at worst, confusing.

R: *VITALITY, OPERATIONAL - The vitality of a system in an actual use and supply environment which may or may not include preventive maintenance as may be appropriate. It may be expressed by:*

$$\text{OPERATIONAL VITALITY} = \frac{MTBM}{MTBM + MDT}$$

where

MTBM = Mean time between maintenance actions.

MDT = Mean Downtime including Supply, Administrative and active maintenance downtime.

If preventive maintenance is not appropriate MTBM becomes MTBF where

MTBF = Mean Time Between Failures.

AVAILABILITY, POTENTIAL - -

PD: The theoretical maximum availability which can be expected, assuming improvements from design changes due to familiarity with operation and maintenance on item, and other types of availability growth.

C1: This definition is so general as to be virtually useless. What is the mathematical expression?

C2: A dangerous definition. Who assigns values to the assumptions? In accordance with this definition, the Potential Availability can easily be 1.0.

C3: Until this meaning can be made more definitive and objective it should be deleted.

CHECKOUT - -

PD: The act or content of testing an item to determine whether it is functioning within specified limits.

C: What is the "content" of testing an item?

R: *A test to determine if an item is functioning within tolerance.*

CHECKOUT TIME - -

PD: The time (either in man-hours or a point in a schedule) required to determine that a system or equipment is in a satisfactory operable or operating condition.

C: It is inadvisable to have two meanings for the same term. In this case it is suggested that the "point in schedule" meaning be deleted.

CIRCUIT MALFUNCTION ANALYSIS - -

PD: Existing Definition: The logical, systematic examination of circuits and their diagrams to identify and analyze the probability and consequence of potential malfunctions for determining related maintenance or maintainability design requirements.

PD: Proposed Definition: The logical, systematic examination of circuits and their diagrams to identify and analyze the probability and consequence of potential malfunctions.

C: The proposed definition is better.

COMPONENT PART - (Piece Part) - -

PD: A part that performs no function by itself and must be connected to other parts and energized before any function can commence, and which is not practical to disassemble for repair or maintenance.

C: There is a serious objection to this first part of this definition. Certainly, if a part performs no function by itself, it is not able to perform any function in combination. A capacitor, by itself, stores a charge - this is a function - if it cannot perform this function it is useless.

R: *A part, which by custom and tradition, is not usually disassembled for repair or maintenance; as a capacitor, a resistor, a transistor, etc.*

CORRECTIVE ACTION - -

PD: The action required to prevent recurrence of a defect, deficiency, failure, or problem by means of a design change, process improvement, tooling change, inspection procedure improvement, change in operational procedure, etc.

C1: The inclusion of this term seems unnecessary since it would seem to be self-definitive. The listed definition certainly adds nothing to such self-definition.

C2: If the term must be included it should be corrected. One can reduce the incidence of occurrence, but one cannot prevent the occurrence of defects, deficiencies, failures, problems, or any other random event.

C3: Why not delete it as a triviality?

DEGRADATION - -

PD: Gradual deterioration in performance, strength, resistance to environmental stress, etc. of a characteristic of an item.

C: How gradual is "gradual"? This definition should be sharpened by including an example of degradation and an example of non-degradation deterioration.

R: *- Gradual (as opposed to abrupt) deterioration in performance of a characteristic of an item. Hence, a continuous change in capacity value of a capacitor would be categorized as degradation. A short circuit occurring essentially instantaneously would not.*

DELAY TIME - -

PD: The time during which no maintenance is being accomplished on the item because of either supply or administrative reasons.

C1: Come, now. Is it reasonable to put such a restrictive meaning on such a commonplace term? Obviously, various adjectives should be appended to the term to designate the type of action in which delay is being experienced.

C2: The distinction of "supply" and "administrative" is neither clear nor comprehensive.

C3: Nothing is mentioned about the necessity of the maintenance.

C4: The word "accomplished" is not quite proper. "Performed" is the more proper word since considerable effort can be expended without any real accomplishments.

R: *DELAY TIME - The time during which a particular needed activity cannot take place because of causes which prevent that activity. For example, Maintenance Delay Time is the time in which no needed maintenance is being performed because of a variety of reasons such as lack of parts, personnel, or tools.*

DEPENDABILITY - -

PD: The probability that a system will be both available and operating at any point in time - - the product of availability and reliability probabilities.

C1: This definition needs rewording to clarify it and to distinguish this term from its constituents.

C2: It is important to distinguish between "operating" and "operable" since this distinction is the essence of this particular definition.

C3: A supplemental mathematical definition might be desirable to unambiguously define the term.

R: *The joint probability that an equipment is operable (q.v.) at time t_0 and will continue to be operable over time interval t_0 to t_1. Mathematically,*

DEPENDABILITY = OPERABILITY X RELIABILITY

If

Operability = P(A)

Reliability = P(B|A)

where

A = *state of being operable at time t_0.*

B = *state of being operable during time interval from t_0 to t_1.*

Then

Dependability = P(A) P(B|A)

= P(AB)

FREQUENCY OF USE PRINCIPLE - -

PD: The principle of positioning the most frequently maintained items in preferred (readily accessible) locations.

C1: This is a classic can-of-worms. The term and its definition seem to be inconsitent. Is the <u>use</u> of the equipment or the <u>maintenance</u> of the equipment being treated?

C2: Is this a principle or a policy?

C3: It would seem that this requires two definitions. Note that these two policies may be in conflict.

R1: FREQUENCY OF MAINTENANCE POLICY - *The policy of positioning the equipment which requires maintenance most frequently in the most accessible locations.*

R2: *FREQUENCY OF USE POLICY - The policy of positioning the equipment which is used most frequently in the most accessible locations.*

INTEGRATED LOGISTIC SUPPORT (ILS) - -

PD: The requirement that the logistic support (provision for system maintenance) be considered jointly with the technical aspects of the system.

C1: How can a "support" be a "requirement", per se?

C2: This definition seems so vague as to be worthless.

C3: Until this term can be better defined - delete it.

INTEGRATED MAINTENANCE MANAGEMENT (IMM) - -

PD: A contractoral obligation upon the contractor for prompt establishment of an organization to achieve the integration and management of maintenance resources.

C1: How can a "management" be a "requirement", per se?

C2: A fine bit of gobbledegook - what does it mean?

C3: Delete it unless it can be defined as a meaningful concept.

ITEM, INTERCHANGEABLE - -

PD: When two or more items possess such functional and physical characteristics as to be equivalent in performance and durability and capable of being exchanged one for the other without alteration of the items themselves or of adjoining items except for adjustment, and without selection for fit or performance, the items are interchangeable.

(No Comments)

ITEM REPLACEABLE - -

PD: An item which is functionally interchangeable with another item.

C1: A comma seems to be missing.

C2: This definition makes this term synonomous with Item, Interchangeable.

C3: Why not put this term to work? Let it denote a different concept than "interchangeable".

R: *An item which can be removed and replaced with another item so as to achieve a different function or so as to achieve a repair.*

ITEM, SUBSTITUTE - -

PD: When two or more items possess such functional and physical characteristics as to be capable of being exchanged only under certain conditions or in particular applications and without alterations of items themselves, they are substitute items.

C: An unnecessarily complex definition which seems to successfully miss the essence of the meaning.

R: *An item which is used because an interchangeable item is not available.*

MAINTAINABILITY - -

PD: Existing Definition: A characteristic of design and installation which is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources. It is denoted by symbol M.

PD: Proposed Definition: The probability (when maintenance action is initiated under stated conditions) that a system will be restored to its specified operational condition within a specified period of downtime.

C1: The proposed definition is clearer than the existing definition.

C2: The proposed definition does not pin down the competence level of the maintenance crew - or the size of the crew. This is a complex situation. Not only does this probability depend upon the equipment and the competence individually, but also as an interaction. The effect of the size of the crew is also complex. One could argue, of course, that the parenthetical clause covers this complexity. However, it does not seem reasonable to dismiss such a vital complexity with such short mention.

R: *The probability that a system will be restored to normal operational condition within a specified period of time subsequent to failure when a specified maintenance crew of specified competence are put to work.*

MAINTAINABILITY, ACHIEVED - -

PD: A statistical estimate of maintainability based on actual demonstration under specified conditions. The specified conditions may be test conditions or operational conditions, but the conditions must be clearly stated.

C1: Again, the confusion of the thing, itself, with the estimate of that thing.

C2: Again, the misleading word "achieved".

C3: Since this is an estimate, why not call it an estimate?

R: *MAINTAINABILITY POINT ESTIMATE - A statistical point estimate of the maintainability based upon analysis of data obtained from real or simulated experience.*

MAINTAINABILITY ASSURANCE - -

PD: The program of inspection and test to determine the degree of compliance of an item to maintainability requirements.

C: Why so restrictive? This definition excludes simulation, for example.

R: *The program to determine the degree of compliance to maintainability requirements.*

MAINTAINABILITY, FUNCTIONAL ANALYSIS FOR - -

PD: Existing Definition: The analytical basis for allocating tasks to personnel and equipment so as to achieve optimum system maintainability.

PD: Proposed Definition: The analytical basis for allocating tasks to personnel and equipment so as to optimize system maintainability.

C1: A cumbersome term. Why not eliminate the comma and the "for".

C2: Bothe definitions (which differ only in grammar) seem to belie the words in the term. The definition seems to concern itself with allocation - not function - and not analysis.

C3: Does one allocate "tasks" to equipment?

C4: How can one "optimize" maintainability? Since maintainability is defined as a probability its maximum value is one. Since this value can be approached but never attained, in what sense does one "optimize"?

R: *MAINTAINABILITY FUNCTIONAL ANALYSIS - An analysis of the system to determine the functional role that personnel and equipment must play to minimize the total cost of the system operation and maintenance.*

MAINTAINABILITY INDEX - -

PD: Existing Definition: A quantitative figure of merit which relates the maintainability of an item to a standard reference, such as the amount of direct productive labor required to support the system, subsystem, or equipment unit per a thousand operating hours of same.

PD: Proposed Definition: A quantitative figure of merit which related the maintainability of an item to a standard reference, such as the amount of direct productive labor required to support the system, subsystem, or equipment per specified number of operating hours.

C1: Both definitions: Why "quantitative" can a figure of merit be other than quantitative?

C2: Proposed definition: Why past tense? Is it implied that this term is no longer in use?

C3: Both definitions: The word "relate" is quite weak in this sense.

R: *A figure of merit which compares the maintainability of an item to a standard reference. For example, the amount of effort required to maintain a system per specified number of operating hours.*

MAINTAINABILITY, MINIMUM ACCEPTABLE - -

PD: A maintainability level, below which the item is considered unacceptable; also, a contractual requirement used as a condition for acceptance.

C1: This definition should indicate that the words "minimum acceptable" can be affixed to all other varieties of maintainability such as "Minimum Acceptable Inherent Maintainability", etc.

R: MAINTAINABILITY, ________, MINIMUM ACCEPTABLE - A combining form as in "Minimum Acceptable Inherent Maintainability" to indicate the minimum tolerable value, often used as a contractual requirement for acceptance.

MAINTAINABILITY, OPERATIONAL - -

PD: The maintainability of an item when operating and being maintained in a specified operational environment, usually by the military.

C: Awkard construction.

R: The maintainability experienced when the system is in actual use by the (usually military) user.

MAINTAINABILITY PARAMETERS - -

PD: Existing Definition: A group of variables (environmental, human, hardware) related to the maintenance on an item.

PD: Proposed Definition: Variables (environmental, human, hardware) related to the maintenance on an item.

C1: Both definitions: In technical use, the word parameter means more than "Variables --- related to ---". If the lay use of the word is intended - it is self defining and needs no formal inclusion here. Technically, a parameter is usually a constant (as opposed to a variable) whose value depends upon specific cases of a general form.

C2: If the lay use of the word is intended - delete the entry, it is not needed. If a technical sense is intended - define it in a technical way - otherwise delete it.

MAINTAINABILITY - POTENTIAL - -

PD: The theoretical maximum which can be expected, assuming improvements from design changes due to familiarity with operation and maintenance on the item, and other types of maintainability growth.

C1: A dangerous definition. Depending upon the optimism of the design changer --- the potential maintainability can have the value 1.0. Who calculates this value? How? What are his guide lines?

C2: Too dangerous - delete it.

MAINTAINABILITY PREDICTION - -

PD: A computed value derived from analysis of failure modes, repair times, and other attributes expected to affect maintainability and supported by past experience with like or similar items.

C: In keeping with the definition - this term would seem to be "Maintainability, Predicted".

R: *MAINTAINABILITY, PREDICTED - (Definition as listed).*

MAINTAINABILITY, QUALITATIVE REQUIREMENT - -

PD: Existing Definition: On which is expressed in qualitative terms; e.g., minimize complexity, design for minimum tolls and test equipment, design for optimum accessibility.

PD: Proposed Definition: A requirement expressed in qualitative terms; e.g., minimize complexity, design for minimum tools and test equipment, design for optimum accessibility.

C1: Why the comma?

C2: Proposed definition: The word "minimize" is objectionable since what is really wanted is a minimization of the over all costs - not the minimization of complexity at any cost. Does reduced complexity always result in higher maintainability?

C3: Proposed definition: The word "optimum" is objectionable. Accessibility (if it had a scale) could be measured from 0 to 1.0. The value 1.0 would represent the utmost in accessibility. Accessibility, then would be a monotonic increasing function with no "optimum" regions.

C4: Proposed definition: Does reducing special tools improve maintainability? One special tool may save hours of work. Ever try to remove a cork without a cork screw? Or open a can without a can opener? Or reline a set of truck brakes without spring retractor pliers?

R: *MAINTAINABILITY QUALITATIVE REQUIREMENT - A requirement in qualitative terms to provide features which are conducive to maintainability.*

MAINTAINABILITY QUANTITATIVE REQUIREMENT - -

PD: Existing Definition: One which is expressed in quantitative items; e.g., a figure of merit in measurable units of time or resources required to accomplish a specific maintenance task, or group of tasks, in relation to the applicable performance requirements (for example, Maintenance Reaction Time, Turn-Around Time, cost per maintenance man-hour, preventive checkout time, depot turn-around time, etc.).

PD: Proposed Definition: A requirement expressed in quantitative items; e.g., a figure of merit in measurable units of time or resources required to accomplish a specific maintenance task, or group of tasks, in relation to the applicable performance requirements (for example, Maintenance Reaction Time, Turn-Around Time, cost per maintenance man-hours, preventive checkout time, depot turn-around time, etc.).

C1: Why the comma?

C2: Since maintainability is defined as a probability how can a quantitative requirement for it not be a probability? Perhaps maintainability is not really a probability after all?

C3: The definition contains jargon.

C4: The definition should be split into two parts - one for Maintainability Index and one for Maintainability.

R1: *MAINTAINABILITY INDEX QUANTITATIVE REQUIREMENT - A requirement that a specified maintainability index be met or surpassed.*

R2: *MAINTAINABILITY QUANTITATIVE REQUIREMENT - A requirement that a specified probability of repair in a specified time period be met or surpassed. If the probability distribution is known or can be reasonably assumed, this probability might be expressed in terms of the parameters of the distribution such as mean-time-to-repair, etc.*

MAINTAINABILITY REQUIREMENT - -

PD: Existing Definition: A comprehensive statement of required maintenance characteristics, expressed in qualitative and quantitative terms, to be satisfied by the design of an item.

PD: Proposed Definition: A statement of necessary maintenance characteristics to be satisfied by the design of an item.

C1: Proposed definition: A triviality.

C2: Proposed definition: This subject seems to have been better covered under the other maintainability requirement entries.

C3: Delete it.

MAINTAINABILITY VERIFICATION AND DEMONSTRATION - -

PD: The test program designed to determine the predicted minimum maintainability and to demonstrate its factual existence.

C1: It is not clear in the definition whether the test program is conducted to make the prediction or to determine the accuracy of the prediction a posteriori.

C2: The word demonstrate is not really an objective term in this context.

C3: What is the "factual existence" of a prediction? All that is necessary to show the existence (factual or otherwise) of a prediction is to say "the prediction" (or write it).

C4: This term seems to overlap "Maintainability Assurance".

R: *See MAINTAINABILITY ASSURANCE (preferred term).*

MAINTENANCE - -

PD: All actions necessary for retaining an item in, or restoring it to a serviceable condition. Maintenance includes servicing, repair, modification, modernization, overhaul, inspection, and condition determination.

C: What is "condition determination" other than inspection?

R: *As is, deleting "condition determination".*

MAINTENANCE ABILITY - -

PD: Existing Definition: A figure of merit for a crew of a using organization defined as the ratio of the maintenance man-hours established on specific item by a trained and expert maintenance crew to the maintenance man-hours figure established by the crew of the using organization on the same item and under similar maintenance conditions.

PD: Proposed Definition: The ratio of the maintenance man-hours established on specific item by a trained and expert maintenance crew to the maintenance man-hours figure established by the crew of the using organization on the same item and under similar maintenance conditions.

C1: **Wow! This is a tough one. The definition is clear - but the utility raises serious doubts. Are average values meant? If the variance is large, how many "runs" are necessary to establish the averages? Is this a stochastically stationary process? What constitutes a "-trained and expert crew"?**

This definition reads like the definition of a kilogram - but doesn't seem to have a similar foundation.

C2: Delete this hot potato unless it can be made more objectively definitive.

MAINTENANCE CAPABILITY - -

PD: The facilities, tools, test equipment, drawings, technical publications, trained maintenance personnel, engineering support, and spare parts required to restore a system to serviceable.

C: This seems like a real misnomer. A capability is usually an attribute of the doing organization - not an attribute of the work piece.

R: *MAINTENANCE LOGISTICS REQUIREMENTS (Definition as is).*

MAINTENANCE COST RATIO - -

PD: The ratio of the cost of maintenance to the initial item cost for a given unit of time.

C1: This term seems practically meaningless unless a unit of time is standardized.

C2: The term "first cost" is well established and would be preferable to "initial cost".

R: *The ratio of the cost of maintenance for one year to the first cost of the item.*

MAINTENANCE, DIRECT - -

PD: The maintenance operations and costs directly associated with keeping the item in operable condition.

C: A circumlocation, which gets nowhere.

R: *The maintenance operations whose costs are directly chargeable (such as the costs of direct labor, of replacement parts, etc.) to maintaining the item in operable condition.*

MAINTENANCE LEVEL - -

PD: The assigned location or stage of maintenance operation, such as, aboard, ashore, depot etc.

C: A misleading term. Why not use the well established "achelon"?

R: *MAINTENANCE ECHELON - The type of maintenance activities assigned to a particular organization level such as aboard, ashore, depot, factory, etc.*

MAINTENANCE RESOURCES - -

PD: Facilities, ground support equipment, manpower, spares, consumables, and funds available to maintain and support an item in its operational environment.

MAINTENANCE RESOURCES, DIRECT - -

PD: The time in man-hours and material in dollars expended directly on the item being maintained during the period of active maintenance.

MAINTENANCE RESOURCES, INDIRECT - -

PD: That time in man-hours and material in dollars which, while not directly expended in active maintenance tasks, contributes to the overall maintenance mission, through the support of overhead operations, administration, accumulation of facility records and statistics, supervision, and facilities upkeep.

C1: The second two definitions are completely inconsistent with the first.

C2: The second two definitions are redundant with "Maintenance, Direct" and "Maintenance, Indirect".

C3: Keep the first definition as is. Delete the second two.

MAINTENANCE SCHEDULE - -

PD: The time-oriented program for service, repair, or overhaul action at predetermined intervals.

C: Pentagonese! "Time-oriented", indeed!

R: *The schedule for performing service, repair, or overhaul action at predetermined points in time.*

MAINTENANCE SUPPORT INDEX - -

PD: The total number of direct and maintenance man-hours for preventive and corrective maintenance required to support each hour of operation.

C: Seems redundant with "Maintenance Index".

R: *See Maintenance Index (preferred term).*

MEAN TIME TO REPAIR - -

PD: Existing Definition: The statistical mean of the distribution of times-to-repair-; the summation of active repair times (in hours) during a given period of observation, divided by the total number of malfunctions during the same time interval (and which have been repaired).

PD: Proposed Definition: A measure of repairability, expressed as the total repair time over a specified period divided by the total repairs made during that time.

C: Proposed definition: The word "time" is used (ambiguously) in two senses.

R: *A measure of repairability; expressed as the total active repair time over a specific period divided by the total number of repairs achieved during that period.*

MEAN TIME TO REPAIR, GEOMETRIC - -

PD: A measure of central tendency for repair time based on observations which show repair time durations to be log-normally distributed. Deals with the same phenomena as the Mean Time To Repair.

C1: This is a measure of central tendency - but not necessarily tied to the log-normal.

C2: To be consistent, this definition should be in terms of how it is calculated.

R: *A measure of repairability; expressed as the n th root of the product of the times to complete repairs where n is the number of repairs completed.*

PART - -

PD: One piece, or two or more pieces joined together, which are not normally subject to disassembly without destruction of designed use; and article which is an element of a subassembly or an assembly, and is of such construction that it is not practically or economically amenable to further disassembly for maintenance purposes.

C: This seems to overlap - Component Part.

R: *See Component Part (preferred term).*

PERSONNEL ERROR - -

PD: Incorrect performance of required duties by operating or maintenance personnel which cause a failure. See Failure, Human-Initiated.

C: One term should suffice - cross reference it.

R: *See FAILURE, HUMAN-INITIATED (preferred term).*

REPAIR - -

PD: The process of returning an item to a specified condition by either repairing it in place; removing, repairing and replacing the same item; or by replacing the same item; or by replacing with a like serviceable item.

C: Gibberish.

R: *The process of returning an item to operational condition following a breakdown.*

REPAIRABILITY - -

PD: Existing Definition: The capability of an item to be repaired easily.

PD: Proposed Definition: The probability that a failed system will be restored to an operable condition within a specified active repair time.

C1: Existing Definition: Ridiculous

C2: Proposed Difinition: Seems to duplicate Maintainability.

R: *See MAINTAINABILITY (preferred term).*

SCHEDULE, REPLACEMENT - -

PD: The specified periods when items of operating equipment are to be replaced. Replacement means removals of items which are approaching the end of their maximum useful life, or the time interval specified for item overhaul or rework, and installation of a serviceable item in its place.

C: The syntax is pretty bad in the second sentence.

R: *A schedule specifying when items of operating equipment (or spare parts inventory) are scheduled to be replaced.*

SERVICEABILITY - -

PD: A characteristic of an equipment design that makes it convenient to maintain and repair in operation.

C1: This definition seems to duplicate the "existing" definition for repairability. The repairability definition was previously criticized as being ridiculous.

C2: Whatever, this is, it would seem to overlap Maintainability.

R: *See MAINTAINABILITY (preferred term).*

SERVICING - -

PD: The performance of any act (other than preventive or corrective maintenance) required to keep an item of equipment in operating condition; such as, lubricating, fueling, oiling, cleaning, etc. but does not include periodic or corrective maintenance.

C1: What a strange definition! Certainly, lubrication, cleaning, adjusting, etc. are normally considered as "preventive" maintenance. Why, otherwise, does one have his car lubricated at periodical intervals. Or his tires rotated? Or his hydraulic brake resevoir checked? Or his battery water level? Or his tire pressure? What, then, is "preventive" maintenance if it does not consist of these acts?

C2: To this commentator, the words corrective and preventive cover the entire domain of maintenance leaving no room for "- any act (other than preventive or corrective maintenance) required to keep an item of equipment in <u>operating condition</u> -".

C3: The act of fueling is not an act to "- keep an item of equipment in operating <u>condition</u> -" as it in no way changes the condition of the equipment.

C4: Delete it.

SKILL LEVELS - -

PD: The classification system used to rate personnel as to their relative abilities to perform their assigned jobs.

C1: It is illogical that "skill levels" can be, per se, a "classification system". There can be a classification system of skill levels, perhaps; or skill levels can be used in a classification system. But, skill levels <u>is</u> a classification system - impossible.

C2: What classification system is being referred to? Is this covered in a MIL-STD? A Federal specification? What?

C3: Unless this term can be clarified - drop it as a formal term and let it be used in the vernacular.

SPECIAL TOOLS - -

PD: Tools peculiar to the maintenance of a specific item.

C1: This term is not sufficiently restrictive. Suppose, for example, that a tool can only be used on two items, does that make it non-special?

C2: Properly, a special tool is any tool which is not a standard tool. But, then, a standard tool must be defined. This can either be done by referring to the common lore as to what constitutes a standard tool. Or better, DOD should prepare a list (periodically revised) of standard tools (another MIL-STD!). All other tools, then, by definition, would be special tools.

C3: Until the new MIL-STD (for standard tools) can be (or is) written, the reference to common lore must be resorted to.

R: *(Interim Definition) Any tool not usually considered standard or part of the ordinary technician's kit of tools.*

SUPPORT COST - -

PD: The cost in dollars or some other suitable measure of those resources expended in the maintenance of an item; the total cost of ownership, excluding operating crews and using personnel, of an item during its operational life including the total impact of requirements for skill levels, technical data, test equipment, spares, spare parts, special tools, operational and maintenance equipment, facilities, levels and location of maintenance facilities, manpower, training, and training equipment.

C1: The use of the word "impact" is, at best, colloquial.

C2: The definition seems confusingly verbose.

R: *The cost, expressed in dollars, manhours, or other suitable measure, expended in the maintenance or ownership of an item. The cost may include interest on the invested funds, storage cost, preventive maintenance supplies and manpower, etc. Specifically excluded is the cost of the operating or using personnel.*

SUPPORTABILITY ASSURANCE - -

PD: The provisions made in the item design, manufacturing and maintainability planning to insure a staisfactory and economical support of the item during its development, production, delivery, installation, and use stages.

C1: The word "assurance" is not consistent with the definition.

C2: Notwithstanding, this term is either a triviality (with a ostentatious name) or an overlap of a maintainability term.

C3: Delete it.

TEST, FINAL - -

PD: That element of maintenance required after completion of adjustments and calibration to verify by measurement of performance that the item is in a condition to perform its function satisfactorily.

C1: This definition is entirely too restrictive. The term "final test" is widely used, as a counterpart of "final inspection" in a production operation. To force, by fiat, the abandonment of this usage is hopeless.

C2: On the other hand, the term, "final check" is used in the sense of the given definition.

R: CHECK, FINAL - *Verification of a completed maintenance action to assure that the item is in satisfactory condition.*

TIME, ACTIVE MAINTENANCE - -

PD: The time during which preventive and corrective maintenance work is actually being done on the item.

(No comments)

TIME, ACTIVE REPAIR - -

PD: The time during which one or more technicians are working on an item to effect a repair.

C: Overlaps Time, Active Maintenance.

R: *See TIME, ACTIVE MAINTENANCE (preferred term).*

TIME, ACTIVE TECHNICIAN - -

PD: That time expended by one or more technicians in active performance of a maintenance task, in man-hours.

C1: This definition is misleading. It is not time that is being measured - but effort.

C2: It might be preferable to designate this as, "Effort, Technician Active".

R: *EFFORT, TECHNICIAN ACTIVE - The effort, expressed in man-hours, expended by one or more technicians performing maintenance.*

TIME, ADJUSTMENT AND CALIBRATION - -

PD: That element of Active Maintenance Time required to make the adjustment and/or calibrations necessary to place the item in a specified condition.

C: This is an example of a specialized term which is trivially self explanatory. One could list a large number of such terms. Delete it.

TIME, ADMINISTRATIVE - -

PD: That portion of Non-Active Maintenance Time which is not included in Supply Time; any type of Delay Time except that of Supply Time.

C: This term is intrinsically ambiguous. The word "delay" should be included

R: *TIME, ADMINISTRATIVE DELAY - (Definition as is).*

TIME, CORRECTIVE MAINTENANCE - -

PD: The time that begins with the observation of a malfunction of an item and ends when the item is restored to a satisfactory condition. It may be subdivided into Corrective Maintenance Time and Delay Time (if a delay is present, and does not necessarily contribute to equipment or system Downtime) if alternate modes of operation or redundancy are u[illegible].

C1: The second sentence seems garbled.

C2: A sub-division of Corrective Maintenance Time cannot be "Corrective Maintenance Time" - why not use Active Maintenance Time?

R: *The time period which begins with the detection of a malfunction of an item and ends when the item is restored to a satisfactory condition. This time may be subdivided into Active Maintenance Time and Delay Time.*

TIME, DOWNTIME - -

PD: That portion of calendar time during which the item is not in condition to perform its intended function.

C1: This term may be poetic - but is grammarically illogical.

C2: Downtime is of no particular significance if there is no demand for usage. If operation is primarily on a single 8 hour, 5 day shift, why account for the remainder of the hours of the week?

R: *DOWNTIME - That portion of time when there is a demand for service and the equipment is not in condition to perform its function.*

TIME, EQUIPMENT REPAIR (ERT) - -

PD: The median value of individual repair times for an equipment or system.

C: To attempt to restrict such a general set of words to denote such a specific concept as "median" seems futile. Why not call the median the median?

R: *TIME, MEDIAN REPAIR (MRT) - The median value of repair times for an item.*

TIME, FAULT CORRECTION - -

PD: That element of maintenance time required under a specified maintenance philosophy to correct the malfunction. It may consist of correcting the malfunction with the faulty item in place, removing and replacing the item with a like serviceable item, or removing the item for corrective maintenance and reinstalling the same item.

C1: It would seem logical and useful to distinguish this term from Fault Location Time (better yet, Diagnosis Time). The present definition does not make this distinction clear.

C2: In the interest of economy of words - why not call this Remedial Time?

C3: "That element of maintenance time -" sounds stilted.

C4: Of what relevance is "- a specified maintenance philosophy -"? What is a "maintenance philosophy"?

R: ***TIME, REMEDIAL - The time required to correct a fault after the fault has been diagnosed.***

TIME, FAULT LOCATION - -

PD: Existing Definition: That element of maintenance required to test and analyze an item to isolate a malfunction.

PD: Proposed Definition: That element of maintenance time required to test and analyze an item to isolate a malfunction.

C1: Again, in the interest of word economy (and established usage) why not call this, Diagnosis Time?

C2: Here's that "element" again.

R: *TIME, DIAGNOSIS - The time required to test for and to isolate the fault in a malfunctioning item.*

TIME, FINAL TEST - -

PD: That element of active repair time required after completion of maintenance, adjustments, and calibration to verify by measurement of performance that the item is in a condition to perform its function satisfactorily.

C1: Consistent with an earlier comment, this term should be "FINAL CHECK TIME".

C2: Why redefine "Final Check".

R: *TIME, FINAL CHECK - The time required to perform a final check of the equipment.*

TIME, INACTIVE - -

PD: Existing Definition: The period of time when the item is available and considered to be operable, but is neither needed, assigned, nor operating for its intended functional purpose.

PD: Proposed Definition: The period of time when the item is available and considered to be in an operable condition, but is neither needed, assigned, nor operating for its intended functional purpose.

C1: By any definition of "available" - it must be operable to be available. Hence, the existing definition contains a redundancy.

C2: The definition seems to be unnecessarily verbose.

R: *The period of time when the item is available but has no demand for use.*

TIME, ITEM PROCUREMENT - -

PD: That element of active repair time required to obtain the needed item or items from base supply stock rooms, etc.

C: This seems to duplicate Supply Time.

R: *See TIME, SUPPLY (preferred term).*

TIME, MAINTENANCE - -

PD: The time during which preventive and corrective maintenance is actually being performed on an item.

C1: This is either, (1) a duplicate of Active Maintenance Time, or (2) a distinct concept which is poorly explained.

C2: Of the two alternatives, it may be useful to select the second.

R: *The total time required to complete a maintenance action including Active Maintenance Time, Administrative Delay Time, Supply Delay Time, etc.*

TIME, NON-ACTIVE MAINTENANCE - -

PD: The time during which no maintenance is being accomplished on the item because of either supply or administrative reasons.

(No comments).

TIME, PREVENTIVE MAINTENANCE - -

PD: Existing Definition: That portion of calendar time used in accomplishing preventive maintenance; made up to time spent in performance measurement, care of mechanical wearout items, front panel adjustment, calibration and alignment, cleaning, etc.

PD: Proposed Definition: That portion of calendar time used in accomplishing preventive maintenance; made up of time spent in performance measurement, care of mechanical wearout items, adjustment, calibration and alignment, cleaning, etc.

C: Why redefine "Preventive Maintenance"?

R: *The time required to perform preventive maintenance.*

TIME, SUPPLY - -

PD: That portion of delay time (non-active maintenance time) during which maintenance is delayed solely because a needed item is not immediately available.

C: To be unambiguous, a distinction should be made between "Supply Time" and "Supply Delay Time".

R1: *TIME, SUPPLY - The time required to obtain repair parts.*

R2: *TIME, SUPPLY DELAY - The delay incurred when waiting for repair parts.*

TIME, TECHNICIAN - -

PD: That time expended by the technician(s) in performance of a maintenance task, expressed in man-hours.

C: Duplicates Technician Active Time.

R: *See TIME, TECHNICIAN ACTIVE (preferred term).*

TIME, TECHNICIAN DELAY - -

P.D.: The number of maintenance man-hours expended on a maintenance task while no maintenance is performed either because of supply or administrative reasons.

C1: "Delays" would be a better word than "reasons."

C2: Again, effort rather than time is defined here. These are two separate (and useful) concepts which should be distinguished.

R1: *INACTIVITY, TECHNICIAN DELAY - The number of manhours wasted during a maintenance operation due to supply or administrative delays.*

R2: *TIME, TECHNICIAN DELAY - The number of hours that technicians are idle due to supply or administrative delays.*

TIME, TOTAL TECHNICIAN - -

P.D.: The total man-hours expenditure required to complete a maintenance task; includes, active technician time, and delay technician time.

C: Once more, effort is being defined - not time. Time is measured in hours. Effort is measured in man-hours.

R: *EFFORT, TOTAL TECHNICIAN - Total number of manhours expended to perform a maintenance operation including both active effort and inactive delay.*

TROUBLE SHOOTING - -

PD: Locating and diagnosing malfunctions or breakdowns in equipment by means of systematic checking or analysis.

C: An acceptable colloquialism but isn't "diagnosis" a more concise term?

R: *An alternate term for DIAGNOSE (q.v.).*

SECTION ENTITLED "ADDITIONAL TERMS WITH DEFINITIONS"

"From AR 750-6"

GENERAL COMMENT

This list does not seem to contain definitions, per se. Rather, they are expositions or descriptions of terms. Some of them, such as the "Maintenance Policy" term are unique to the regulation document. This list does not seem suitable, as is, for inclusion in a definition standard.

MAINTENANCE SUPPORT PLAN - -

PD: A continually updated plan initiated at the beginning of the development phase for an item of military design and at the beginning of the procurement phase for a commercial item. The plan provides narrative data concerning the planned use of the item and establishes a time-phased schedule of the major actions required for mainenance support of the item in the field (AR 750-1).

C1: This seems to be more than a definition - perhaps a description. A plan can be a maintenance support plan whether or not it is "-continually updated -", or when it is initiated.

C2: The term should be defined - not exposited.

R: *A plan for providing maintenance to an item or system.*

MAINTENANCE POLICY - -

PD: Published statement of guidance by Headquarters, Department of the Army on the general course to be followed in the development of maintenance support concepts.

C: This is not a definition in the "standard definition" sense. A maintenance policy is a maintenance policy regardless of the authorship.

R: *A specific policy to be followed in the operation of a maintenance process.*

MAINTENANCE CONCEPT - -

PD: A concept which describes the manner in which an end item will be maintained and supported. It indicates maintenance capabilities required of the using unit and supporting units and provides information concerning the tactical employment, unusual maintenance environment, mobility considerations, allowable downtime, and other operational requirements. Additionally, the technical information required to develop military and civilian occupational series codes to recognize new or changed skill requirements is included.

C: This seems to add nothing (of a definition nature) to the "Maintenance Policy" recommended definition.

R: *See MAINTENANCE POLICY (preferred term).*

LOGISTICAL SUPPORT PLAN - -

RD: A Department of Army approved document outlining the logistical factors involved in the support of the particular end item and related ancillary equipment. This plan normally is written to provide the tactical commanders the necessary information to assure orderly deployment and support of an item in the field. Logistical support plans will be prepared only for those items specified on an individual basis by DCSLOG.

C1: Again, a non-definition. Approval is not part of a definition, the purpose is not part of a definition, and for what items they shall be prepared is not part of a definition.

R: *The plan for providing logistical support to an item.*

MAINTENANCE ALLOCATION CHARTS - -

PD: A listing of maintenance operations applicable to an item of equipment with an indication of the lowest category of maintenance to which each operation is allocated. This chart will cover the major end item and accessories issued with the end item. (Format included in AR 310-3).

C1: Still, a non-definition.

C2: The first sentence is classic Pentagonese.

R: *A chart showing the assignment of maintenance functions for a specific item (or system) to each maintenance echelon.*

EQUIPMENT SERVICEABILITY CRITERIA - -

PD: Tests and measurements prescribed for each mission-essential maintenance-significant item of equipment to evaluate its capability to satisfactorily perform its combat mission for a period of 90 days as established by AR 750-10.

C1: Awkward syntax. Non-definition.

C2: How can criteria be "Tests and measurements -"?

C3: The question of satisfactory performance for a period of 90 days is a probabilistic question (indeed, it is reliability, itself). Nothing is stated here about this probability nor about a confidence level for predicting (or determining compliance with) such a probability. If this meaning is meant, it should be called "90 Day Combat Reliability" or some such term.

R: *Criteria to determine if an item is in sufficiently satisfactory condition to perform its function.*

"From MIL-M-55214 (EL)"

PERSONNEL INJURY - -

PD: The probability of injury to maintenance personnel during performance of normal maintenance.

C: If this is to be defined as a probability - it should be called a probability.

R: *PERSONNEL INJURY PROBABILITY - (Definition as given)*

UNITIZED CONSTRUCTION - -

PD: A type of equipment construction consisting predominately of replaceable assemblies or modules.

C: This seems like a real misnomer. "Unitized" usually means "in one piece", as a unitized chassis for an automobile.

R: *MODULARIZED CONSTRUCTION - (Definition as given).*

EQUIPMENT DAMAGE - -

PD: The probability of damage to equipment by maintenance personnel as a result of performing normal maintenance.

C: Should include the word "probability" in the term.

R: *EQUIPMENT DAMAGE PROBABILITY - (Definition as given).*

"From Calabro"

UP-TIME RATIO (TIME AVAILABILITY) - -

PD: An expression of equipment availability applied to continuously operable maintained systems. It consists of a steady-state component and a transient component. The complete expression is given by:

$$UTR = \frac{\mu}{r + \mu} + \frac{r}{T(r + \mu)^2} - \frac{r}{T(r + \mu)^2} \exp[-(r + \mu)T]$$

This represents a measure of availability of the system, since it gives the probability that it is on at time T. As $T \to \infty$ the transient state disappears and the general expression for UTR reduces to the steady-state equation: $UTR = \frac{m}{m+\phi}$, or since $r = \frac{1}{m}$ and $\phi = \frac{1}{\mu}$, $UTR = \frac{\mu}{r+\mu}$. (This is the ratio of the up, or operable, time to the sum of the up and down, or inoperable time.)

C1: This definition should be attributed to Barlow and Hunter - not Calabro. (See Calabro footnote P. 135) Barlow and Hunter use μ in place of r and λ in place of μ. This seems to be consistent with general use, Calabro's use is therefore inconsistent. There seems to be no purpose in not using Barlow and Hunter's symbols.

C2: The text of the definition, especially in the latter part, seems somewhat garbled.

C3: The symbols should be defined.

C4: Consistent with this commentator's earlier comments regarding "availability" this term should be changed to "operability". Notice that Barlow and Hunter do not use the word "availability" in connection with their expression. Their term is "expected fractional on-time".

C5: This should be defined as an <u>expected</u> uptime ratio since it is a mean value.

R: EXPECTED UPTIME RATIO (EUR) - *The expected fraction of the time, over interval 0 to T, that an item (or system) is operable. This term is applicable to maintained systems.*

$$EUR = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{T(\lambda + \mu)^2} - \frac{\lambda e^{-(\lambda + \mu)T}}{T(\lambda + \mu)^2}$$

where

EUR = expected uptime ratio
μ = repair rate
λ = failure rate
T = time period of interest

As $T \to \infty$

$$EUR \to \frac{\mu}{\lambda + \mu}$$

DOWN TIME RATIO - -

PD: An expression of equipment availability applied to continuously operable maintained systems. It consists of a steady-state component and a transient component. The complete expression is given by:

$$DTR = \frac{r}{r + \mu} - \frac{r}{T(r + \mu)^2} + \frac{r}{T(r + \mu)^2} \exp\left[-(r + \mu)T\right] .$$

As $T \to \infty$ the transient state disappears and the general expression for DTR reduces to the steady-state equation: $DTR = \frac{\phi}{m + \phi}$, or since $r = \frac{1}{m}$ and $\phi = \frac{1}{\mu}$, $DTR = \frac{r}{r + \mu}$. (This is the ratio of the down, or inoperable, time to the sum of the up and down, or inoperable time.)

C: **All of the comments for UPTIME RATIO apply here.**

R: *EXPECTED DOWNTIME RATIO (EDR) - The expected fraction of the time, over interval 0 to T, that an item (or system) is inoperable. This term is applicable to maintained systems.*

$$EDR = 1 - EUR$$

where

EDR = expected downtime ratio
EUR = expected uptime ratio (q.v.)

"From AR 705-25"

PREDICTED TURN AROUND TIME - -

PD: The predicted time necessary to service or check out the materiel for recommitment.

C1: Is this intended to be an average value? If so, the definition should so state.

C2: From the words used in the term, it seems an unwarrented presumption to restrict the term to such a narrow meaning. Such a restriction is particularly unfortunate with this term since it has such wide usage in many fields.

R: - *The predicted average time necessary to complete an operation including all attendant delays, transportation time, etc. The term is usually applied to an operation, such as maintenance, which is auxilliary to the primary, operation of the equipment.*

USAECOM MAINTAINABILITY SPECIFICATION

MIL-M-55214(EL)

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U. S. Army Electronics Command

16 July 1965

USAECOM MAINTAINABILITY SPECIFICATION

MIL-M-55214(EL)

If in 1959 we were to ask any of the departments for a specification that permitted the measurement of maintainability, the chances are that we would be greeted by the taking of the Fifth Amendment, pleas of temporary amnesia, and excuses that there was no breaktrhough in the state of the art.

By 1964 that breakthrough must have bore more than a passing resemblance to the Mississippi at flood time, because you would trip over the number of techniques that found their way into specifications. The Air Force had its MIL-M-26512; the Navy, the Bu Ships side, had its MIL-M-23313 (ships) while their Weapons people had WS-3009 (Weps) and MIL-M-23603 (Weps). Not to be outdone, the Army's Electronics Command had its MIL-M-55214(EL); the Missile Command, its MIL-M-45765(MI); and the Mobility Comands's contribution was MIL-STD-1228 (Army). This impressive array was further rounded out by a NATO standard on maintainability, STANAG No. 2817. The advantage of the latter document was that if a contractor didn t like the wording in English, he could switch to French, or any of the other NATO languages.

While questions could undoubtedly be raised as to the absolute validity of any of these techniques, there is certainly no doubt that their application to a design would unquestionably result in a vast improvement in the ease with which the design could be maintained in the field. In fact, it is possible that in the absence of a universally acknowledged technique, we may be able to borrow from the efforts of our counterparts within other organizational segments of the DOD, and thereby further improve the means by which each of us are currently assuring the integration of maintainability into our designs.

It is in this context that I will discuss the Electronics Command's specification MIL-M-55214(EL) entitled: "Maintainability Requirements, General; For Electronic Equipment." Copies of the specification will be distributed to each of you at the conclusion of this talk.

Our approach to the quantification of maintainability, was developed under contract with the American Institute for Research. It essentially is a technique on which the equipment design is checked and audited for maintainability.

In brief, the technique identifies the design features which affect or influence the maintainability of an equipment. Principally, this was developed by the preparation and submission of a questionnaire consisting of all possible design features which could influence maintainability. The original list of 241 design features was rated by experienced field maintenance personnel on a five-point scale to indicate the relative importance that the absence of that feature would have on maintenance operations. Though these design features were primarily applicable to communications-electronics equipment, they were found to be sufficiently general to be used for a wide variety of electronic equipment. They were further categorized into nine design factor groups.

USAECOM Maintainability Specification (MIL-M-55214(EL) - Con't.

To establish a relationship between design features and the ease with which maintenance could be performed, the concept of maintenance consequence areas was developed. As defined in this study, a maintenance consequence is the way in which adequate or inadequate design for maintainability affects maintenance load and operation. Five such consequence areas were established. These were:

1. Down time: The time required for the performance of preventive and corrective maintenance, which prevents the scheduled operation of the equipment. This total time is expressed in equipment hours and does not include maintenance lag time, which is the time lost due to unavailability of parts, personnel, or facilities.

2. Maintenance time: The total time expressed in man hours, required to carry out all preventive and corrective maintenance procedures.

3. Logistics requirements: The demands made on the logistics system for the maintenance of an equipment. This includes such factors as tools, parts, personnel, facilities, etc.

4. Equipment damage: The probability of damage to equipment by maintenance personnel as a result of performing normal maintenance.

5. Personnel injury: The probability of injury to maintenance personnel during performance of normal maintenance.

During evaluation, each design feature is scored 'yes' or 'no' indicating its presence or absence in the equipment, and weighted proportionate to the influence it exerted on the consequence areas. The design feature weights are summed up by consequence area and Factor Group into raw score form, and then converted into computed scores. To convert the raw schores, the total 'yes' scores are divided by the total 'yes' plus the total 'no' scores and multiplied by 100. Design features not applicable to the equipment being evaluated are eliminated from the scoring. The data from this evaluation is the maintainability profile of the design under investigation. Chart 1

To provide a base for determining the acceptability of the design from a maintainability standpoint, standard profiles were established which represented the user's minimum acceptable maintainability requirements. This was obtained by submitting a questionnaire to a cross section of command personnel who expressed their maintainability requirements on a hundred point scale for each consequence area for six different equipment categories. These were for:

1. Permanent Installations — Chart 2
2. Fixed Field Installations
3. Mobile and/or Operator Carried — Chart 3
4. Airborne
5. Test Equipment
6. Recorder Reproducers — Chart 4

USAECOM Maintainability Specification (MIL-M-55214(EL) - Con't.

By comparing the computed profile with that of the applicable standard, it is possible to determine whether the maintainability of the equipment as measured by the index has met the requirements of the eventual users of that equipment.

In addition to this, the index provides the designer with an analytic tool for identifying specific deficiencies in the design and thereby indicating areas for redesign. The weighting factors, on the other hand, furnish the basis for trade-offs between various design features.

While the aforementioned technique is not based on any requirement for time measurements, it is to be emphasized that if a specific design feature is not included in the design, any repair task involving that feature will take longer to accomplish.

Though this technique represents the hard core of the Electronics Command's maintainability specification, MIL-M-55214(EL), there are many maintenance factors which, while not currently susceptible to quantification, must be considered if the design is to be maintenance oriented. It is hoped that the various efforts to obtain a measure of system's effectiveness will utlimately permit the assignment of a "number" to these elements. In this connection, the Air Force deserves much credit for spark-plugging the development of such a methodology through their WESIAC group. Chart 5

However, since this is still in the future, the Electronics Command felt that the contractor should be given an envelope within which he should conduct his maintainability program. Thus, in addition to furnishing the contractor with the minimum acceptable scores in each of the consequence areas, it is also necessary that he be provided with the basic concept that describes the manner in which the government will maintain the design. Chart 6 Chart 7

This, in turn, must be supplemented by information as to the operating and maintenance conditions. This includes the hours of operation per day, how and where the equipment will be used, tolerable down time, and work environment. Chart 8

Since we are very much concerned over the increased complexities of equipment as they affect our training requirements, it is necessary that the designer develop his equipment and its support so as to minimize or even eliminate the need for upgrading exisitng operating and maintenance skills. To do so, it is essential that he be advised as to what MOS's are available for this purpose, as well as their technical capabilities and limitations. Chart 9 Chart 10

If we are to minimize the unnecessary introduction of new items of tools and test equipments to the maintenance organizations, we must tell the contractor what is currently available in these organizations. Nor should the interests of standardization be neglected by not requiring him to screen Air Force, Navy, or other Army Commodity Commands' resources in those instances where organizational items are not adequate. Chart 11

USAECOM Maintainability Specification (MIL-M-55214(EL) - Con t

Because any effective maintainability program must consider all of these aspects in the design, it stands to reason that the knowledge acquired by the designer should not be restricted to efforts directed to the design alone. Instead, it was felt that the system analysis could also be applied, and at very little addtional cost, to the determination and preparation of:

1. Tool and test equipment requirements and allocations,

2. Maintenance procedures and instructions.

3. Maintenance technician classification to include specific requirements for training.

4. Repair parts lists by item, number, and echelon allotment.

In other words, implementation of the specification should not only result in the improvement of the inherent maintainability of the design, but of equal importance--to derive for us the specific requirements of all elements of maintenance support.

Chart 12

This gentlemen, concludes my talk. Are there any questions?

COMPUTATION OF MAINTAINABILITY

a. For each of the five columns in Table 1, total the weighting factors for all design features adopted and present in the equipment. To be counted "yes," the feature must be present in every possible application in the equipment. Omission in specific situations shall be adequately justified.

b. Total all design features weighting factors for features not included in the design for any reason other than not applicable to the nature of the equipment under design. Those "no" items shall include those features not employed to the maximum extent possible.

c. The "not applicable" features shall be dropped from the computation.

d. Perform the following computation for each column:

$$M = \frac{Y}{Y+N} \times 100$$

where M = maintainability,

Y = total of "yes" weighting factors, and

N = total of "no" weighting factors.

CHART 1

PERMANENT INSTALLATION

PROFILE SHEET

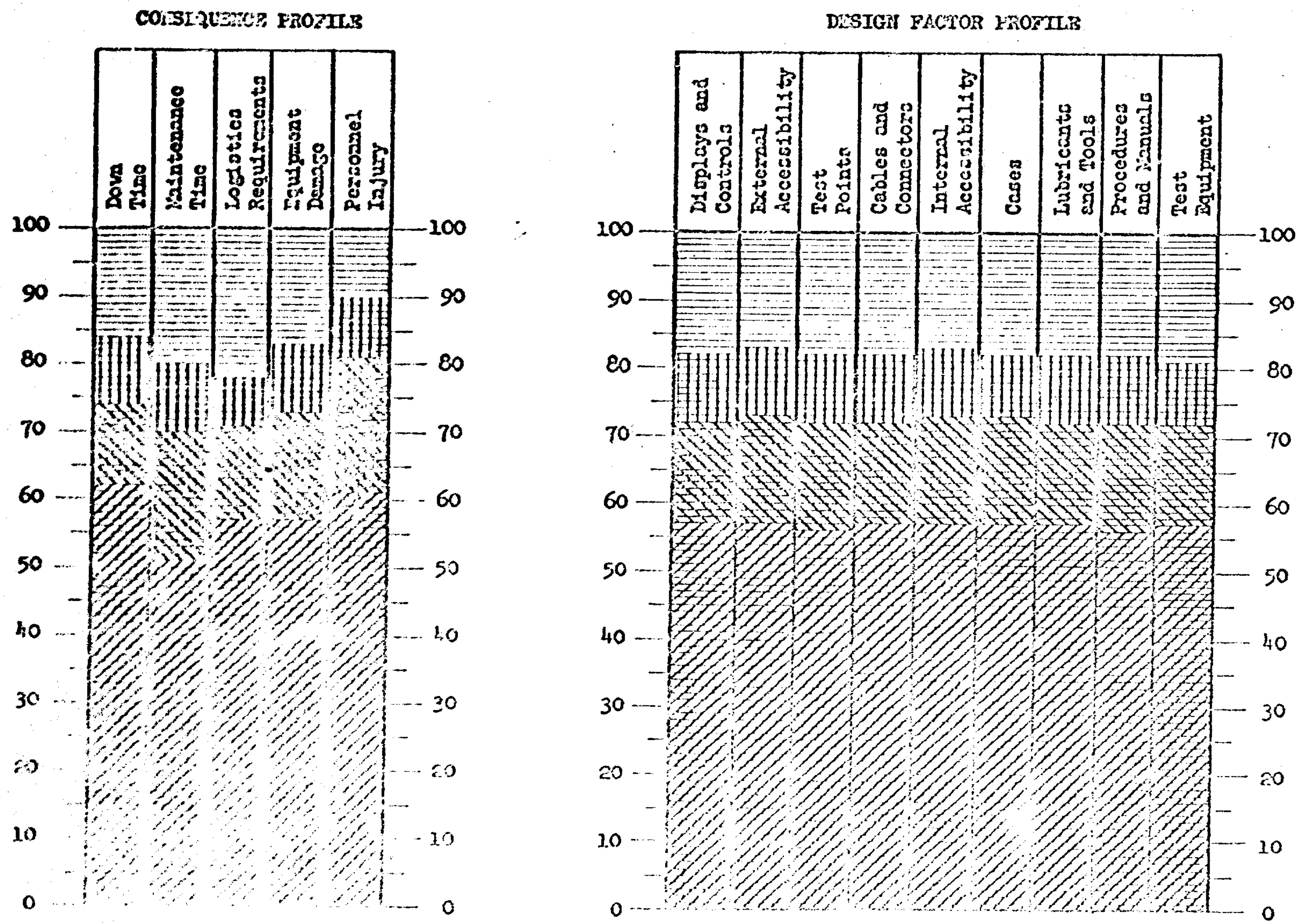
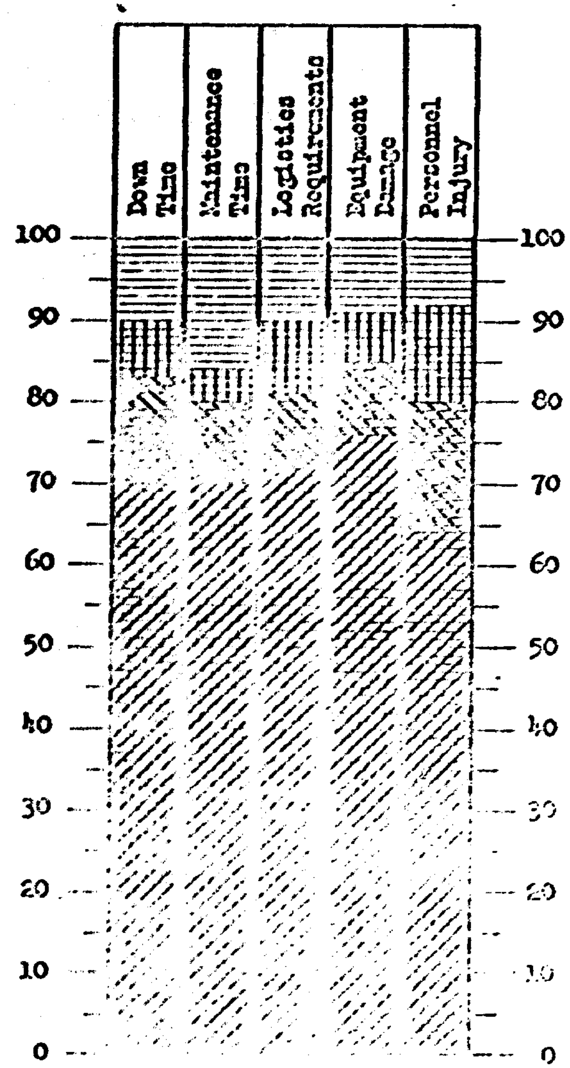


CHART 2

MOBILE AND/OR OPERATOR CARRIED

PROFILE SHEET

CONSEQUENCE PROFILE



DESIGN FACTOR PROFILE

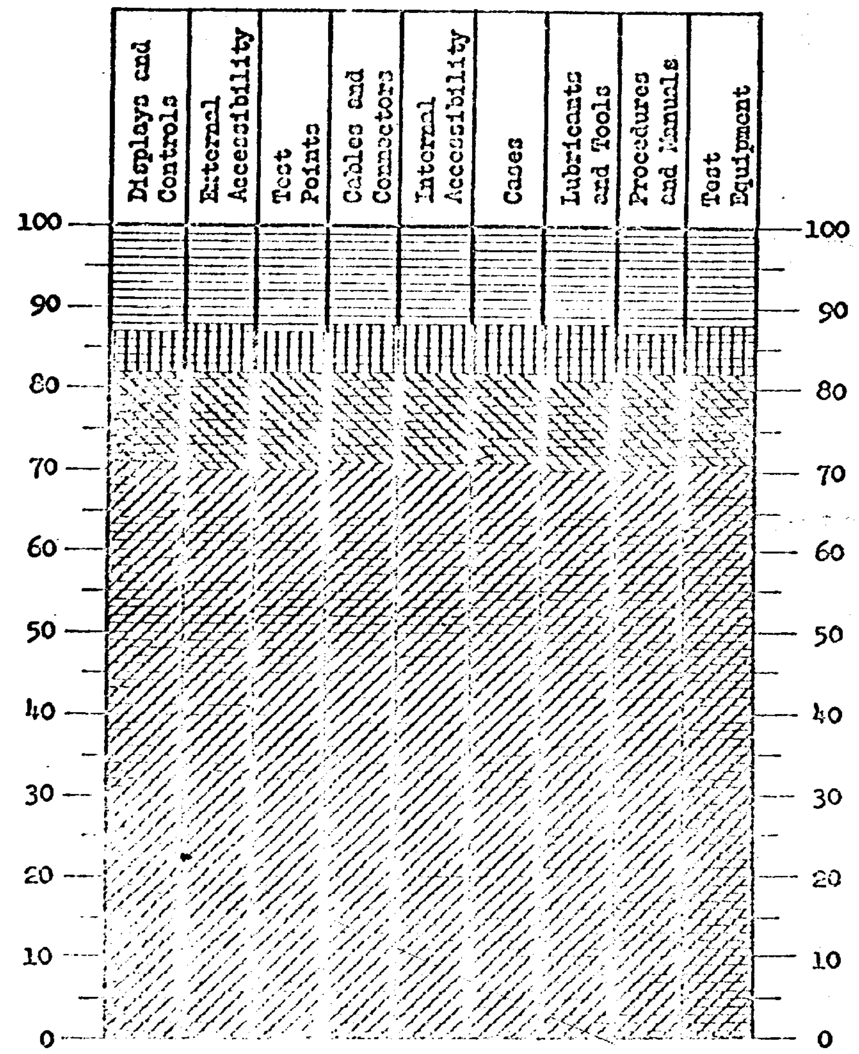
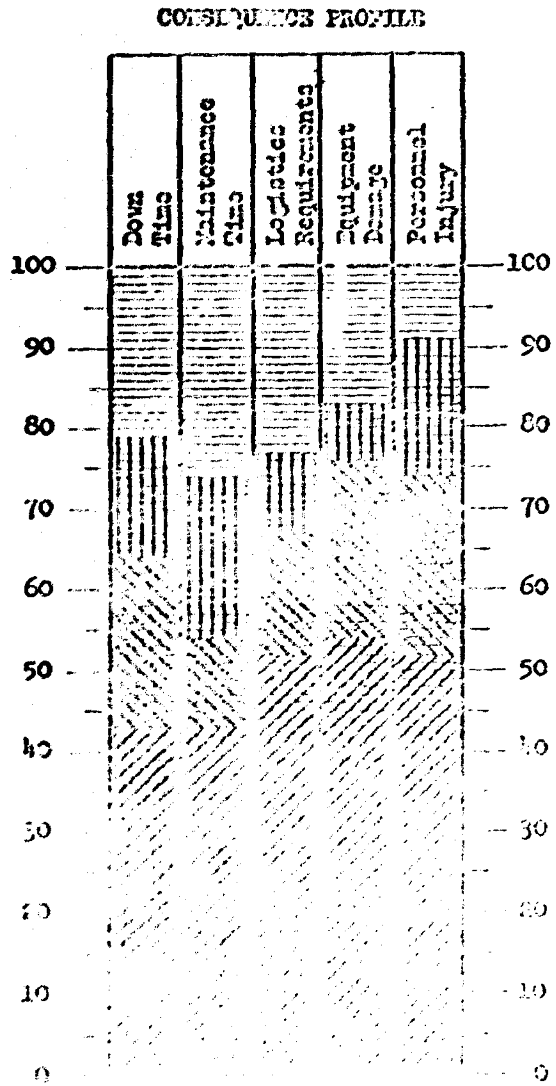


CHART 3

RECORDER-REPRODUCER

PROFILE SHEET



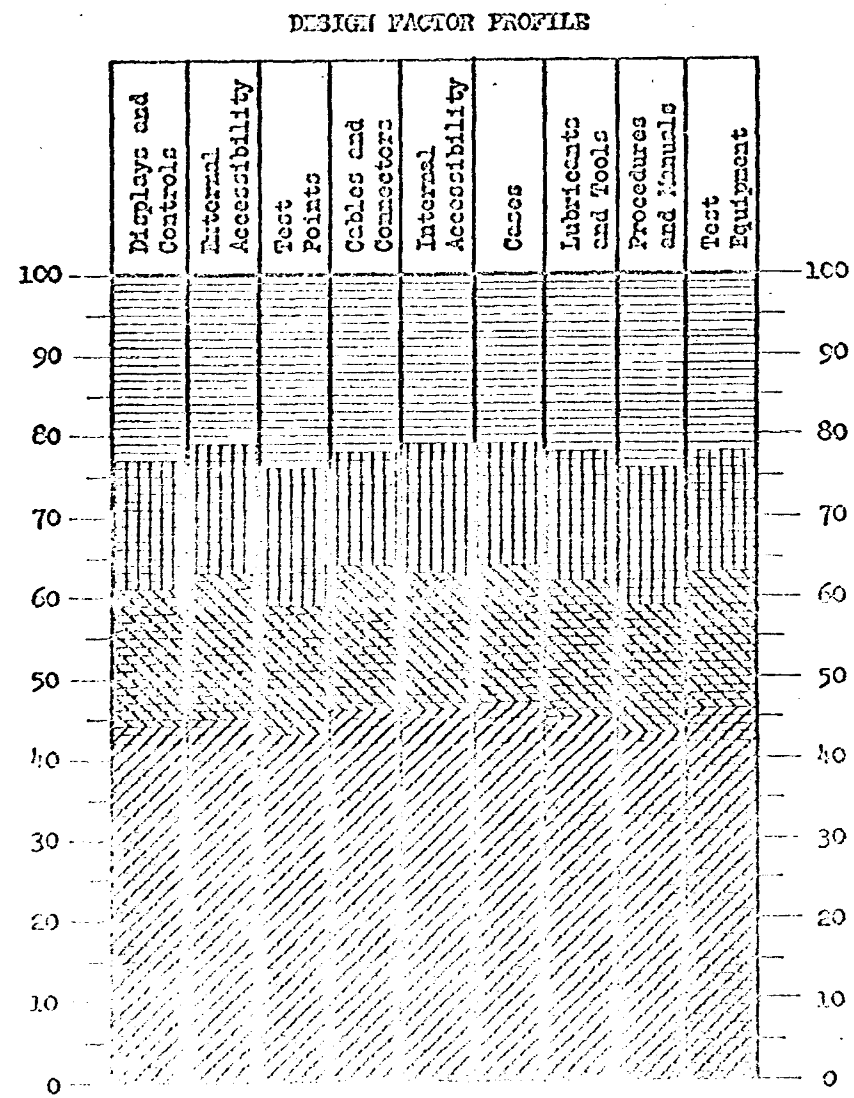


CHART 4

FACTORS TO BE CONSIDERED IN M DESIGN PLAN

a. Analysis and allocation of maintenance functions.

b. Allocation of maintenance skills and facilities.

c. Maintenance time requirements and limitations.

d. Logistics requirements and limitations pertaining to maintenance.

e. Maintenance technician decision, and information analysis.

f. Consideration of technician safety requirements.

g. Analysis of interacting calibration and adjustment effects.

h. Design and layout of maintenance displays and controls.

i. Design of maintenance accesses.

j. Determination of requirements for maintenance support facilities and the necessity for the development of special purpose maintenance support equipment.

CHART 5

M REQUIREMENTS

Column #	Consequence area	Minimum acceptable score
1	Down time	80
2.	Maintenance time	75
3	Logistics requirements	80
4	Equipment damage	85
5	Personnel injury	80

MAINTAINABILITY GUIDANCE FACTORS FOR RADIO SET AN/XZY-000

CHART I

MAINTAINABILITY DESIGN FACTORS FOR RADIO SET AN/XZY-000

1. Modular design should be employed.
2. A maximum of 15 modules is recommended.
3. Modules should be capable of replacement without need for tuning, peaking or realignment of the equipment or the module.
4. Modules costing less than $50 should be designed for throw-away.
5. Design for less than available capability and facilities indicated in Charts II, III, IV and V.

1. Conditions of employment - Organizational level

a. Daily hours of operation - twenty-four.

b. Criticality of equipment to user mission - approximately one hour scheduled down time per week.

c. Mobility of using organization - 90% mobile.

d. Work environment for maintenance - available sheltered area of semi-permanent structures.

e. Power available to organizational mechanic - 24v dc; auxiliary equipment to permit operation from 110/220 volts, 50/60 cycles ac.

f. Climatic conditions encountered - all types of temperature and environmental extremes.

g. Mode of employment - Radio Set AN/XXX-000 will be installed and operated in 1/4 ton trucks and personnel carriers. In addition to radio voice communications, it may be used in the FSK or teletype mode of operation. It will operate in forward areas where vehicular travel is [illegible].

CHART 8

2. Nature and extent of maintenance

a. Organizational

(1) Operator. Performs normal preventative maintenance, replaces running spares. When Radio Set AN/XXX-000 is used in the FSK or teletype mode of operation, the user will become a teletypewriter equipment operator. Auxiliary equipment must be added for teletype communication.

(2) Organizational Mechanic. Locates and replaces faulty modules through use of a "go-no-go" defective module locator. Performs limited replacement of easily removable parts such as knobs, cables, assemblies, tubes, and other items not requiring major disassembly. Receives support and technical backup from Direct Support Unit (DSU).

b. Direct Support Unit. Field radio repairman. Performs field maintenance on equipment for return to user. Trouble shoots and repairs conventional circuitry (replacement of parts external to modules, including adjustment and alignment).

c. General Support Unit (GSU). Field radio repairman. Rebuilds subassemblies as required.

d. Depot. [illegible] Performs major equipment [illegible] rebuild for return to depot stock. [illegible] $50 will be considered for [illegible]" rather than repair.

CHART 9

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OPERATIONAL AND MAINTENANCE PERSONNEL FOR RADIO SET AN/ZZY-000

1. Organizational Maintenance - Operator

   MOS 050, Low speed operator
   MOS 051, Intermediate speed operator
   MOS 053, Radio teletypewriter operator
   MOS 311, Infantry Comm. Specialist
   MOS 313, Artillery Comm. Specialist

2. Organizational Maintenance - Unit Mechanic

   MOS 296, Field Radio Repairman
   MOS 311, Infantry Comm. Specialist
   MOS 312, Armor Comm. Specialist
   MOS 313, Artillery Comm. Specialist

3. Direct Support

   MOS 296, Field Radio Repairman

4. General Support and Depot

   MOS 296, Field Radio Repairman

NOTE: A detailed description covering the above MOS's shall be furnished to the successful bidder.

CHART 10

MAINTENANCE FACILITIES FOR
RADIO SET AN/XZY-000

Tools and Test Equipment Items	Echelons 2	3	4	5
1. Indicator, Panoramic IP-173/U			X	X
2. Multimeter AN/URM-105	X			
3. Multimeter TS-352/U		X	X	X
4. Multimeter, Meter MR-26/U		X	X	X
5. R. F. Signal Generator Set AN/URM-25		X	X	X
6. R. F. Wattmeter AN/URM-120			X	X
7. Audio Oscillator TS-382/U		X	X	X
8. Votlmeter, Meter, ME-30/U			X	X
9. Frequency Meter AN/USM-26			X	X
10. Sound Analyzer, TS-615B/U			X	X
11. Tool Kit TK-87/U		X	X	X
12. Tool Kit TK-88/U			X	X
13. Tool Kit TK-115/G	X			
14. Module Tester (being investigated)	X			
15. Test Set, Electron Tube TV-7/U	X	X	X	
16. Test Set, Electron Tube TV-2/U				X
17. Two-tone Audio Generator			X	X
18. Signal Generator				
19. Spectrum Analyzer TS-723/U			X	X
20. Oscilloscope AN/USM-81			X	X
21. Oscilloscope OS-8A/U		X		
22. Selective voltmeter				
23. Dummy Load DA-195/U		X		
24. Watch, FSN 6645-719-8670				X
25. Attenuator, Variable CN-764/U				X

CHART 11

PRODUCTS of MAINTAINABILITY SPECIFICATION

a. The results of the maintainability evaluation.

b. Requirements for tools, test equipment, and facilities with which to maintain the equipment under development.

c. Maintenance task analysis.

d. Maintenance procedures and instructions.

e. Maintenance technician classification selection.

f. Allocation by echelon of recommended repair items.

CHART 12

OPERATION WOODPILE

DEVELOPMENT OF TECHNIQUES FOR MAINTAINABILITY DEMONSTRATION

AUTHOR: Michael Bialkowski

U. S. Army Electronics R&D Activity
Fort Huachuca, Arizona

OPERATION WOODPILE
DEVELOPMENT OF TECHNIQUES FOR MAINTAINABILITY DEMONSTRATION

Operation Woodpile is an in-house research project on techniques to derive reliability and maintainability data from operation of standard Army communications-electronics equipment. It is directed by Jim Lamb, Chief Scientist of the Army Electronics Research and Development Activity at Fort Huachuca, Arizona. The program uses as a research vehicle the large scale EMETF program at Fort Huachuca, which is to test interference effects among groups of electromagnetic radiating equipments in a field environment simulating large-scale Army tactical operations.

A feature of our program is the use of running-time meters and functional cycle counters installed with selected equipments to assure comprehensive quantitative time data. Typical installations are shown in Photos 1 and 2. Combined with accurate knowledge of the operating environment and with disciplined reporting of failures and maintenance actions, the data collected are ideally suited for the analysis of equipment reliability and maintainability.

While Operation Woodpile generally treats reliability and maintainability studies as inseparable, certain information and conclusions on maintainability alone will be discussed.

To start with, our mutual objective is to maximize availability of equipment. Availability, as defined in one form by Mil-Standard 778 is MTBF over MTBF plus Mean-Active-Maintenance-Downtime. This simply means that downtime must be minimized. One of the objectives of Operation Woodpile is to obtain a realistic measure of this time. No scheduled maintenance is practiced on this project; however, maintenance checks are made during active repair. The Active Repair Time is separated for analysis into Diagnostic Time and Corrective Time.

As one example, operating with consistently high-level disciplined maintenance personnel, diagnostic and corrective times were obtained for 110 repairs on 12 types of radio equipments to determine the statistical characteristic distribution. These times were aggregated and ranked without regard to equipment type and without regard to whether failure occurred in TRANSMIT or RECEIVE mode. From these data, graphs on logarithmic normal probability paper were developed indicating percentage of equipments versus time as shown in Figures 1, 2 and 3.

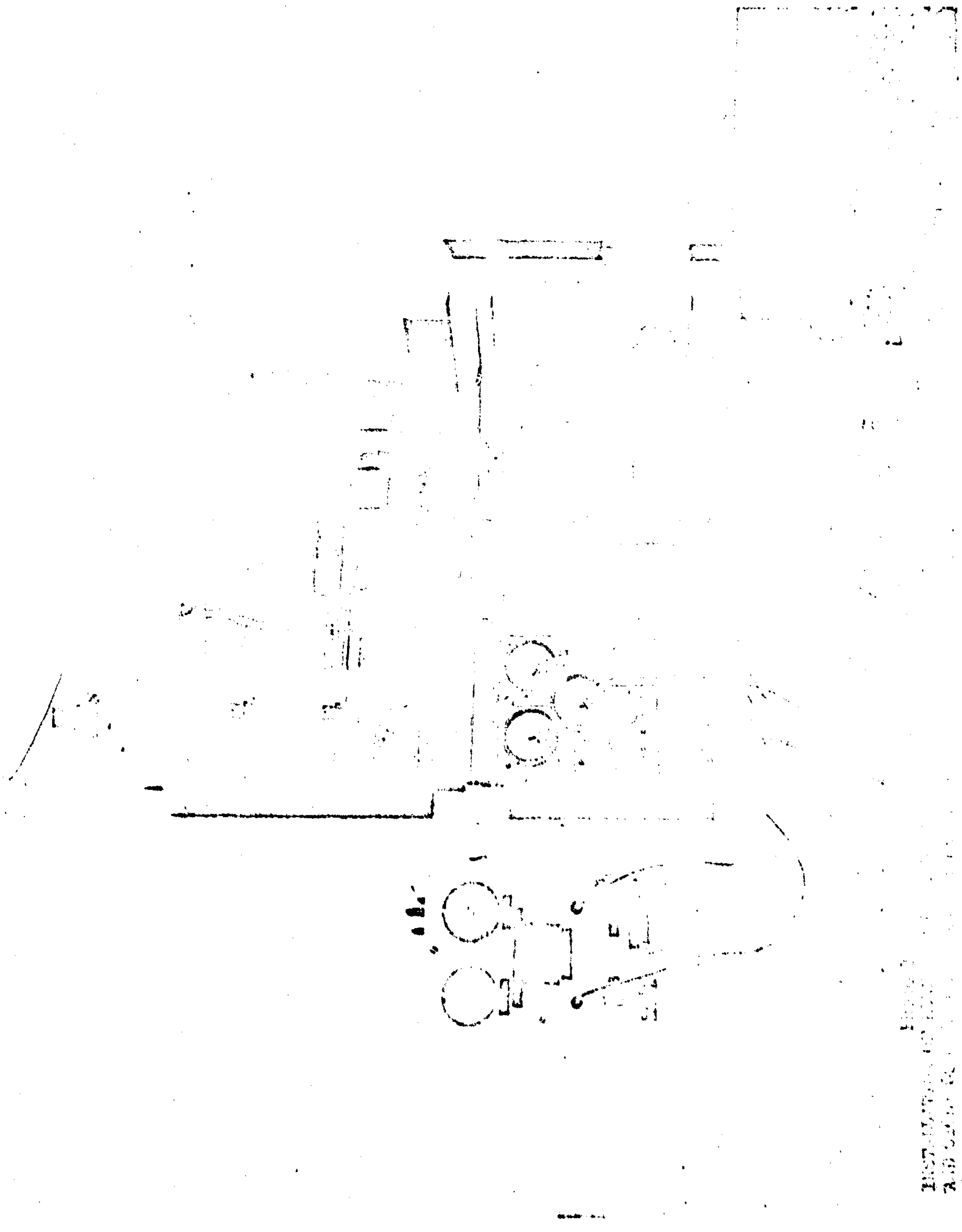
The fit to a straight line is good in each case, indicating that the data are well described by the log-normal distribution. Estimates of the parameters of this distribution are also included as shown. It is to be noted that the mean times are larger than the medians. This is typical of skewed distributions such as the log-normal and the exponential. The median is easy to determine from the data and is usually the parameter for characterizing the log-normal distribution and the one often reported. However, for purposes of calculating equipment availabilities or estimating long-term maintenance requirements, the mean times are used. It is also of interest that in this aggregate of mixed types of communications equipment, about 60% of Active Repair Time is consumed in diagnosis of failure before corrective action begins. This suggests room for improvement in our standard diagnostic procedures.

To indicate the effect of different equipment types on Active Repair Time, data are plotted in Figure 4 for two equipment types which represent extremes in repair time characteristics. As shown the median time to repair VRC-9 equipments (RT-67 FM Radio) is 1.3 hours whereas the median time to repair GRC-19 equipments, which contain a complex automatic tuner, is 8.7 hours.

An additional aspect of Operation Woodpile is to develop techniques for computer analysis of reliability and maintainability. This is facilitated by formats designed for punched cards. Another aspect is the development of conversion factors for different operational environments.

To summarize, Operation Woodpile seeks to establish a basis for maintainability quantification for both standard equipments and for future equipments. The essential attribute for maintainability measurement is time. Elegantly, the relation can be stated as M=f(t). Inelegantly, it is stated as follows: "It ain't worth a dime if you ain't got that time."

NOTE: Presented by Mr. M. Bialkowski, USAERDAA, on 19 July 1965 at the Army Technical Meeting on Quantification of Maintainability During Research and Development of Materiel.



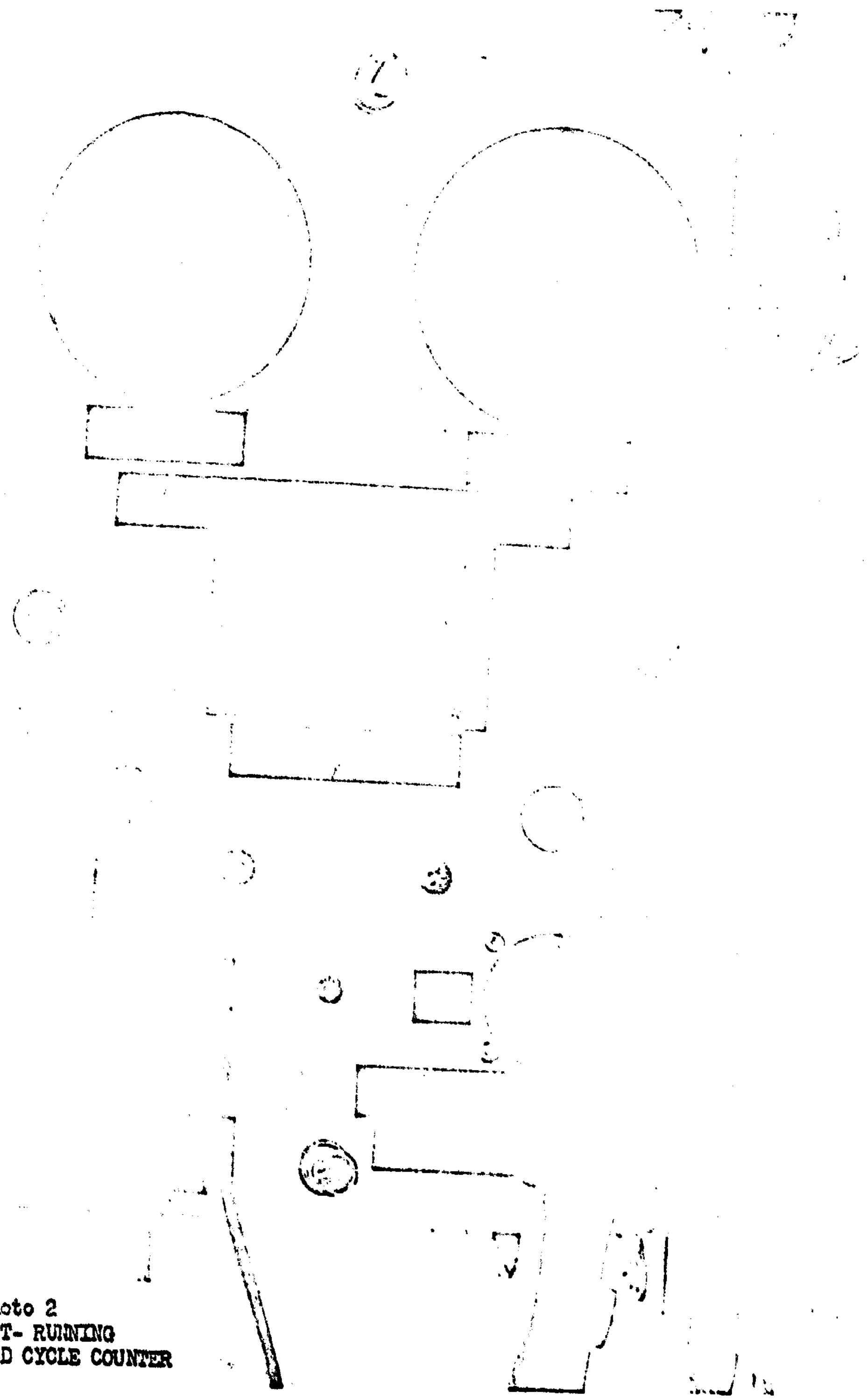


Photo 2
RECORDING UNIT- RUNNING
TIME METER AND CYCLE COUNTER

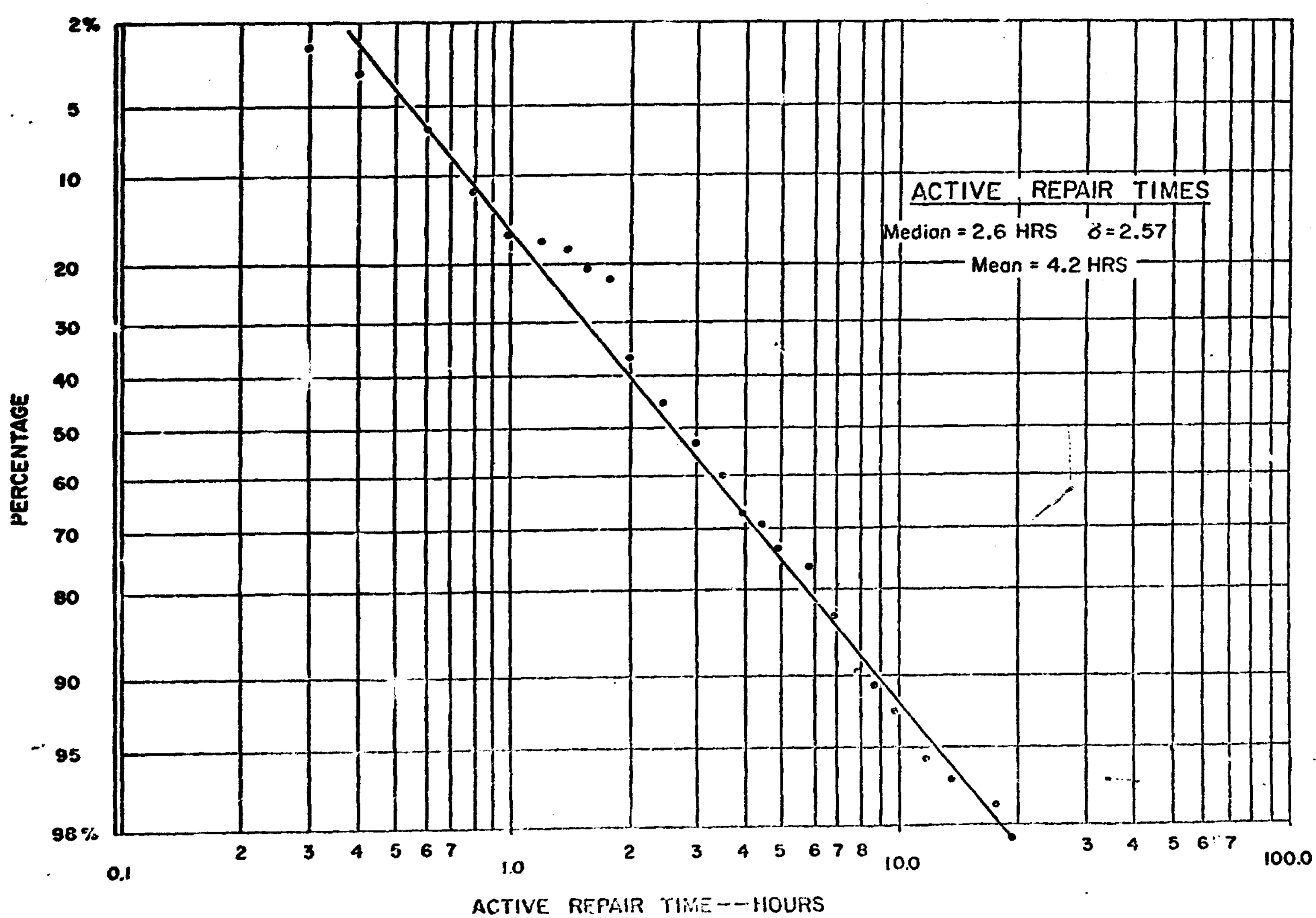

ACTIVE REPAIR TIMES
Median = 2.6 HRS δ = 2.57
Mean = 4.2 HRS
PERCENTAGE
2%
5
10
20
30
40
50
60
70
80
90
95
98%
0.1
2
3
4
5
6
7
1.0
2
3
4
5
6
7
8
10.0
3
4
5
6
7
100.0
ACTIVE REPAIR TIME--HOURS

Figure 1

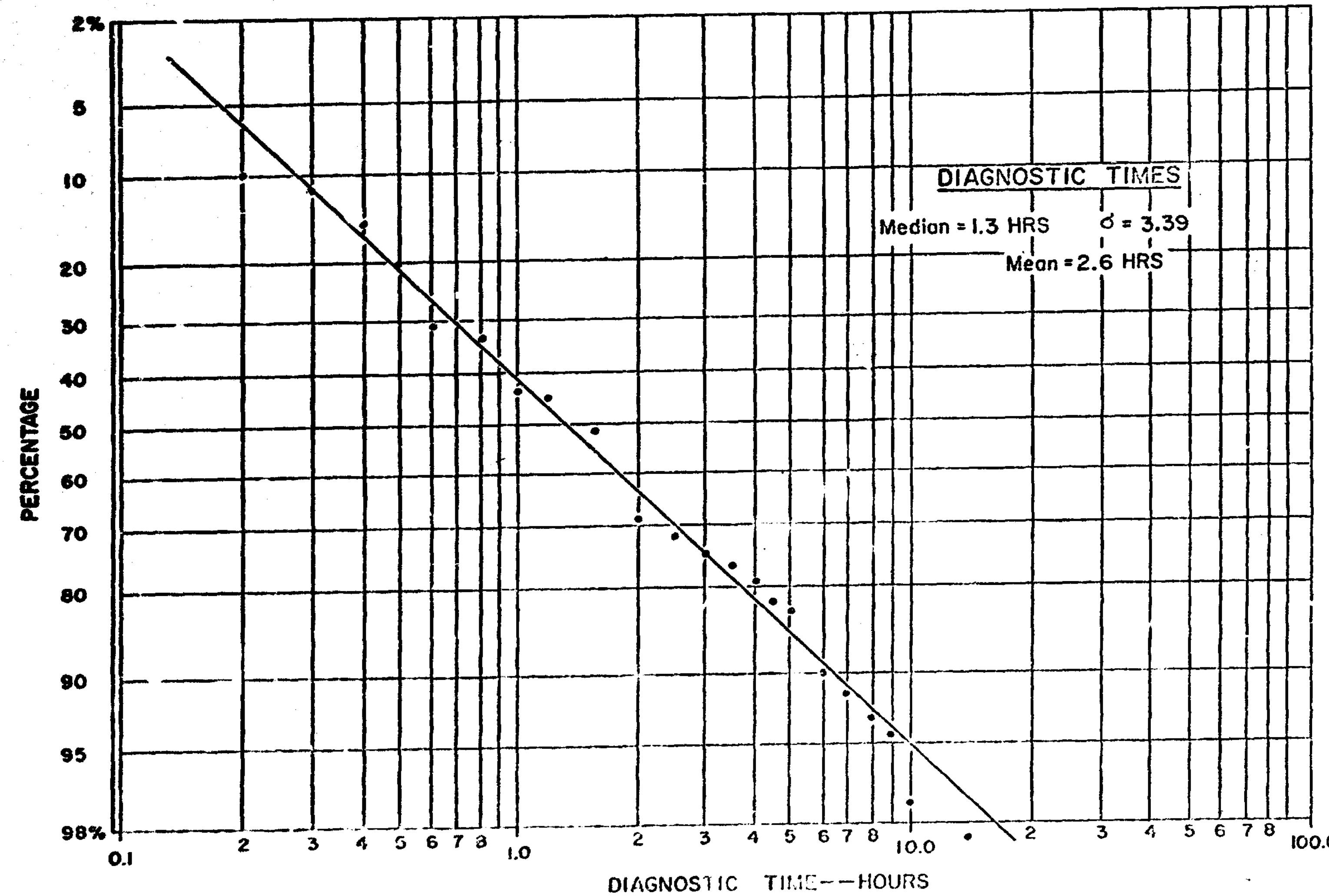

DIAGNOSTIC TIMES
Median = 1.3 HRS
σ = 3.39
Mean = 2.6 HRS
PERCENTAGE
2%
5
10
20
30
40
50
60
70
80
90
95
98%
0.1
2
3
4
5
6
7
8
1.0
10.0
100.0
DIAGNOSTIC TIME--HOURS

Figure 2

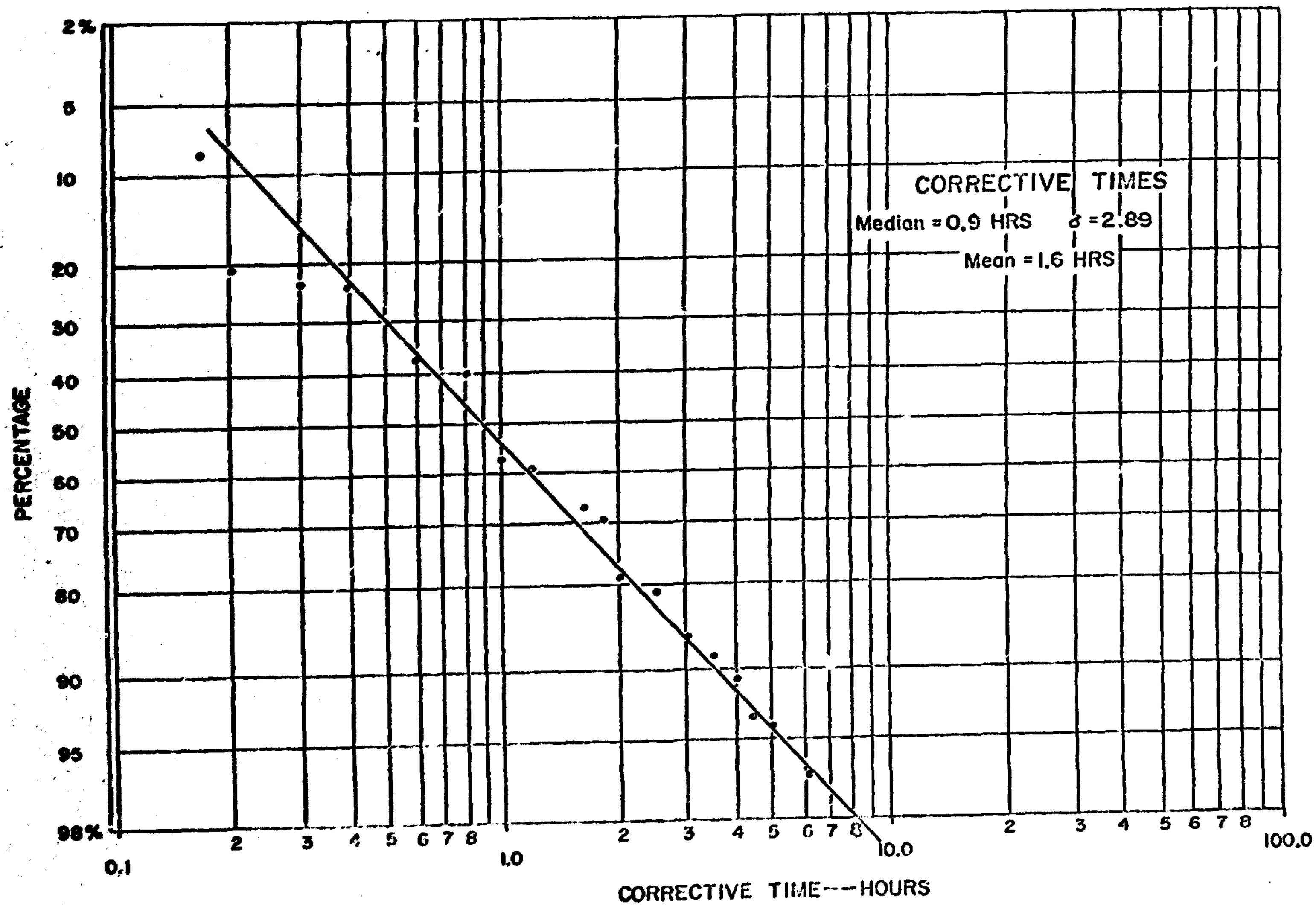
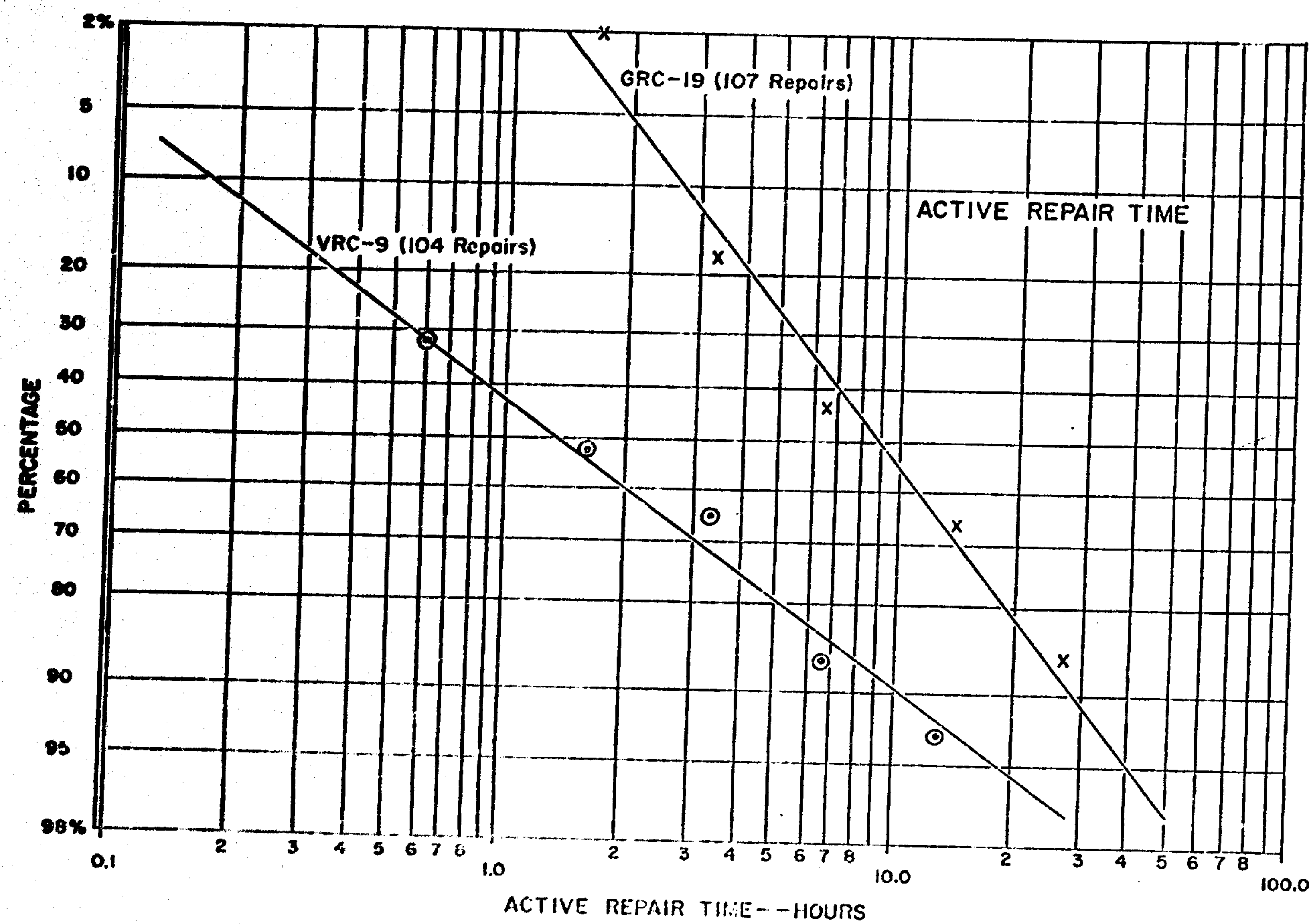

CORRECTIVE TIMES
Median = 0.9 HRS
σ = 2.89
Mean = 1.6 HRS
PERCENTAGE
2%
5
10
20
30
40
50
60
70
80
90
95
98%
0.1
2
3
4
5
6
7
8
1.0
2
3
4
5
6
7
8
10.0
2
3
4
5
6
7
8
100.0
CORRECTIVE TIME---HOURS

Figure 3



ACTIVE REPAIR TIME
GRC-19 (107 Repairs)
VRC-9 (104 Repairs)
PERCENTAGE
2%
5
10
20
30
40
50
60
70
80
90
95
98%
0.1
2
3
4
5
6
7
8
1.0
2
3
4
5
6
7
8
10.0
2
3
4
5
6
7
8
100.0
ACTIVE REPAIR TIME--HOURS

Figure 4

HUMAN ENGINEERING RELATIONSHIPS TO MAINTAINABILITY MEASUREMENT

AUTHOR: P. Lawrence Sova, Jr.

U. S. Army Human Engineering Laboratories
Aberdeen Proving Ground, Maryland

HUMAN ENGINEERING RELATIONSHIPS TO MAINTAINABILITY MEASUREMENT

B. Lawrence Sova, Jr.

(Presented at the Army Technical Meeting on Quantification of Maintainability During Research and Development of Materiel, 19 July 1965, sponsored by the Chief of Research & Development, Department of the Army).

I am sure that most of you are somewhat familiar with what Human Factors Engineering is and what it does, but just for the record I would like to present the definition contained in AR 320-5. Human Factors Engineering is, "The application of scientific principles concerning human physical and psychological characteristics to the design of equipment, so as to increase speed and precision of operations, provide maximum maintenance efficiency, reduce fatigue, and simplify operations."

As can be seen from this definition, the Human Factors Engineer studies the relationships between humans and machines.

Many handbooks have been written on the subject of human factor aspects of Maintainability (M), and there is no need to dwell on the details of these points. It is presumed that if the suggestions in these handbooks are followed, the equipment will be properly human engineered for M.

There are several problems with the handbook approach. This morning we have had several definitions of M and have been talking about costs and specifications. I would like to enter another major problem into the discussion, "How do we give the individual designer the tools to design the most effective system." It is here after all that the effectiveness of an M program or reliability program lies. The first problem with the handbook approach is that the designer may not apply the suggestions in the handbooks because of cost and scheduling problems. He must design a low-cost item that meets all sorts of physical specifications and he must do it in X weeks. With these pressures he may not have the time or the inclination to study the suggestions made in a handbook. His problem is far more immediate; his boss told him to have the design ready in two weeks.

A second problem is that even if he does study the handbook, it usually presents several alternatives for a design since it was written for a wide range of equipment, and in different equipment different courses of action are best. However, the designer has no way of deciding which of these alternatives are best for him unless he carries each of the alternatives to its ultimate conclusion; all of which takes more time, more time than he wants to give, more time than he has.

One approach to quantifying the human factors in an *M* program is presented in Mil M-55214. This specification takes many of the Human Engineering handbook-type statements and applies a weighting to them. In this respect it eliminates some of the objections of handbooks in that it is quantitative and less vague. However it still incorporates a considerable number of subjective statements, hence is not a direct measure of the adequacy of a design.

This specification is probably the best tool to date that we in Human Engineering have to evaluate a design for *M*, but I disagree with the implication that we now have a measure of *M* by simply assuming the presence or absence of a design consideration. Many changes can be made in a design without affecting the thing we are really interested in. Therefore it seems that in order to quantify *M* we should have some direct measure of the effects rather than try to evaluate the causes subjectively. In Mil M-55214 we have a better tool to evaluate causes, however the specification should be employed as such.

In conclusion, our problem is to define the relationship between *M* and Human Engineering design considerations. An additional problem is to find techniques more effective than handbooks which will insure that the individual designer can make the proper choice of alternatives.

USING MAINTENANCE FLOAT TO MEASURE THE MONEY VALUE OT MAINTAINABILITY

AUTHOR: Boris Levine

Office, Chief of Engineers

USING MAINTENANCE FLOAT TO MEASURE THE MONEY VALUE OF MAINTAINABILITY

One of the problems associated with improving maintainability is demonstrating its value in money terms. This is important, because some basis must be found to justify spending time and money for the purpose and the simplest, although not the best, measure is its money value. This brief paper describes a quick and reasonably accurate method of doing this by its effect on a high-cost element of support, the maintenance float. The effect is sufficiently pronounced that it can be used as a decision guide.

Maintenance float is a pool of equipment held at a maintenance facility as replacement for items which fail. The replacement is placed in operation and the unserviceable item is repaired and returned to the pool. It is this feature of replacement and concurrent repair that is unique to the float system. The amount of float required is related to the supported population by a float factor. In army operations, the float factor ranges from 3% to 30%, averaging about 15%.

One way of measuring maintainability is in terms of repair time or, more formally, Mean Time To Repair (MTTR). It has been shown, for equipment which has an exponential failure distribution, that the maintenance float factor is a function of population and g, the ratio of MTTR to MTBF. That is

Total Float $F = Q_o f$ (Eq 1)

Float Factor $f = 1 - (e^{-g})\left(\frac{Q_o - 1}{Q_o}\right)$ (Eq 2)

The float factors are plotted in Fig 1 and, for practical values of g, in Fig 2. (Ref. 1)

Using this relation, it is possible to calculate the cost of maintenance float for present and projected values of repair time and to show the savings directly. Using the expression in reverse, it is possible to calculate a maintainability goal which will achieve a given reduction in the cost of the float.

As an example, take a radio for which data are available from a Research Analysis Corporation study (Ref. 2). Consider the following summary:

a. Cost: $4000 each

	Present	Assumed Improvement
MTTR	2 days	1 day
MTBF	16 days	16 days
Float factor from Fig 2)	12%	7%

Prepared by Boris Levine, Electrical Engineer, Military Engineering Division; Office, Chief of Engineers, U.S. Army

b. Float Cost for 1000 units

Original design	\$4000 (1000x.12) =	\$480,000
Assumed improvement	\$4000 (1000x.07) =	280,000
Gross savings		200,000
Less: assumed engineering costs		- 100,000
Net savings due to improved maintainability		\$100,000

That is, if the repair time can be cut in half, the reduction in float will pay for \$100,000 worth of engineering and still leave \$100,000 net savings.

Thus, application of this approach to demonstrating the value of maintainability is quite direct. The two basic parameters, MTTR and MTBF, can be obtained from TAERS data for existing equipment or estimated for new developments. They can then be used to estimate the value of changes accomplished or the money available to expend on improving maintainability. Or, conversely, the amount of money available for float can be used to estimate a maintainability goal.

Data with which to check the validity of the float factor expression are hard to come by. However, float factors computed in the same RAC study are about 1.3 times the factor derived from Eq. 2. Thus, the savings previously estimated are, if anything, on the conservative side.

For simplicity in the example the maintainability was improved without effecting reliability. In practice the two would probably be mutually affected. However a discussion of this inter-relationship and the resulting trade-offs is beyond the scope of this brief presentation.

References:

1. "Estimating Maintenance Float Factors on the Basis of Reliability Theory" Boris Levine, Industrial Quality Control Feb 1965.

2. "Allocation of Maintenance and Support Resources for Tactical Communications Equipment." John H. Moss, Carl F. Blozan, Robert W. Bluehdorn, Margaret H. Tupper Research Analysis Corporation Technical Memorandum RAC-T-413, August 1963.

13 July 1965

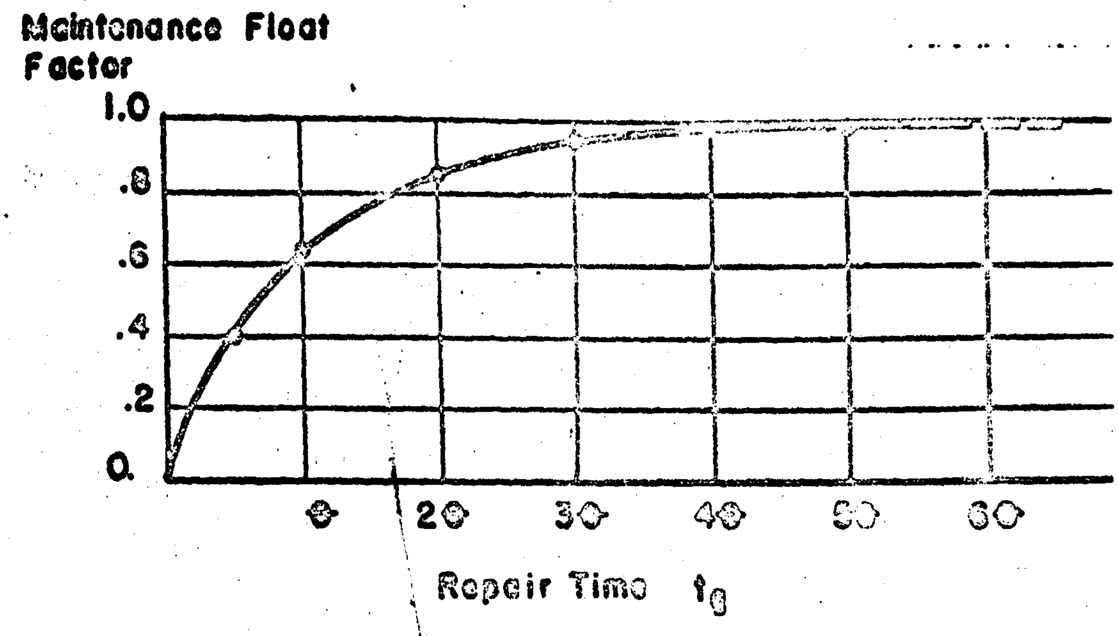


Figure I - Maintenance Float for Extreme Repair Times

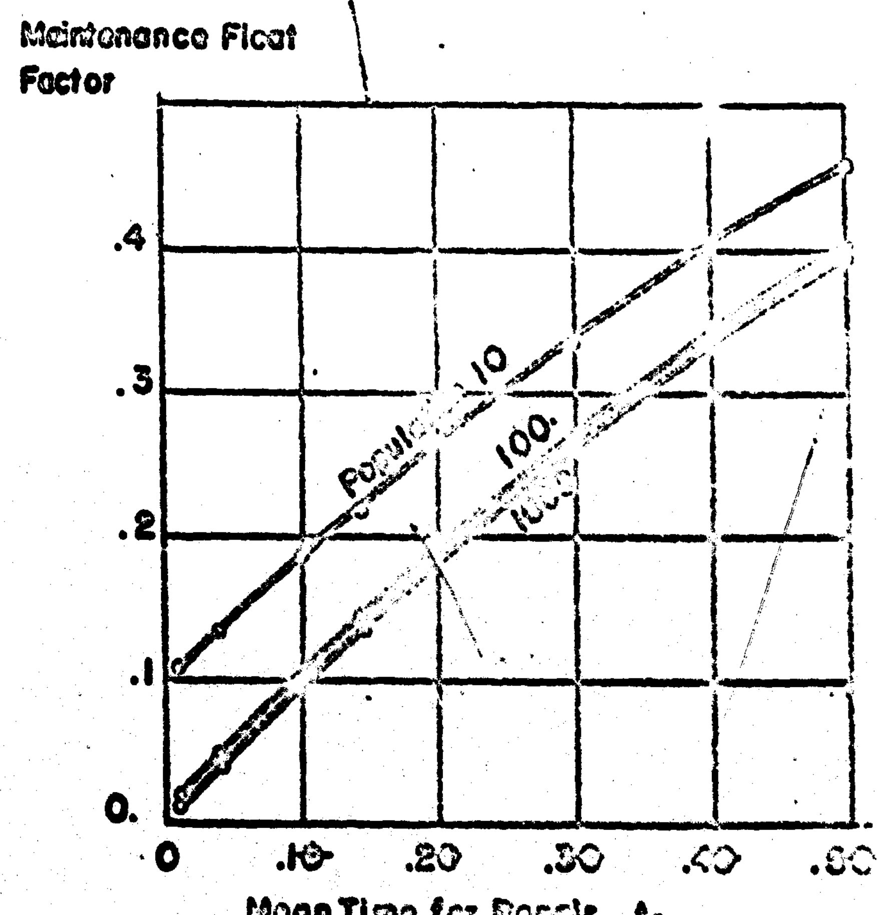


Figure 2 - Maintenance Float Factors

TITLE: SCIENTIFIC AND TECHNICAL APPLICATIONS FORECAST ON RESEARCH ON MATERIEL FAILURES

AUTHOR: Sumner Meiselman

Research Plans Office
Office Chief of R&D
Department of the Army

Army Research Office Sponsors Research on State-of-the-Art on Reliability

by Sumner Meiselman

The Scientific and Technological Applications Forecast (STAF), entitled "Research on Materiel Failures" a reliability research effort is sponsored by the Research Plans Office of the OCRD, D/A. This project was initiated very early in 1964 which resulted in the award of a contract to the University of Michigan in October of that year.

This STAF will consist of a published compendium on major areas of prime interest to military research and development organizations, industry, universities, and other organizations concerned with military materiel requirements. Many such organizations will be contacted for STAF source information, and their support is being solicited.

The major areas covered in the reliability STAF are: 1. State-of-the-Art, 2. a Forecast of the State-of-the-Art over the next 20 years, 3. a research plan suggesting how identified gaps in the State-of-the-Art may be filled, 4. a matrix section reflecting the scientific and engineering interdisciplinary relationships and reactions of some 17 life cycle program milestones (of prime interest to managers and engineers) and five major categories of scientific and engineering considerations, 5. an annotated bibliography, 6. a directory of selected organizations and personnel engaged in reliability research activities.

This reliability STAF was initiated after a review and sampling of reliability activities in the research, development, and production areas of industry, government and universities over the past three years. It is well-known that a great deal of reliability oriented research has been accomplished since World War II, especially since the release of the AGREE* and the PSMR-1 (Darnell)** reports. However, early in 1964 there appeared to be an urgent need to collate the results of these research efforts in order to identify those which were being oversupported as well as those which may be lacking support. The mechanical reliability area is being particularly emphasized since reliability activities in the electronic field has received significant attention and financial support from the military establishments over the past few years. The current administrative efforts to reduce costs and to obtain the optimum return on basic and exploratory research dollars not only justified but made mandatory this STAF in order to increase the effectiveness of research planning.

A successful reliability STAF focused towards mechanical engineering required project personnel thoroughly familiar in this field. Hence, the contract was awarded to the University of Michigan and a managerial team was established by the designation of Mr. Sumner Meiselman of the Advanced Technology Branch of the Research Plans Office as the Contracting Officer's Technical Representative, and Dr. Charles Lipson of the Mechanical Engineering Department of the University of Michigan as the Contractor's Project Director.

The reliability STAF work is presently on schedule and the analysis leading to the establishment of the state-of-the-art is being performed. For example, the work accomplished to date has included the review of some 4,000 classified and 10,000 unclassified abstract

* AGREE Report "Reliability of Military Electronic Equipment," dated 4 June 1957 - OASD(R&E).

** PSMR-1 (Darnell Report) "Parts Specification Management for Reliability," Vol I & II, dated May 1960.

reports from the Defense Documentation Center. This included the Center's total input on reports relating to reliability and furnished to the Center by various activities sponsored by the Department of Army, Department of Navy, and the U. S. Air Force. In addition, some 1800 National Aeronautics and Space Administration abstracts and technical reviews prepared by the Research Triangle Institute concerning Reliability oriented papers published in Professional and Trade Journals have been analyzed. An unspecified number of complete papers and texts are being scrutinized as part of the input to the state-of-the-art analysis. However, this effort is not considered or required to be an exhaustive analyzation, but rather a sufficiently comprehensive one to identify and establish the state-of-the-art on reliability.

One of the most difficult aspects of this Scientific and Technological Applications Forecast was the development of the identification and relationships of the vast number of scientific and engineering considerations directly affecting the reliability of materiel. For example, the selection of material is an important factor, but other coequal but less spoken about factors, are environmental conditions, physical or mechanical loading, human factors, and evaluation techniques, all acting in their independent modes but interacting to affect the materiel's reliability. To compound the problem, these impacts and interactions do not have a fixed or constant relationship but vary as the materiel system progresses through its life cycle from concept through development, production and use phases; or, in the jargon of reliability, the specification, prediction, verification and preservation phases. As a result of the managerial team effort, Dr. Lipson's assistants have tentatively identified approximately 200 interacting groups of matrix elements which are further subdivided. These major groupings do not include some 76 environmental factors which have also been identified as causing damage to materiel and which are not generally specified in system development contracts. However, these environmental factors will be discussed in the STAF.

The managerial team expects that certain elements of the Scientific and Technological Forecast will be of great value to industry and government organizations alike such as the selected directory and bibliographical sections. In view of this, the University of Michigan will solicit the assistance and cooperation of many industrial organizations and professional and technical groups for source information. For example, it is well-known that the Society of Automotive Engineers, the Society of Mechanical Engineers, the Aerospace Industries Association, the American Society of Quality Control, the Institute of Environmental Sciences and others have ad hoc and standing committees engaged in reliability efforts. Yet much of this information is not known or readily available to personnel who are actively engaged in work which can or should advantageously utilize the knowledge and/or engage the services of these groups. To this end, one of the motives of the Reliability STAF is to open channels of communications amongst personnel working towards the common goal of known reliability in materiel. For example, the managerial team has contacted depositories of research reports such as those sponsored by the Bureau of Reclamation and the Smithsonian Institution of the Department of the Interior. These organizations have responded with enthusiasm and have already contributed to the Army's reliability STAF.

Another very important section of this STAF will be the identification of basic and applied research needed to fill voids in the total reliability effort. This identification will enable industrial, university and government organizations to channel research support to the needed areas rather than duplicate efforts already accomplished but not known generally. To assist in this effort, current plans call for the primary distribution of the unclassified portion of this reliability STAF to select industrial and educational research institutions who indicate an interest and a desire for the compendium scheduled for publication in September 1965. Inquiries relating to this reliability STAF should be addressed to the Chief of Research and Development, Attn: Research Plans Office, Hq, Department of the Army, Washington, D. C. 20310.

FOREWORD TO VIEWGRAPHS

The Army contractor surveyed industrial, educational and governmental sources for reliability and maintainability research information pertinent to this STAF.

In view of this maintainability meeting, he was asked to pull random samples of replies to his letters of inquiry. Accordingly, the following information was furnished by the contractor and is presented without bias.

Page 2 - Personnel

NAME OF DEPARTMENT	HEAD OF DEPARTMENT	DATE OF ESTABLISHMENT	NUMBER OF PEOPLE IN DEPARTMENT				
			MANAGERIAL	SCIENTISTS	ENGINEERS	TECHNICIANS	OTHER
RELIABILITY		1963	1	0	4	1 *	0
MAINTAINABILITY	"	1965			1 req'd 8-1-65		
(OTHER)							
(OTHER)							

* Only 1 Reliability Tech. per se, but can draw upon entire [illegible] Product Assurance Organization as needed.

Part [illegible]

	NAME OF PROJECT	CONTRACT NUMBER	SPONSORING AGENCY	TYPE OF PROJECT: BASIC RESEARCH	APPLIED RESEARCH	DEVELOPMENT	TESTING	EVALUATION	PRODUCTION
[illegible]CTS COMPLETED [illegible] THE PAST [illegible] YEARS	Discrete Output Equip. Design & Development	NAS8-11780	MSFC, NASA			X			
	Reliability Testing of Compon.	NAS10-1360	KSC, NASA				X	X	
	Zero Leakage Program	NAS8-11166	MSFC, NASA					X	
	Failure Effects Analysis & Criticality Ranking Program	NAS8-5287	MSFC, NASA					X	
	Failure Effects Analysis & Criticality Ranking Program	NAS8-5289	MSFC, NASA					X	
	Reliability Testing of Compon.	NAS8-11166	MSFC, NASA				X	X	
	Parts Reliability Information Center Program	NAS8-11177	MSFC, NASA					X	
	Maintainability Engineering Program for Sat. I.	NAS8-5289	MSFC, NASA					X	
[illegible]	Parts Analysis Summary Prog.	NAS8-11252	MSFC, NASA					X	
[illegible]ENT PROJECTS	Maintainability Engineering Program for Sat IB & V	NAS8-20073	MSFC, NASA					X	
	Parts Reliability Information Center Program	PO-377-82	Spaco					X	
[illegible]	Parts Analysis Summary Prog.	B-34334	IBM					X	
	Discrete Control Equipment Program	NAS8-15479	MSFC, NASA						X
	Reliability Testing of Component Program	NAS10-1360	KSC, NASA				X	X	
	[illegible] Effects Analysis [illegible]	NAS8-20073	MSFC, NASA				X	X	
	[illegible]	[illegible]	[illegible]				X	X	

Page 4 - Expenditures-Present

	PRESENT ANNUAL EXPENDITURES			PRESENT SOURCES OF FINANCIAL SUPPORT (INDICATE PERCENT FOR EACH)					
	LESS THAN $25,000	$25,000 TO $100,000	GREATER THAN $100,000	GOVERNMENT CONTRACTS	PRIVATE CONTRACTS	GRANTS	INTERNAL FUNDS	(OTHER)	(OTHER)
RELIABILITY		✓		53%			47%		
MAINTAINABILITY	✓						100%		
(OTHER)									
(OTHER)									

NOTE:
(If above information is confidential, it will be used solely for statistical purposes)

Page 5 - Expenditures-Future

	FUTURE ANNUAL EXPENDITURES			FUTURE SOURCES OF FINANCIAL SUPPORT (INDICATE PERCENT FOR EACH)					
	LESS THAN $25,000	$25,000 TO $100,000	GREATER THAN $100,000	GOVERNMENT CONTRACTS	PRIVATE CONTRACTS	GRANTS	INTERNAL FUNDS	(OTHER)	(OTHER)
RELIABILITY			✓	70%			30%		
MAINTAINABILITY		✓		80%			20%		
(OTHER)									
(OTHER)									

*NOTE:
(If [illegible] confidential, it will be used solely for statistical purposes)

STAF PERSONNEL INQUIRY

1. What ~~reliability and/or~~ maintainability projects are you presently engaged in?

TITLE	CONTRACT NUMBER	SPONSORING AGENCY	COMPLETION DATE
Maintenance Resources Model	NOw 65-0457-f	U. S. N.	July 1965

2. List a few of your recently completed (or most important) projects.

TITLE	CONTRACT NUMBER	SPONSORING AGENCY	COMPLETION DATE
F-5 Maintenance Requirements	AF 33(657)-9735	USAF	July, 1964
Mai tenance Analysis of Northrop/P.1127 STRIKE Reconnaissance Aircraft.	In-house	USAF	Nov, 1963
F5A/B Operations, Maintenance Concepts	AF33(657)9735	USAF	July, 1963

3. What programs or specific areas of maintainability do you plan to work on in the near future?

Application of Maintenance Resources Model predictive inputs in Program Definition Stage to periodic updating from field maintenance data to develop an "Automated Progressive Closed-Loop Maintainability Program".

DISCUSSION: QUESTIONS, PROBLEMS, CHALLENGES AND RECOMMENDATIONS

Moderator: Mr. Abraham S. Pollack, OCRD

LT COLONEL LEDFORD:

Let us see if we can get some discussion, some recommendations, something constructive and concrete if at all possible, and whether there are fuzzy areas or areas where we cannot get solutions. The rest of the afternoon, other than a short summarization I will attempt to give at the end, we are going to spend in a period for discussion. The presenters that you have heard today will act as a panel for this discussion.

MR. GARDNER:

The objective of the symposium today was to discuss the problems of maintainability in research and development. I think the first step we should take is to define just where we start applying maintainability and reliability factors as defined in AR 705-25 and 705-26 and required by AR 705-5. I don't think in basic research you are going to have maintainability coverage. I don't think in exploratory or advanced development it is proper. I think the proper place to really delve into this is in engineering development, the 6.41 element. Yet we have TDP's required by CRD in the 6.31 element, in which it is very hard to define maintainability and reliability aspects of a proposed weapon system; which we are only getting prototypes to define whether we should go on into an engineering development. I think we should define right now which should be the applicable elements to which these AR's are directed.

LT COLONEL LEDFORD:

Okay, can I just postpone a little bit until I finish here, a few administrative arrangements and then I will address myself to the question. Mr. A. Pollack will act as the moderator, here this afternoon, for this question period. I ask that you state your name so that we can catch it on the two mikes that are in the front of the room and try to tape this discussion period. Now are there any more questions before I turn this over to Mr. Pollack? All right Abe, we'll give it to you.

MR. POLLACK:

Thank you, Gerry. Before we field that question, suppose we start this discussion period by outlining what we are trying to accomplish. I think we are trying to discuss things aimed at identifying the base factors which will give us an ability to predict and measure maintainability and secondly, generate some relatively specific suggestions for tackling the problem. I am happy to note that our speakers have given us a lot of excellent material suitable for generating questions, opinions, suggestions, controversy, challenges, etc. and I would like you to feel free to direct yourself at the speakers or at anybody on the panel or at the panel as a whole. I would like to add a couple of targets for you to shoot at in addition. As a general comment, I think that studies and research in maintainability should concentrate on those problems which can yield large potential pay-offs, in putting in hand the first significant figure of the sort of information needed for systems analysis or cost-effectiveness models, before we jump into efforts to define the second significant figure. Now a couple of problem categories which generally meet this sort of criteria of potentially big payoff. One, I guess, is kind of obvious from the meeting here - establishing analytical techniques which recognize the effects of more of the significant parameters in the practical situations and which are relatively simple to apply. Of course, this is not an easy thing to do. These techniques must account for the fact that what is important in each case is not necessarily the same specific form of downtime or say of maintenance costs or manpower that was used in another situation but rather that form of downtime which serves as a needed input to the next higher level of decision that must be made. Present techniques, I feel, sometimes ignore or insufficiently recognize such things as effectiveness of the human subsystem, supply system effectiveness, preventive maintenance, assessment of individual elemental tasks rather emphasizing, say, the statistical distribution. This would make the usefulness of data more easily transferable from one system to another. Perhaps, a second big problem category would be establishing a data base which is useful to designers. Data is needed on both effectiveness and costs and speakers have mentioned the need for study of data format and things like Operation Woodpile - more of this sort of thing. A third category which I feel meets this criterion is detailed breakdown of the elements of supply and administrative downtimes which constitute the major portion of your actual downtime in practice. A couple of notes before we go on. I would like to recommend the fairly new book by Goldman and Slattery since it is one of the few texts on Maintainability. It is called "Maintainability - a Major Element of System-Effectiveness." Mr. Frishman of the Army Research Office, who had to leave, asked me to inform you that if there are any areas of mathematical or statistical research problems, there is a continuing effort that Army is supporting at several Universities, including the Mathematics Research Center at the University of Wisconsin. He suggested contacting his office if there are any specific suggestions. Now I would like to turn it over for open discussion.

LT COLONEL LEDFORD:

As to the question where do we pick up with reliability and maintainability, specifically? TDP's go back into the Advanced Development 6.31 as you say. Colonel Erickson, in the future TDP, will it again be 6.31 and 6.41, or will there be a cut off?

LT COLONEL ERICKSON:

To answer that question, specifically, yes; however, the draft DOD Instruction which we have only worked on informally makes provision for the fact that there is a requirement for less detail in 6.31 to include reliability/maintainability than there will be as you go on into engineering development. I think this same caveat is in the current regulation. It's just a practical acknowledgment of the fact as you point out that you just can't write these things definitively for 6.31.

COMMANDER SARGENT:

I think one of the problems that is plaguing this whole area is a failure to address reality and it goes both directions. R/M are an implicit part of your design. When you design a system or an equipment - the minute you take this pencil and put it to the vellum you are establishing the maximum reliability and the maximum maintainability that you are going to get in that system. And from there on out, having established this inherent maximum, all the rest of the efforts, including quality control, are avoidance of degradation of this theoretical maximum that you have put in your design and if you don't address reliability and maintainability in the advanced development phase you're not going to be able to backfit it in. This is not the sort of thing that retrofits. It means you are going to have to redesign when you get into the engineering development. Now this is in one direction - in the other direction I think we have got to face reality just as well. It matters little how much inherent reliability or inherent maintainability you've got in your design if you do not follow through with a reliability assurance and maintainability assurance effort all the way through, including delivery and operation, you haven't accomplished a thing. You have only kidded yourself and tried to impress your conferees on your own erudition. The payoff is, and can only be, in the ability to accomplish the mission. This mission must be accomplished with the GI out there in the field, not with some PhD in the laboratory. So I think that we in reliability, maintainability and systems effectiveness have got to look both ways and while it's all nice to say "well, that is not my area of responsibility" and "I couldn't control that," these are nice built-in excuses for the individual but the payoff for the U. S. comes from looking both ways in reliability, maintainability in exploratory development. We will never be successful in either reliability or maintainability until these considerations are a way of life thinking for every design engineer and every production engineer right from the very concept of the idea until the thing is in operation out in the operating forces.

MR. JACKSON:

I want to make a basic comment. The DOD Instruction 3200.6 requires the more formalized program for maintainability and reliability in engineering development and operational systems development categories. Now, the

Instruction also basically says that you have to give adequate consideration for R/M in the earlier categories to the extent that is is appropriate. When you are talking about advanced development or even exploratory development this covers a pretty wide range of area in the types of things that you are dealing with. It is pretty hard to be real specific, as to what is to be included there but the Instruction is very specific with regard to engineering development and operational system development. I think this was intended to be reflected in your regulations.

MR. NUCCI:

May I add to that? In advanced development and exploratory development we're concerned mainly with innovation and feasibility and we do not take the attitude that you should contract/for the hard requirements. Goals are appropriate, but let's be realistic here - we do not want to constrain innovation but we are looking to advanced development for designing building blocks which will later go into engineering development, but on the other hand one of the most important objectives is innovation and feasibility for reliability as for any other performance capability. The goals I think are more appropriate than any hard requirement.

MR. MEISELMAN:

Commander Sargent raised some interesting points. However, I raise the question as to how the design engineer can put in the inherent reliability and maintainability if he doesn't have the necessary tools and cannot understand the language of the individual who has prepared the TDP or the MC's or the basic requirements documents.

COMMANDER SARGENT:

You have two things that have to be done. One I understand to be the purpose of this conference. Until we learn how to measure - he <u>can't</u>, and indeed I have raised the question this morning about how do we handle this annual fiscal appropriation thing. The answer there is measurement. If we can't measure and can't express it in measures we simply just can't come to grips with the problem that we have with annual fiscal appropriations. On the other side is also an unexpressed purpose of this conference, as I understand it. And that is education.

MR. WEINGARTEN:

Yes, isn't it basically true that, like the many other -abilities that have been around; as we who are theoretically leading this onslaught get smarter those who follow behind also get smarter. Some years ago the Human Factors people started in with tremendous innovations and now they are kind of pooh-poohed in their own circles as the "knobs and dials boys." We should not forget them. These "knobs and dials boys" put a school of information at the design level that take away the requirement to go into these great details and to be able to address the more theoretical and perhaps more esoteric underlying things. As we know more about what we're talking about, they in turn also would get smarter. It has to follow.

MR. BYRNE:

I would like to address my question to the nuts and bolts type problem as regards data collection. It appears to me that the output of the maintainability program can only be as good as the input data first of all. My information leads me to believe that the input data in the electronics area is better and more realistic than the input data in the mechanical field. I would like to restrict my question on data to the mechanical field. My basic question is "Where is this data on mechanical items or mechanical components and how do you develop this data if, in fact, it is not available and finally, what are the recommendations." If this question can't be answered because the state-of-the-art of gathering this data is such that the data is not available, and if nobody has worked out how to compile it, is it possible to address future studies in this area to acquiring for design engineers this data, methods of getting data, methods of communication between the various Services for pursuing acquisition of this data. Is this possible?

LT COLONEL LEDFORD:

I will try to field that question. Army-wise, I think that we have to take a hard look at the TAERS system. The TAERS system is costly for us, costly in manpower, costly in dollars. It has, inherent to it, a communication channel and electronic data processing equipment. I think that from the research and development standpoint that we have to take a real hard, cold look at this TAERS data. One of the times to do it is right now during TAERS Evaluation. If the data collection is not what we need, if we need to take small samples (quality versus quantity) without paying the overhead costs for world-wide collection, then maybe that's what we should consider. But I think Army-wide, we are going to have to look to TAERS for the big bulk of the data collection system and to feedback MTBF, MTTR, and the logistics time. Now, today we have a dichotomy of information. Out of TECOM and out of the R&D contracts, we do have a feedback of information failure data similar to some of the data published in the FARADA. It could be published in IDEP and some of the others, but the information is of a small quantity and in talking to some of the people who analyze this, the raw data is many times questionable. Our data is getting better but we may have to look at data in the light of can it be also incorporated into the bigger data banks such as TAERS and can we get readouts here which are beneficial, not only to maintenance and consumption people, but back to the engineer in R&D. We haven't even begun to scratch the surface here, but it appears right now that for a data collection effort we have the basics here, the framework by which we can build. Now is there any question?

MR. RICHARDSON:

The TAERS system is good and it's a historical collection agency. That's what it is. It will do us no good when we are working on a new innovation in a weapons system such as the SHERIDAN/SHILLELAGH. All the components there are new, untried, being tested now by the Test and Evaluation Command. As you point out, however, there are some rather frightening things in this R/M bit. We in TECOM get so few prototypes that almost every failure we come up with, the developer is inclined to say "This is a random failure." All I say is we are having a lot of random successes too, which are rather frightening. We do furnish data to the developer and how he uses it is his business. The only thing I do point out - we cannot come up with the MTBF too well nor the Mean Time To Repair because we have to knock out the logistics implications. All the supplies required are not in the supply system. They are all hand-made. So certain things we have to knock out. Our information has to be used judiciously. There isn't any question about it.

LT COLONEL LEDFORD:

We recognize this I think. TECOM comes closer to having inherent data that you can measure than we get from the field, but we must be able to measure the inherent as well as the logistics down time. I think that the Air Force, in their system, has gone into data collection by which they are tying their contractor into their overall data collection system, have you not, Dick?

MAJOR STANTON:

Yes, sir. Of course you are probably going through - I am guessing because I am not intimately familiar with your TAERS system - the same problem areas and growing pains we had with the 66-1. It was basically a maintenance management data collection system that everybody wanted to be all things to all people. It did not address itself to the R&D environment and as a recourse we have had to supplement some 21 additional data elements that the normal 66-1 data system did not provide. In this respect it is feeding back to us and if it were used single-thread through the evolution of the weapon system in development on through to the operation and we could sell a single-thread data system, then we would have the basis for the types of data that I think you people are really looking for. It would have historical significance and could be used to update prediction models, for example, and that in itself would be a tremendous help data-base-wise for follow-on evolutionary systems, not revolutionary, of course. So I think you are probably going through the same growing pains the Air Force had for a number of years. We don't have the ultimate solution, but I think we have an acceptable temporary one.

MR. BURCHFIELD:

One thing the TAERS system does is to provide a means of determining where product improvement is necessary. I understand that there has been a move to discontinue going out with copy 5 of 2410 reports, which shows the wear-out rate and consumption rate of various parts for components. With sufficient information in this area and proper distribution, we can determine a great deal from this information. I understand they are planning to discontinue this before it even gets started.

LT COLONEL LEDFORD:

The frequency of the report has changed from a weekly to a monthly or quarterly, I forget now. I don't know of any attempt to discontinue the DA Form 2410.

COLONEL KNIGHT:

The 2410 is a record of components, is it not?

MR. BURCHFIELD:

Right. The back of copy 5 lists the items that are replaced on each overhaul of the component.

COLONEL KNIGHT:

I don't know of any move to discontinue using the 2410.

MR. BURCHFIELD:

I know there have been deviations granted to certain organizations which deletes certain information we need.

MR. UHRIG:

I have two questions that I believe are basic and germans to this discussion inasmuch as so much emphasis is placed on it by the speaker. The first one is, that if there is a communication problem, and apparently there is, because everyone says there is, who is going to decide and write the definition of maintainability and when are we going to get it done? This appears to be the very first thing that has to be done before we can even start getting measurements.

MR. JACKSON:

Yes, we definitely have a definition. It is in the MIL-STD-778. There may be some reason for modifying it at the present time. We have this Tri-Service Working Group who is reviewing it and we have had time now since April of 64 to get a reaction to what we have had out. I think that the only modification, unless something comes out of this that might indicate a change and there might well be, the change that is being contemplated is not basically different from the way it is defined right now. The only change contemplated might clarify it a little bit; but the basic elements, unless something comes up that indicates that we do have something real wrong with the definition that we are not aware of, we have a definition and we don't anticipate a change. It is pretty specific.

MR. NORTON:

Is that pretty much in line with what Major Stanton suggested?

MR. JACKSON:

Yes, that's right.

MR. NORTON:

I think what he has there is a real fine definition. I don't see why we don't take it and go with it and quit stewing about it.

MR. JACKSON:

It is basically no different from the present definition except that it clarifies one point.

MR. NORTON:

I don't think anyone objected to the definition he's got except the people in the audience.

MR. MEISELMAN:

I don't think there is a problem of what the official definition is, I think the problem is what will industry buy in terms of interpreting it.

MR. JACKSON:

Industry participated in this definition. Because of the fact, as you have mentioned, that there were some 30-odd definitions, we decided that it was high time that we established a definition. Initially, when we talked about maintainability we wanted to give time for people to have their say. There was time. There were many definitions proposed. In April 64 we established a definition which was coordinated with industry and to my knowledge was accepted by industry and that is the definition that is being used in contracts to the extent that we know about it.

MR. POLLACK:

The definition is not really the problem but we have to be aware that in using this definition on a specific contract or job that we have to communicate properly anything that this definition doesn't cover. No definition can be all-encompassing to everybody.

MR. UHRIG:

There were at least 4 presentations that stated that this particular thing was a real problem and if this is a fact and if these people recognize the problem, perhaps we're missing a good point here in not getting it clarified.

MR. COX:

I think the communications problem is not the definition itself, it is the way individuals use it. Let the individual read the definition and understand what it says and then go out and use the word, I don't think you will have all these communication problems.

COMMANDER SARGENT:

I think this is a manifestation of the semantic problem. The point was made this morning that we have to have two definitions. I thoroughly subscribe to this. I have a definition in layman's terms, if you will, for everyone of the terms that we use in systems-effectiveness. These definitions do not use the term "probability." To begin with, outside of the statistician and the engineer who has been exposed to statistical analysis, there is a misunderstanding of what the term probability means. Now we use this definition for the lay people for this area of effort. Then we have the definition which uses the term probability. It is used within the trade, as it were. The term probability has meaning to anyone who understands statistical analysis.

MEMBER OF AUDIENCE:

Now Commander, how many designers are statisticians?

COMMANDER SARGENT:

Not very many - too few of them. We have to educate. For instance, one of the great critical problems that we have in trying to work with our engineering people is to get them to understand that the probability is completely devoid of any meaning unless you express the associated confidence factor. Probability doesn't mean a thing without this. As a matter of fact, my professor in statistical analysis said "you give me your data and your objectives and I will prove it, and as long as I'm free to establish the confidence factor I can prove anything I want with any set of data." Now this is a difficult area and it takes a degree of expertise in statistics in order to be able to handle it. This is our educational problem with the designers.

MEMBER OF AUDIENCE:

All right, then let's get back to it. We are handing the AR's and all the rest of the publications to the designer. Therefore, the semantics should be clarified so they can understand it; if it is necessary in layman's language.

COMMANDER SARGENT:

We are guilty of very loose use of our own verbiage.

MR. NUCCI:

But here is where the designer can make use of his reliability expert. Put him to work. Use him as your consultant. Let him unravel some of these implications for you if you don't understand. That's why we have full-time reliability people. One of our troubles is/ that this is a new area, the techniques have been derived and developed by a handful of people called reliability people who spend their whole time at it. Now we have to educate designers into accepting these kinds of data and these kinds of techniques like we have done in other areas. How are we teaching integral circuits now to designers? They have integral circuit people who are working closely with the designers.

MEMBER OF AUDIENCE:

I think we are confusing an engineer with a special job to do with the total job to be done. But I have yet to see anyone visit a design activity and all they found were engineers. Surely they must have found people with a lot of other specialties and this design talent should be able to produce the ultimate design product that we're searching for; which would include some amount of maintainability or reliability. But, I assure you, I defy anybody to find that one man who says here's the designer that is going to have this bulk of talent. So when you say design, let us talk at activity level and then look at your organization. If you are hiring the wrong people that's a problem. You have to hire the talent to meet your requirements. If one requires the hiring of a statistician, an engineer, or a technician, this is what must be done. Don't tell me it is an engineer with all your problems. I only contribute a certain amount of information to solving a design problem, but certainly not all of it. We must define this thing.

MR. MEISELMAN:

We have been talking about the design engineer. These chaps are fresh out of college. They are not reliability people, they are not maintainability people. We have got to bridge the gap down to those "design engineers" and we ought to identify who they are and what their background is.

LT COLONEL LEDFORD:

Within the Army there is a program now underfoot by which we will take on an annual basis, some 22 fresh out of college engineers and put them through a year and a half program at AMETA where the first six months will be a formalized reliability/maintainability type curriculum. They will be farmed out for a year to the various commands. I think that there we have a nucleus for these young designers that you talked about that will have some capability to lead them down the road for a specialty in reliability and maintainability. The AF in its Officer Corps, to a degree, has that today. They have had it now since 1961 and they are seeing the products of it. We will do that here if plans go according to AMC and AMETA and they intend to recruit the first class about February of this year. Now, as to the definitions problem, is it fair to say that with the staffing tri-service-wise and ending up again industry indorsed for this maintainability/reliability definition document, that we can expect this problem to have further errors and no hope for a solution? Every command, Army, Navy, and Air Force, has an ample opportunity to interject, and I hope that the working committee at a later date comes up with a definition, if the existing does not fill the bill, that is compatible with the requirement.

MR. JACKSON:

I would only say at this time that we would want to get some real specifics together in terms of making any major change to the current definition, because it has taken a long time to arrive at what we have. One of the problems is trying to get some stability into some of the basic maintainability techniques and language and things like this. This is the reason that we are consolidating some specifications and trying to arrive at some stability here. But we are at a time when in all of these areas we are in a position to take inputs that would come out of this conference, or come out of the coordination that is taking place on all of these documents. These major documents right now are in a coordination stage. I would suggest that we take a real hard look at these because this is one of the few times you have a chance to really do some good.

MEMBER OF AUDIENCE:

I think we should prescribe our requirements under maintainability requirements and forget about the definition - we already have a definition. If we are going out to buy something let's say what we want under maintainability to the contractor.

MR. POLLACK:

May I suggest that we drop the definitions problem and go on to something else?

MR. KICAK:

In the design we try to meet the requirements of the QMR. The format for the QMR is specified in AR 705-5. You don't find the term "maintainability" mentioned whatsoever. You look at it and you see that reliability requirements are picked up under "Performance Characteristics." You don't find "maintainability." You find a section called "maintenance characteristics." So in this case, we, the designers, are never really shooting for satisfying a maintainability requirement as called for in a QMR. The only thing we have is AR 705-26 which specifies that it shall be cranked into a QMR. The format as specified by AR 705-5 doesn't provide for this to be cranked in at all.

MR. POLLACK:

We are aware of this problem and as you know we are kicking it around informally with a view towards doing something about it.

LT COLONEL LEDFORD:

Like many of our specifications, by reference, it references one which references another, etc., etc.; AR 705-5 does carry the reference to the AR 705-26.

MR. KICAK:

Nowhere within the framework of the QMR format can you crank in the maintainability aspects.

MR. POLLACK:

Yes, it is somewhat nebulous, that's true.

MR. NUCCI:

Now to get back to your TAERS program, I tried to go back and find the AF reference, the supplement to the 66-1, which is AFSC 258-5. Now, they have put a lot of work into it. It might save you some work if you got a copy of that in the adjustment of the TAERS form. One caution, even the AFSC 258-5 has got to be used with an operating log, so you count the living with the dead because there is a big difference when you count everything. The reporting system only counts the dead and needs to account for both.

LT COLONEL LEDFORD:

The operating log today is an integral part of our TAERS system.

MR. NUCCI:

If you have equipment that has not failed, there will be no reporting back.

COLONEL KNIGHT:

That is a separate report but it is all a part of the TAERS system.

MR. WILSON:

One of the things that I don't think has come out in the open here (having been a member on the DOD Group working on a requirement for M program) is the fact that we've got two facets of maintainability which get expressed here in the conversations. One has to do with the support and logistics and the other has to do with the design. Now the M basic standard which I allude to - early in the process we considered that which is in the Navy specifications, in the AF specifications, and in Army specifications - the fact that these documents had considerable coverage of the logistics. Now, in the DOD standards draft which has been prepared and dated the 13th of July and sent out to everybody and his brother within the three Departments and industry, this alludes to the design and it reflects the logistics consideration as an interface and a tradeoff. Therefore, much of this which we have heard today is going to have to be covered by different documents, integrated logistic support planning, systems effectiveness or something else, and therefore it would seem to me that we ought to be addressing ourselves to how do we express the quantitative requirements for M as covered in this DOD draft document, unless we don't think this is going to go down the road.

MR. POLLACK:

Is this a statement which someone might like to comment on?

MR. JACKSON:

I think what you are referring to is that in this particular MIL-STD it establishes the basis for requirements for a M program. The M program must be based upon certain mission requirements and certain basic M requirements that are established as a part of some of our earlier discussion that we talked about, either in your QMR's or whatever other type of documents. We expect to see these types of characteristics included in the TDP's because this is required in 3200.6. We are auditing the TDP to see to it that this type of information is being included in it. But now the adequacy of this information and what type of operational malices went into establishing these requirements is a basic problem. I don't know that it is something that is within the scope of this meeting.

MR. WILSON:

As an example, I would read from para. 5.11 draft MIL-STD, Requirements for a Maintainability Program: "Prepare M Program Plan" and down under "i" it says "Plan to accommodate the interfaces between the M program and the following closely related programs or efforts.

(1) Maintenance analysis or evaluation

(a) Maintenance requirements analysis, maintenance task analysis, tools and test equipment, manpower, training, skill requirement determination, maintenance information system, or equipment and facilities determination, reliability program, etc."

The plan will describe the interfaces between these. The thing that we have got to do as far as coming to grips with the quantitative requirements is to develop the quantitative term that will apply to the contractual effort in getting your M requirement out of the contract, not necessarily these interfaces. It will describe what these interfaces are.

MR. WIENGARTEN:

We are back to our statement earlier on design. We are dealing with a system, therefore the systems designer or if you will, the program office, is supposed to be paying attention to, among other things, reliability as an effort, maintainability as an effort, and logistics as an effort. We could go into a long hassle on when logistics should get in here, but disregarding when there is an explicit tradeoff which can be made under the guise of both reliability and maintainability in the logistics world, just stay with it for the moment. I think that rather than merely discussing interfaces, it is implicit that there are honest-to-God, deep and dirty arguments in the room under program management on what you do. Do you now revise and buy Minuteman parts or do you modularize this so that you buy N spare black boxes? These kinds of tradeoffs I think can be made much more explicit rather than merely keynoting some passing words on interface. I would suggest an AF document (SSD) on where maintainability fits into a program plan. One of the things that I think we are doing is a pretty usual thing. We are now worried about reliability and/or maintainability alone. We are against the world until this is a part of a larger system, which is FOB target, if you will. I think we have got to lay ourselves open to the arguments back and forth within the total program context - trading off a CEP vs an hour of life, a logistics black box vs an hour of maintenance time. These kinds of things are explicit tradeoffs, not to the designer, but to the <u>systems</u> designer or the program office. It first requires that the military does its homework so it can look down and know what it wants.

MEMBER OF AUDIENCE:

I am rather surprised in all the discussions this morning no one has come up with the idea that the maintenance engineering, and logistics people should take part in the design reviews, the milestone reviews, that the systems office conducts.

MR. UHRIG:

They are supposed to by Army Regulation. I have only been in this a few months now, but already I am beginning to detect the side effects of all these prescriptions that maintainability must be defined - that people are beginning to listen to the maintenance engineer in the IPR. He used to be far away from the conference table, now he is getting a place up there in front. He is getting a chance to be heard as the design proceeds. The programs now, which are going well at ATAC and other places, are the ones in which the maintenance engineer is getting a chance to talk. When he is ignored because he is subordinate to the design agency, the design gets into trouble. I think that while we are working toward getting maintainability defined we are also going to have people paying attention to the maintenance engineer. Now he has to be qualified to talk to the designer in the language the designer uses.

MR. NUCCI:

By the way, Col Ledford, despite the fact that everybody says it is in the regulation and required, I have had Army officers come to me and tell me that the maintenance people were not wanted at the design reviews.

MR. BONOSEVICH:

This has happened, but you'll normally find that if your top man will go to their top man they will attend. AR 750-6 now calls for a maintenance portion of the service test to be prepared. The test itself is to be conducted by the Test and Evaluation Command to determine whether the maintainability requirements included in the QMR have been met or to what degree, if they are included. If they are not included, then I say that we, ourselves, are to blame.

MR. RICHARDSON:

You force us to establish the criteria if it is not included.

LT COLONEL LEDFORD:

Today, the QMR, good or bad, quantitatively does have expressed a maintainability design characteristic before it goes out of DA Staff as an approved document and prior to AMC setting up a project or task. The quantification can be left to doubt, at times, as to whether or not it is right or wrong, but until we have a reporting system that will give us historical data by which we can predict, then we have to go with what we have now.

MR. BONOSEVICH:

It appears to me that the majority of presentations which we had this morning were presentations which were primarily oriented toward the electronics area and it is true that only two of the commands have electronic equipment. We haven't heard from ATAC, MOCOM, Weapons Command, and MUCOM. I am wondering what maintainability programs they have afoot because we are coming out with military standards that are going to be put on your shoulders to accomplish. This DOD Standard that Mr. Jackson is talking about is going to supersede any bit of paper you have got at the present time. It was mentioned also that there is a problem in determining what reliability figures can be tagged on to mechanical items. To my knowledge there are very few, if any.

MR. MYRON:

There are very few right now. We are just getting our feet wet. We are getting more information. Data is starting to come in from all the test sites. Some of the test stations are kind of lax but it is coming along pretty good now. We have another problem. How many articles are we going to test? If you are going to test as many trucks or combat vehicles as you would electronic equipment, that poses a problem.

LT COLONEL LEDFORD:

I think to try to answer you, Mike, that if we go back to history in reliability that the AGREE came along some ten years ago - 1955-57 - with emphasis into electronics. It recognized the unreliability of electronic components and something had to be done. The mechanical end of it, I think will prove to be much more difficult, more complicated than were the electronics. Today we can express in the electronics field with a fair degree of confidence, reliability and unreliability of many of our components. Now, on the mechanical end, it is difficult to come up with an expression for other than historical trends and historical data. The prediction methods for reliability that we have today are largely based upon historical data. In the mechanical end, until we know whether we can make a matrix which includes all of the variables of tolerances, temperatures, et cetera (if we are ever able to do it with the computers and the technology at hand), I think we have to go based upon historical data, applying it with a K factor for the state-of-the-art in the foreseeable future. The mechanical people no doubt are behind. In maintainability too the mechanical end, I think, will go along at a slower pace than the electronics end.

MR. BONOSEVICH:

My only reason for raising the point is that I feel that the mechanical end is going to suffer once we are going to be required to implement these standards. Somebody will monitor and tell us that maintainability has to be incorporated. Electronically, sure, I think we can handle it, but mechanically, I suspect we are going to be stuck.

MR. MYRON:

One of the problems I find is that a lot of people are confusing "reliability" with "durability" in mechanical equipment. This is one of the big stumbling blocks I have found. Even in the literature that is available on mechanical components some of them seem to confuse "durability" and use it interchangeably with "reliability."

LT COLONEL LEDFORD:

We find that in the QMR's and I think that in this new definition document we have to face up to the fact that we have to know what we are talking about when we talk durability. Maybe that is one other of these terms that we don't find in MIL-STD 721A or MIL-STD 778 today. We have to recognize this so that at least we are on the same footing.

MR. MYRON:

Right now all our plans that I have seen all specify durability and they interchangeably use it as reliability.

MR. NORTON:

I can't see the difference between durability and reliability. To me these terms are synonomous. I can't say anything about one that I can't say is true about the other. I have queried dozens of people on it and no matter how they define durability I can also twist it around and get reliability out of it. The only difference I see is some emotional difference in this thing. Durability is the law that permits you to maltreat something, to mistreat it, whereas reliability is treating it the way it is supposed to be treated. Let me speak to Mr. Nucci here about the mechanical part of it. I am wearing two hats today. I am representing the Maintenance Board and also AVCOM. On the mechanical part and in the airplane part of this thing for the past 3½ years I have consistently tried to use MIL-M-26512 and MIL-R-27542, two MIL-STD's for reliability and maintainability. Let me tell you, this brings up another little thing which could be a crusade, maybe for somebody. That is the fact that these things have got the simple little letters USAF after them which stands for "not too well accepted." The Army won't accept these things because they don't understand them. They are good documents. I have tried over and over, but I cannot get the Army to accept anything that has a Navy or Air Force symbol on it. The real fine Navy document "Engineering Reliability" and the one that came out of the Electronic Systems Division, the book on reliability and maintainability monitors - both of these are excellent documents. It seems to me that the Army should take these things, adopt them, put an Army label on them and start using them before this week is over. I just got another one which I talked to you on the phone about and that is the ESD document on Maintainability Validation. This is a real fine paper - it almost reads like a novel.

MR. NUCCI:

We are fixing part of that now. MIL-STD-785 will supersede MIL-R-27542.

MR. NORTON:

One other problem is how to fix airplanes, how to be a mechanic, how to work on a helicopter or an engine. I keep getting these crazy documents over my desk and Lord knows there is no greater advance in the state-of-the-art than how to work on an airplane but the Army keeps wanting to redo these documents. The ones they are redoing are only 5 or 6 years old. Not only that, the Air Force published real good ones years and years ago and so did the Navy and you can buy them on the bookshelf. Why do we have to redo these things and support a little empire that keeps redoing these documents that we already know how to do?

MR. BURCHFIELD:

You should have stuck to the Aviation Board. I'm from AVCOM too. We are using MIL-R-27542. We are also using the maintenance documents by the Air Force, especially on some of our new development systems.

MR. SIBTHORP:

I object to his comment that the Army doesn't use the AF or Navy specs. The MICOM spec on M is almost a verbatim copy of AF spec.

MR. NORTON:

Why don't we just use the Air Force one without changes?

MR. COX:

I will tell you why. On page 2, I think, is a list about 6 inches long of Air Force references that we couldn't get our hands on. Our standardization people said we couldn't reference it unless we had all of these documents so all we did was to take off in an Army direction, knocking out Air Force references, knocking out some of what we considered unnecessary.

MR. NORTON:

Couldn't we have just called the Air Force and asked to get together on this?

MR. COX:

Had we waited until MIL-M-26512C came out, we could have used it as it is because the list of references is much smaller and we can get ahold of those now. We wanted to go through an exercise of deleting MIL-R-45765 in favor of MIL-M-26512C, but the new MIL-STD-785 coming up, it was no longer necessary.

SUMMARIZATION

Lt Colonel Ledford, OCRD

LT COLONEL LEDFORD:

Our time is running out here. I think that from the discussions that we have had here we see that we are a long ways from solving all the Army, the Navy, or the Air Force problems in maintainability. We have hardly scratched the surface but at least in our own minds I think that the definition of the problem should have been clarified to a degree. The presentations that we have had - one of the big things to me has been that the problem of definition of maintainability evidently is in the minds of many of the people. The difference between maintainability and maintenance still is in the realm of conjecture. I think that the solution is within your own commands in the staffing of these documents - give it a real try. If our definitions now aren't sufficient let's come to accord on these definitions, let's get them where we can use them, where we can speak the same language. The conference that we have had today has been an endeavor to bring our R&D people, materiel readiness, and maintenance people together to mutually discuss some of the problems that we know are inherent to our business. To drop the conference now is part of today's business, but to continue in the future with the question of maintainability - what do we do about it - what can we do about it - can we really quantify it - can we measure it - still has not been answered by this conference. I think that within the individual commands of you representatives here you have a big job to do individually and collectively. We recognize here that the Army, Navy and Air Force have a big problem talking the same language - to be able to quantify maintainability, measure it, test it, and collect data, and meaningfully to express what we have done. I would welcome any suggestions from you members of the commands here from the floor as to any continuance, whether or not this has been a worthwhile conference on your part, whether or not you think that in the future like conferences are apropos. I am open to any suggestions from the floor.

MR. NORTON:

We have been somewhat successful but rather frustratingly not as successful as we think we should be. I think this is an excellent start at something that might speed up this program very fast. I would like to see and I would certainly recommend that maybe a small working group of somebody from your office and from the Maintenance Board or AMC or AVCOM or CDC get together and see if we can't plan for a continuation of this sort of thing because we really have just skimmed the surface of these problems. We all have ways of getting them solved and I think we should certainly earn our money and make this thing pay off as a continuing thing.

MR. KICAK:

I agree with Jack that this should be a small group. Initially, though I think it should be from HQ, AMC and perhaps SMC, select personnel to more or less establish a position. After we establish a position then we can go and bring in review elements.

MR. NORTON:

I think we need CDC on this too.

MR. KICAK:

Yes, I forgot.

LT COLONEL DIAMANTES:

I certainly agree that we should have more meetings like this one. I think that a conference during the next quarter might be worthwhile. I am certain that CDC would be very anxious to participate. We are anxious to crank into all our QMR's, SDR's all the necessary data. We recognize all these problems and have been looking at it for several years now. We are very anxious to participate in these types of meetings.

MR. NUCCI:

I would like to make a suggestion. I don't know whether you can do it within the next quarter but in the future I think it would be well if we could get some case histories. I know Jack Norton would be real happy to talk about the LOH because I, personally, think he did a beautiful job on it and it is really buttoned down. And I think the AAFSS was very well done. There is some real good work and if you could show other people this real good work and how they did it I think a lot of this hullaballoo about definitions will fall by the wayside because with all the shortcomings of the technology, the technology is being used and used effectively in many quarters, maybe not as accurately as we would like to see, but to a real advantage to the Army.

MR. NORTON:

I would like to remind the colonel that this quarter just started and there is almost a whole quarter before the next one starts. I would like to do this before the next quarter.

LT COLONEL LEDFORD:

I would like to just throw out a thought on this timing and phasing. We have, by example, shown you the way. I would like for the commands represented here, with their major headquarters, to examine and determine if they would like to host. My office, General Marlin's office, and OCRD itself would be only too happy to work with and assist any host. We would like to see it perpetuated and hosted by other agencies represented here.

MR. NORTON:

Would it be appropriate if I got the Maintenance Board to do this?

MR. KICAK:

One thing I wanted to bring in. I still think we should have our small groups together to work some of these points out before we start going out all over the country.

COLONEL KNIGHT:

I am more inclined to agree with Mr. Kicak - that we ought to get DA, AMC, CDC, SMC together to lay out the ground rules, establish the parameters we are going to work in and then bring in the additional people. But the fewer people you have talking the more you are going to get done.

MR. SANDS:

In September, I think it is the 9th of September, we have the General Breakefield Seminar to be held at ATAC. I would suggest that Colonel Ledford be on the agenda to make a summary at that seminar of what this meeting discussed, the comments on maintainability, and then carry on and add to it any developments that may occur between now and the day of the seminar.

LT COLONEL LEDFORD:

That can be arranged if the invitation is forthcoming.

MR. WEINGARTEN:

May I make the suggestion that that first small work group take a look at that blackboard[1] and at least approach that first column. Ideally, I think we should hit both columns but that board looks strangely blank.

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1 Blackboard showed two columns at this time. First column was headed "Problems" and second column was headed "Recommendations." Columns were blank other than the headings.

Maybe a first-cut delineation of those problems which are most apparent would be worthwhile if only as a point of departure to discuss what other points should be looked at, let alone solved. I think that kind of thing - a list of problems immediately apparent for written report or whatever form you would like to see it would be worth at least the time involved in compiling it, sending it out, and looking at the returns.

LT COLONEL LEDFORD:

In our letter that went out originally, we tried to anticipate some of the problems facing us to give you food for thought in coming in here and I heartily endorse that these problems be put out. I know that a working group of this size in the consideration of these problems cannot accomplish too much. A small panel probably is the best way to do it. The small panel will address themselves to specific problems and come forth with recommendations. That type of a meeting is, of necessity, longer than one day. To kick off such maintainability here, one day is all that I could foresee that would be constructive. In future meetings of this type, the panel and the picking of panels should be a consideration by anyone who hosts these meetings. Is there any comment on that?

MR. NUCCI:

If you could make known the names of these panel members, the people in the commands could be urged to send any specific problems to the focal points so they could bring them to the small panel meetings. This might help a lot.

LT COLONEL LEDFORD:

I think probably that this is along the line that John Kicak had in mind when he said "We want to get our ducks in a row and line ourselves up."

MR. JACKSON:

One of the things that we discovered in going through these various specifications to consolidate them into MIL-STD's was that there were some real problems that we had to deal with and we had to consider; what do you put in this document, and what is it that we need that we don't have now that we can't put in the document. I think that these documents that are circulating around and the other one that will be available you might want to look at it from that standpoint. What we have tried to do is put a basis for the use of technology as it is today. Let me illustrate: In the Demonstration MIL-STD we have, I think it is six test methods. We are not sure all these are going to stay in the Standard. We are going to see what happens as a result of the comments, but these were the best test methods that we found available today. At least this was the judgment of the group that worked on it. It may have some shortcomings. There are some who feel there are some shortcomings, but be that as it may, this is the best that we have today that we are knowledgeable of. Now, looking this over, we don't want to say "this is no good." We use what we have and what's best for now, but looking at this might give some of you a basis for saying "Here's where we need to go from here in improving our test methods for demonstration" or maybe I should use "verification." By the same token, in looking over prediction techniques we have a lot of criticism about prediction techniques but we say these are the best prediction techniques we have now. Let's use what we have now and try to determine which of these are the most useable, but where do we go from here. These types of things, I think you can deal with as you go through this coordination process. Be thinking about where you can go from here and give us constructive comments on what we've got and then be thinking of the future.

LT COLONEL LEDFORD:

General Marlin, have you anything to say before we break up?

GENERAL MARLIN:

Yes, I would like to just take a couple minutes of your time, gentlemen. When Gerry and Abe came up with the idea of this conference here today, I think they anticipated a lot of resistance on my part and that of General Dick. They arranged for some time to come in to convince me about the need for a meeting such as this. I looked at their outline paper and they said "When can we come in?"; I said "What do you want to come in for?" I agree with you 100% that we need to do something in this area. The question in my mind is how much initiative should we display in OCRD and who picks up the ball? Now I would suggest that we have aired a lot of views and it has been fruitful. I never expected to see problems clearly defined and recommendations made concerning their solution as a result of one day's discussion. I think that we are looking for someone now to pick up the ball, to enlist the cooperation of CDC, to ask us for any possible input we can make so that we can be helpful at any particular time. But we are looking for AMC to pick up the ball. Is that a fair statement? Now if we're wrong about this and you would like us to keep the initiative up, I wish you would let us know. As a result of this meeting here in which a lot of fruitful thinking has been done, we are really in the back of our minds, looking at AMC. If you don't think that is right; if you think we should maintain the impetus and keep the ball rolling, set up the conferences, the agendas, and so on; we'll do it. But I was a little reluctant to get too deep into this without knowing just how AMC felt about it.

MR. NORTON:

May I just ask one question, please? Who is responsible for seeing that AR 705-25 and AR 705-26 are adhered to. That's the agency that should do it, it would seem to me.

MR. KICAK:

I would like to say, Jack, in your case AR 705-25 and AR 705-26, logically speaking, it should be R&D. But such is not the case. In other words, those particular regs go outside of areas other than R&D. We can't pick up the ball for total AMC. This has been one of our problems.

LT COLONEL LEDFORD:

For policies set forth in AR 705-25 and AR 705-26, OCRD has the responsibility. The implementation, of course, goes down into AMC, CDC, OCE and Army Security Agency. Now, on this implementation, the intricacies of how it is implemented rests within those agencies. Generally speaking, AMC has the bulk of this and because there is some split maybe all of it doesn't rest within R&D at AMC, but part of it may be in Materiel Readiness, or it may be in Quality Assurance. Still within AMC is the bulk of maintainability and reliability that is done Army-wide. They also take that responsibility on to a degree for ASA and for Chief of Engineers projects.

MR. NORTON:

Is there any particular agency in AMC that follows these regulations diligently?

LT COLONEL LEDFORD:

That question has to be addressed to the AMC people. I can't answer it.

MEMBER OF AUDIENCE:

How much of this is delegated to the Commodity Commands?

MR. NORTON:

Whoa, stop passing the buck that way.

MR. KICAK:

I, personally, was looking toward OCRD more or less to keep this rolling until we, in turn, can pick up our own responsibility.

GENERAL MARLIN:

You would like us to continue the momentum in some fashion?

MR. KICAK:

Since CDC gets into the picture, OCE, ASA, etc., etc., yes.

GENERAL MARLIN:

Okay, well I got out of it what I wanted. Frankly, in the back of my mind, I felt we were not going to come up with specific quantification problems; we were not going to come up with recommendations to solve these problems; we were going to get just what we've got - a group of rather diverse vi... on the whole thing which is probably why we haven't moved out a little faster.

LT COLONEL LEDFORD:

Gentlemen, there are handouts available for those who haven't picked them up on the table. We appreciate your attendance, the attention you have given the presentations. I thank each and every one of you here on behalf of General Dick and General Marlin.

MEMBER OF AUDIENCE:

This is the first time I ever heard of the Maintenance Board. Is this an AMC activity? Is there any R&D representation on this board?

MR. NORTON:

I represent R&D on the Board along with the other three gentlemen alluded to in the field of reliability and maintainability.

LT COLONEL LEDFORD:

The Army Maintenance Board is a subordinate command of Supply and Maintenance Command of AMC located at Fort Knox, under the President of the Army Maintenance Board.

Gentlemen, with that we will close the conference. Thank you.

MAINTAINABILITY DESIGN
AND
MAINTAINABILITY-RELIABILITY-MAINTENANCE
INTERRELATIONS

A DISCUSSION PAPER

by

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MAINTAINABILITY DESIGN
AND
MAINTAINABILITY-RELIABILITY-MAINTENANCE
INTERRELATIONS

I. Introduction

The original title of the discussion paper assigned to me was to have been "Maintainability Design; Maintenance-Reliability Interrelations." I have modified this title to "Maintainability Design and Maintainability-Reliability-Maintenance Interrelations" feeling that this broader coverage would better respond to the objectives of Panel No. 5 and the discussion areas outlined in the Memo to All Members of Panel No. 5, dated 10 March 1965.

If the objectives of Panel No. 5 include the development of criteria for evaluating maintenance requirements and the determination of management techniques for optimizing maintenance capabilities it would seem appropriate that there be discussion not only of:

a. Maintenance-Reliability interrelations but also, -

b. Reliability-Maintainability interrelations, and

c. Maintainability-Maintenance interrelations.

Of the discussion areas outlined in the aforementioned memorandum this paper will attempt to address some remarks to the following:

a. Determination of maintenance demands for a new weapon system (in advance of its detailed design).

b. Design for <u>optimum</u> maintainability

c. Determination of support requirements

d. Assessment of impact of maintenance needs for new systems on existing workloads.

e. Determination of management information needs for effective maintenance management.

f. And, finally, design of systems to fill these needs most effectively.

II. Abstract

Accordingly this paper will treat of the following:

a. Definitions of Maintainability, Reliability and Maintenance.

b. DoD Policies for Reliability and Maintainability (as applicable to Engineering Development and Operational Systems Development projects).[1]

c. Maintainability Design (including development management and design techniques).

d. Reliability-Maintainability interrelations.

e. Maintainability-Maintenance interrelations.

f. Maintenance-Reliability interrelations.

g. Human Factors interface with Maintenance/Reliability/Maintainability.

h. Maintainability Research.

i. Conclusions and Recommendations

III. Definitions of Maintainability, Reliability and Maintenance

It seems appropriate that we should first define these three terms to establish a clear understanding and a true base for discussion. Though I find it difficult to believe, very often we find the terms Maintainability and Maintenance used synonymously; and sometimes all three terms are used synonymously. Therefore, the definitions are as follows:

A. Maintainability [2]

Maintainability is a characteristic of design and installation which is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources.

Reference 1 - DODI 3200.6
Engineering development includes those development programs that are being engineered for Service use but have not yet been approved for procurement or operation. Operational systems development includes research and development effort directed toward development engineering and test of systems, support programs, and vehicles and weapons that have been approved for production and Service employment.

Reference 2 MIL-STD-778 "Maintainability Terms and Definitions"

Maintainability is a system performance characteristic relating to the probability of restoring or maintaining a system in a condition of satisfactory performance, within a specified period of time.

Often we will find measures of maintainability specified in terms of "Mean-Time-To-Repair" (MTTR). The measure "Maintenance Man Hours Per Operating (or Flight) Hour" is sometimes used as a Maintainability Index but it relates more closely to the maintenance load factor rather than the maintainability characteristic of the system, which depicts the relative ease and speed of accomplishing maintenance actions.

B. Reliability [3]

Reliability is the probability that a system, subsystem, component or part will:

a. Perform its intended function,

b. for a specified period of time,

c. under stated conditions.

Again we have a system or equipment performance characteristic related to the critical time period over which satisfactory performance (within the specified tolerances) is sustained.

Reliability is often expressed as "Probability of Mission Success" and at times in terms of "Mean Time Between Failures" (MTBF). The MTBF can be quickly converted to a "Probability" related to a critical time period (mission time duration). And though it may appear obvious, "Probability" alone does not express reliability.

C. Maintenance [2]

All actions necessary for retaining an item in, or restoring it to a serviceable condition. Maintenance includes servicing, repair, modification, modernization, inspection, and condition determination.

In summary, Reliability is the system performance characteristic related to the period of satisfactory operation (UP-Time); while Maintainability is the system or equipment characteristic relating to the system or equipment outage (Down-Time). These characteristics Reliability and Maintainability must be designed into the hardware. Maintenance, the effort and actions required to restore or retain equipment operating within specified tolerances, is a function of

Reference 2 MIL-STD-778 "Maintainability Terms and Definitions"

Reference 3 MIL-STD-721 "Definitions for Reliability Engineering"

Reliability relative to the frequency of maintenance and a function of Maintainability relative to the time and effort required to restore or preserve the Reliability designed into the hardware.

IV. Reliability and Maintainability Policies

The reliability and maintainability policies, as applied to Engineering Development and Operational Systems Development[1] Programs, are in direct support of the prime objective - the acquisition of adequate weapon systems in proper time scale and at reasonable cost. Also, they support a basic DoD development management policy that program approval will be based increasingly on evaluation of the cost/effectiveness of the system for its total planned operational life.

These Reliability and Maintainability policies are as follows:

1. Reliability and Maintainability goals, stated in quantitative, mission-responsive terms, must be established for all development programs.

2. These Reliability and Maintainability goals shall be the basis of technically realistic requirements that can be contractually specified with appropriate demonstration plans.

3. Reliability and maintainability can be obtained effectively only by sound engineering during design and development.

4. Reliability and maintainability must be designed into the equipment, but must be designed in on a system basis and must be subject to tradeoff consideration with all other critical characteristics, such as performance, weight, cost, etc.

5. Reliability and maintainability are the direct responsibilities of the project management organization.

6. Achievement of reliability and maintainability requirements can be assured only by constant monitoring by the project manager and his staff, utilizing carefully conceived plans for periodic review and for selected demonstrations. Such plans must cover the gamut of development, procurement and operations.

In these policies you will note that we are committed to a quantitative approach to <u>Reliability</u> and <u>Maintainability</u> and the customer (the military) must establish quantitative goals based on a complete analysis of the military missions.

[illegible] 1 - DODI 3200.6

These goals then become the basis for establishing technically realistic contractual requirements and appropriate demonstration plans. These requirements and demonstration plans will go through a process of refinement and definitization in going from the Preliminary Technical Development Plans, through the Project Definition Phase, and finally into the contract for development. These policies recognize and establish reliability and maintainability as integral system performance characteristics that must be established on a total system basis, with achievement a direct function of sound engineering. Reliability and maintainability monitoring by design reviews, prediction calculations or selected demonstrations is essential to their achievement, providing the means for design and management decisions. And finally, the project manager (the line manager) is directly responsible for the system reliability and maintainability.

The above relates directly to the development management for Reliability and Maintainability. However, Maintenance Planning Activities should be monitoring and following this development process of establishing goals, refinement and definization, tradeoffs and final hardware achievements to continually refine the maintenance and logistics planning if effective Integrated Logistic Support for Systems and Equipment (DoD Directive 4100.35) is to be achieved.

V. Maintainability Design

A. To give the impression that design for Maintainability is new would certainly be fallacious. In fact there have been extremely successful past efforts in the development of automatic check-out equipment, design for accessibility, etc. Though efforts along these lines have continued, the more recent efforts have focused on the development of design techniques through which maintainability (and also reliability) can be dealt with in a quantitative fashion and controlled during design. A review of these techniques reveals that they basically represent refinements in our engineering practices with a quantitative orientation. This quantitative treatment results in a complete change in design philosophy, design approach and design management, which in the past emphasized design for maximum or optimum reliability and maintainability (a point of discussion in the 10 March Panel No. 5 Memo). These new techniques attempt to bring the intuitive, qualitative design judgments into a realm of quantitative measures and estimates. They permit us to establish design goals for these characteristics and orient the design to these specific mission responsive goals - not the "optimum" or "maximum" and "unknown." Additionally, they draw upon mathematical and statistical techniques as tools for obtaining quantitative assessment and evaluation of design achievement. As a result, the application of the quantitative technology provides an improved basis for design and management decisions.

B. Maintainability Design Techniques

Much effort and study, yet not enough, has been devoted in recent years to the development of methods for the quantitative approach to design for maintainability. These include prediction and measurement techniques; maintenance task time analysis; statistical analyses of maintenance task times for test point allocation, sensor selection and location; design reviews for maintainability; design for reduced maintenance (servicing); allocation and planning of scheduled maintenance actions; modular construction; computerized performance monitoring and rapid fault isolation, etc.

B-1. Maintainability Prediction

Perhaps the technique being given the most attention is Maintainability Prediction; and, it is one of the important innovations. The state-of-the-art in Maintainability Prediction is that there are several methods available and studies continue to refine these for increased accuracy. The following methods are presently used:

Method 1. Often referred to as the RCA method, was developed under Air Force contract originally for Ground Electronics. A review and analysis of the design features and maintenance factors is made using check lists and associated criteria to score Design Factors, Design Dictates (Maintenance Skills) and Design Dictates (Facilities). These scores are applied in a prediction equation or in a nomograph to estimate the Active Down Time (time when work is actually performed on the system). By a conversion chart this time is converted to the time expended by a technician in active performance of the maintenance task. This Corrective Down Time then can be used by applying a factor of 1.4 to make an initial estimate of Preventive Maintenance Time. (See Appendix A for Nomograph, Charts and Check Lists).

The individual scoring of specific elements of hardware design or maintenance tasks is valuable in detecting those hardware locations needing maintainability improvement. These scores can be used as an aid in selecting Maintainability features to effect the improvement; and, of course, this scoring is useful in evaluating alternate designs.

A recent attempt to apply this technique to TITAN II strongly suggests its applicability for general use if the checklists and criteria are generalised. There is also a current effort under way to refine this technique and extend its applicability to Airborne Systems.

Method 2. Developed by Republic Aviation, the method is based on maintenance task-time analysis of the many maintenance actions required. Utilizing past experience data for maintenance task times, the predictions become a computation of these average task-time figures. Where experience data is not available, estimates are made based on prototype tests, laboratory tests, mock-up analysis or engineering judgments made from design analysis.

Though developed for analysis of aircraft design, the method is a basic maintenance task-time analysis and computation. Therefore, this technique should be applicable to any type of hardware.

Methods 1 and 2 are presently permitted in the Air Force Specification MIL-M-26512C "Maintainability Program Requirements for Aerospace Systems and Equipment" (See References 4, 5, 6).

Method 3. A third method is one developed by ARINC Research Corporation for flight-line maintenance. It predicts active repair times and down times of airborne electronic equipments. The prediction computations are based upon past field experience related to equipment characteristics such as numbers of components, flight line replaceable components, spares, test points, failure rates, mission length and maintenance policies. The computations, which can be done manually and have also been programmed for the IBM-1401 computer, result in estimates of the distributions of the active repair times and system down-times. (Reference (7)).

Method 4. Another method is one developed by Federal Electric Company under contract to Bureau of Ships. As a result of analysis of shipboard electronics maintenance experiences, a set of charts have been developed to indicate the average task times for Diagnosis (Localization and Isolation), Replacement (Disassembly and Reassembly) and Test (Alignment and Checkout) for system malfunctions caused by failure of tubes or plug-in assemblies and those caused by part failures. The task times are charted for the several functional levels within a system reflecting depth of penetration to effect the repair action (Appendix B). The studies establish the distribution of down-times as a log-normal distribution which becomes the basis of the mathematical computations. This method is required in Bureau Ships Specification MIL-M-23313A(Ships). (Reference 8).

There are other variations of the prediction technique. A review of the presently used Maintainability Specifications (Appendix C) will reveal these. In the main, the Maintainability Prediction methods are based on Maintenance Task-Time Analysis. The method used in the Army Specification MIL-M-55214(EL) differs. It is not truly a Maintainability Prediction in that it does not result in a computation of MTTR. It is a method of design analysis and scoring of the design features. The index number computed is a numerical rating of the maintainability.

There are efforts presently under way to obtain better validation of the available techniques, to increase their accuracy and to extend their applicability. An OSD/Tri-Service task group effort is presently evaluating the available techniques to adopt the best for inclusion in a Tri-Service Military Standard. (Appendix C). From Appendix (C) you will note the plan of the effort under way to consolidate present Maintainability Single-Service specifications into a few Tri-Service Military Standards.

Another effort which should be mentioned is the Air Force contract effort with ARINC Research to develop a method of Maintainability Prediction by Function. The object is to provide a technique for establishing a quantitative relationship between equipment Line Replaceable Unit (LRU) function (i.e., transmitter, receiver, scope, recorder, data processor, display, etc.) in terms of Maintainability design characteristics expressed as an influence on MTTR. Such Maintainability factors as skill level, packaging, accessibility, adjustments, depth of penetration, etc., will be included. The product output will be a computation method to predict equipment (LRU) maintainability during the planning stages when required functions and some system parameters (weight, volume) only are known and during early design before circuit detail has been decided.

B-2. Other Maintainability Design Techniques

Formal Design Review for Maintainability. Discussion of this valuable technique will touch on several other specific techniques. The Design Review is closely allied to the Maintainability prediction inasmuch as the predictions are generally based on design and task time analysis. A very interesting tool is the Analysis of the Distribution of Observed or Predicted Downtimes. If the distribution is bimodal or if it has decided spikes, this knowledge can be very valuable. This information can be used to allocate, relocate or optimize the location of test points or sensors. The bimodal nature might indicate the need for greater accessibility for those areas (in the distribution) representing poor maintainability. Perhaps, for these areas, the use of modular construction (quick replacement, plug-in design) is suggested. It may also lead to a consideration of ultra-reliable, long-life design for these sectors so that the infrequent difficult maintainability can be tolerated or possibly eliminated for the useful life of the system.

From a slightly different point of view - the results of a test observing the maintainability for a system revealed a bimodal downtime distribution. This equipment contained both integral and modular construction. A conclusion drawn was certainly obvious: - The bimodal distribution clearly revealed the value of modular construction.

Another technique: Where Performance Degradation Rates can be estimated, these can be used to determine requirements for marginal testing devices and optimizing scheduled maintenance.

Further an Analysis of Downtime Distributions versus Performance Degradation Rates may allow a maintenance plan that will permit a group of failures to occur and establish the maintenance action for the group of failures.

C. Development Management Techniques for Maintainability

(C-1) Technical Development Plans (TDPs): Documenting the development program content, plan and approach, the TDP is a principal document in the program approval process. Guidance for preparation of a TDP is contained in the DoD Instruction 3200.6 (Reference 1). The 7 June 1962 revision established the requirement that TDPs include specific operational use data, which is essential in the design for reliability and maintainability and the plans for achievement. Inclosure (2) of DODI 3200.6 establishes the following as the types of data required in a TDP.

1. Operational information that affects reliability and maintainability design.

- Planned deployment
- Reaction time required
- Mission duration requirement for each type of mission
- Turnaround time required (e.g., for aircraft, the elapsed time from landing to take-off assuming no repair action)
- Over-all mission reliability for each type of mission
- Availability or combat ready rate (percent or number of an item capable of performing the designed mission vs the total number of items)
- Maintenance and operating environmental conditions (climate, facilities, support, etc.)
- Planned utilization rate (concerns the number of hours, miles, firings, flights, etc., per unit of time)

2. Planning information needed for reliability and maintainability design.

- Mean-time-to-return-to-service goals
- Reliability after storage goals (e.g., 90% reliability after 3 years storage)
- Minimum allowable time between scheduled maintenance

- Test and checkout philosophy (extent of automaticity, complexity of test, degree of fault isolation at various echelons, special vs multi-purpose test equipment, etc.)

- Echelons of maintenance or maintenance concept to be used and specific maintenance responsibilities for each

- Maintenance and crew personnel (numbers and skills) and training allocated for support of this program

3. Plans for a reliability program outlining how reliability will be achieved.

- Determination of equipment environmental conditions (system, subsystems, parts, etc.)

- Periodic specification review (when, how often, etc.)

- Reliability apportionment and prediction

- Reliability design reviews

- Human error analysis and prediction

- Reliability test and demonstration

- Malfunction and failure reporting and analysis

4. Plans for a maintainability program outlining how maintainability will be achieved.

- Quantification of maintainability (concerns the development and application of numerical measures of maintainability. This also involves allocation of over-all system measures of maintainability to all major lower-order elements of the system. Mean-time-to-return-to-service is an example of one such measure).

- Maintainability prediction (extent, schedule, design, influence, etc.)

- Maintenance task and skill analyses

- Maintainability design reviews

- Test and demonstration

- Maintenance data collection, feedback and analysis

It is obvious that the purpose of this DoD Instruction is to (1) ensure adequate consideration of reliability and maintainability in the early planning phases, and (2) to establish specific quantitative mission requirements that need to be met and the planned operational use of the system. These data then establish the necessary quantitative, mission-responsive goals which become the basis for technically realistic contractual requirements and demonstration plans.

Technical Development Plans are mandatory for all engineering and operational systems development projects.

Periodic audits - reviewing the TDPs to determine their adequacy relative to the reliability and maintainability requirements should be made. We did conduct an audit some time ago and requested that the Services correct deficiencies. These reviews should be accomplished while the programs are still flexible and changes can be made.

Of course, to close the loop, periodic audits should be made of contract specifications and work statements to ensure that the TDP approved plan is properly reflected in the contract.

(C-2) Maintainability Status Recording

Status recording of the predicted and achieved (tested) maintainability (for all subsystems and the over-all system) against the contractual requirements is most valuable to both design and project management. Logistics and maintenance planners should keep this kind of Maintainability progress under continual surveillance.

Status recording of operational reliability and maintainability should prove most valuable not only to maintenance management but also for product improvement programs, for operational planning and for feedback to design.

VI. Reliability (R) - Maintainability (M) Interrelations

What can be said of the interrelationships and trade-offs between $\bar{R}$ and $\bar{M}$? The same rules apply to $\bar{R}$ and $\bar{M}$ as to other performance characteristics; as such, they shall be subject to trade-offs with each other as well as with the other performance and critical characteristics.

A. Let's consider Availability - the applicable basic formula is:

$$A = \frac{\bar{R}}{\bar{R} + \bar{M}}$$

where A = % Availability
$\bar{R}$ = MTBF
$\bar{M}$ = MTTR

It is obvious that the same availability can be satisfied by a number of R and M combinations. Availability can be increased with increased R or decreased(better)M. Conversely we may be willing to forsake some R with an improved Maintainability. This is all well and good; the mathematics is simple and time and money might be saved in this consideration. However, one safeguard! If tradeoffs are considered in this manner, the resultant requirements should be checked to assure that these computed values of R and M remain consistent with the specific mission requirements. For example:

1. A requirement states that a Prime Search Radar must be capable of 23 of 24 hours of operation.

2. An Availability of at least 90% is required.

3. A Maintainability of 2 Hours MTTR is acceptable.

The computed R turns out to be roughly 22 Hours. Yet this R is far from satisfactory to meet the 23 of 24 Hours Search Radar operational requirement. To meet a requirement of "23 Hours - no failure at 90% probability" the MTBF is approximately 230 Hours and not 22 Hours.

B. Mission and Product Considerations - The design for and tradeoff of R and M is also dependent on the product and its mission requirements. For expendable items it is more appropriate to assure reliability achievement. The Maintainability must only be consistent with pre-operation test and maintenance; and periodic inspection and test during storage. And here we have some of the criteria for Discard-at-Failure-Maintenance concepts, and the concept of plug-in Modules.

C. Continuous Performance Monitoring - Techniques including marginal testing to monitor and detect performance degradation (sometimes considered a Reliability technique) becomes a valuable tool for Maintainability improvement. This technique reduces the fault detection time and allows planning of scheduled maintenance for replacement during convenient off-line time.

D. Frequency of Automatic Checking - In reference (9) the author speaks of improving the Reliability and Availability by increasing the frequency of Scheduled Automatic Checking. Here again, a word of caution! When this is done, care must be taken to assure that the probability of inducing failures during this checking does not become a significant factor. There is evidence that maintenance induced failures can become significant as indicated in Reference (10).

VII. Maintainability - Maintenance Interrelations

What are some of the relationships between Maintainability (M) and Maintenance? The Maintainability is designed and built into the equipment. Maintenance must live with whatever Maintainability is inherent to the hardware; and, conversely Maintenance must preserve this design capability. Further, by poor training, poor judgment, carelessness, improper instructions or tools, Maintenance can degrade Maintainability. Maintenance load, however, is a direct function of Maintainability.

Maintenance Engineering as a function must and has a responsibility to collect and analyze operational maintenance data. This experience data should be fed back to design with any recommendations for design (Maintainability) improvement.

Maintenance Engineering personnel should provide an input in the establishment of system Maintainability characteristics for new system development projects. Maintenance Engineering personnel should be represented in Design Reviews for Maintainability to again bring the benefits of field experience to the proposed design.

With Maintenance being dependent upon many variables (i.e., maintenance environments, installation, personnel capability and training, logistic support) the maintenance effort will in all probability differ for each operating command, depot or installation. This becomes apparent when we observe the same equipment installed and operated at different bases, in different ships, aircraft or other type vehicles. The "mean-time-to-repair" or "mean-time-to-restore-to-satisfactory-operation" can be expected to differ. These experience data should be collected, collated and analyzed to establish average maintenance task-times and, where possible, estimates of correlation factors to the variable maintenance conditions should be developed.

VIII. Maintenance - Reliability Interrelations

To close the triangle (Sections VI, VII and VIII) how does Maintenance effect Reliability and vice-versa? Maintenance loads will be a direct function of Reliability since the failure-rate or the "Mean-Time-Between-Failures" is the prime factor in establishing the frequency of Maintenance actions. The Maintenance Load is a direct function of the combined R and M. Again, as in case of "Maintenance-Maintainability" interrelations, Maintenance must live with the inherent reliability of the hardware - with its inherent time-between-failure. Maintenance, however, has responsibility to preserve the built in reliability; and, again by poor personnel capability or training, poor maintenance manuals, poor logistic support, poor maintenance environment, carelessness, etc., maintenance can easily degrade the reliability.

A. Communication Between the Designer and the Operator and Maintainer

In a recent article it was stated that a vital factor for improved reliability and system effectiveness is improved technical communications between the designer and the operator and maintainer during system operation. The equipment or system technical manual is the general form of communications between the designer and the operator and maintainer. It also stated quote: "An ideal technical manual is one that transmits all the designer's knowledge to the operator and maintainer." This is a good statement of concept - but it is labelled "ONE WAY STREET!" Maintenance must report back all failures and the associated circumstances. True that this data can and should be used for maintenance management but equally important is the feedback of this failure data to design. However, to meet design needs, this failure reporting should provide the data necessary for reliability assessment and improvement -- time information is essential - "time-to-failure" of the item as well as the mode of failure, location in the system, equipment operating environment, etc. Most of the failure reporting systems in operation today do not provide "time-to-failure" information. This was recognized in the AF 66-1 Maintenance Management reporting system. The Air Force Systems Command has modified the AF 66-1 form to AFSC-258-5 to correct this deficiency and AF Regulation 80-14 states that this form is mandatory for Category I, Category II testing and optional in Category III testing. This improved form, I understand, is not required for reporting during operational use. Even with the AFSC-258-5 refinement for data related to maintenance task time, it must be used in conjunction with an independent operational log which combines with date and time to assess reliability - we must count the "living" as well as the "dead" in the overall reliability computation.

Without the modification to require date/time of failure through which frequency of failure can be estimated, it is difficult to understand how accurate maintenance loads can be estimated. The Army TAERS system does provide for reporting "time-to-failure" but this system is newly instituted and not as yet f lly operational.

Needless to say, designers need feedback not only on what failed but how, where, and when including estimated (if not measured) "time-to-failure." This feedback to design is essential if field operational reliability is to be assessed; and, it is most important for design and management to have all the facts by which they can assess the criticality of the failures (besides quantity) to properly evaluate priorities of maintenance or design improvement programs.

B. Reliability versus Maintenance Load

As indicated above, the Maintenance Load related to the frequency of failures. In the case of the AN/ARN-21C Airborne TACAN the reliability was increased from 17.9 Hours MTBF to 150 Hours MTBF. Based on 9000 units to be installed and a 5 year life, the Air Force estimates that this improvement in reliability results in an estimated savings in maintenance funds of $123,000,000.

In discussing Reliability and Maintainability tradeoffs I mentioned expendable systems. In the case of the Bullpup Missile, field checkout equipment was made unnecessary due to the increase in reliability. As a result the Navy has cited a saving of about $6.7 Million in the first year of production that would have been spent for field checkout equipment.

With the DoD annual maintenance support now exceeding the $11 Billion mark, it is obvious that any small increases in reliability will decrease the maintenance load and maintenance costs substantially.

C. Advanced Design and Maintenance Policies

Some of the Advanced Design techniques, particularly the electronics solid state and semi-conductor integral circuits, are starting to appear in our inventory. The technology features micro-construction where for example a 5 inch cube may contain 90,000 elements and this is far from optimum density. These elements are assembled in modules which may be mounted on boards or encapsulated. These new devices are showing a potential for orders of magnitude improvement in reliability. Reference (11) cites for example APOLLO computers having 13,000 circuits which were put on life test by Massachusetts Institute of Technology. These models have had over 33 million circuit hours with no failure. The circuit failure rate reported by M.I.T. -- 0.0065 percent per 1000 hours at a 90% confidence level -- is based on one mechanical failure that occurred while the equipment was being assembled. With respect to Maintenance we have a condition of virtually no failure in these circuits. Further, their micro nature raises the question as to what level of assembly will Maintenance be planned, at what level will repairs be made and at what organizational levels. The advent of micro-circuitry will demand a serious re-evaluation of Maintenance policy and approach. Relative to Reliability, other than physical damage (or new but not anticipated modes of failure), the Maintenance Load in this area should reduce sharply. Reference (11) states, quote: "Already there is every indication that those parts of military systems that can be built of integrated circuits will last through the system's useful life with very few failures, perhaps none at all."

IX. Human Factors Interface with Maintenance/Reliability/Maintainability

The human factor is the common element to Maintenance/Reliability/Maintainbility and to the total operational System Effectiveness. The capability, the training, the motivational attitudes, the operational environments, and the variability between personnel all have a definite impact on the system or equipment operational effectiveness. These human factors must be included in: (1) the design considerations to ensure that the equipment is compatible with human capabilities (e.g., MIL-STD-803), (2) the planning of the maintenance and logistics support (DoD Directive 4100.35), (3) the instructions and training for operation and maintenance; and, these are all reflected in the actual operation, maintenance and logistcs support of the systems in use. Though much has been done in Human Factors Engineering much remains to be done to measure human capabilities and correlate these to design, construction and maintenance techniques. Some of these aspects are outlined under "Maintainability Research Needs."

X. Maintainability Research

Much progress has been made in the development of quantitative techniques for both reliability and maintainability. However, our experiences to date are revealing how much remains to be done in terms of needed refinements, extension of the technology, and gaps in the technology. These then are the areas to which our efforts and research should be directed.

Since the main focus of this paper is "Maintainability" the following addresses the "Maintainability" sector; for "Reliability Research Needs" see Reference (12).

Some of the more important maintainability tasks and problems are as follows, categorized as (1) Immediate Tasks, which are being pursued; and, (2) Maintainability Research Needs to which studies and research are being encouraged.

1. Immediate Task Efforts

a. The first immediate task is to see that greater use is made of presently available maintainability methods and techniques (i.e., apportionment, prediction, measurement and design reviews for maintainability, etc.)

b. We need to expedite the evaluation of presently available maintainability prediction and measurement techniques to determine their adequacy and applicability to the major categories of systems and equipment in our inventory.

d. Needed is the compilation of maintainability task analysis data that can be put into handbook form to establish a base for maintainability prediction (a series of handbooks may be required relating to different products). This (or these handbooks) would be similar to the MIL-HDBK-217 failure-rate data for reliability prediction. Each agency should be encouraged to develop their own data; and, any possible consolidation can be considered once the initial handbooks are available.

d. With recent emphasis given to maintainability (and reliability), there is a tendency to simply add separate tests for these parameters to the total test program. Greater emphasis should be given to the design of Integrated Test Program wherein the demonstration of reliability and maintainability might be combined with the demonstration tests for other performance. This could result in substantial savings in costs for testing, reduce the need for procuring additional systems or equipment for test, better utilization of test facilities and reduce test time. This is not a new concept but certainly one that needs increased attention. This concept is being emphasized in our specifications.

e. One last item, as an immediate task, is the education of line managers, at all levels, in maintainability (and reliability).

As previously noted, experience to date has indicated the usefulness of the techniques for improved program and design management as well as for more efficient procurement. Yet these techniques and the efforts expended in their development become meaningless unless they are put to use by all levels of line management in their program decisions, by engineers in their designs and invoked contractually. Line managers, design engineers and procurement officers must be made aware of these reliability and maintainability techniques so that they fully understand the benefits to be derived, the usefulness of these tools and, at the same time, recognize the limitations in their use. That these educational efforts be undertaken is a responsibility of management, but the educational efforts per se must be undertaken by the reliability and maintainability specialists. Reference (13) stresses the need for maintainability education.

2. <u>Maintainability Research Needs</u>

a. <u>Requirements Definition</u>: Uniform methods and guides are needed in how to establish realistic, mission responsive maintainability requirements.

b. <u>Prediction and Measurement Techniques</u>: Early validation is needed of the accuracy of existing maintainability prediction and measurement techniques and their applicability to the many different types of military systems and equipment. Simplified methods are needed for quick estimates of feasibility in the early stages of design as well as for early monitoring of development.

c. <u>Contractor vs. Military Maintenance</u>: Determine correlation factors between contractor maintenance personnel and military operational personnel related to the system maintainability and methods for integrating these factors in prediction and measurement methods.

d. <u>Design Techniques</u>: Continued efforts are needed in the development of simplified, rapid fault location techniques and methods for early detection of deterioration and the prediction of imminent failures.

e. Design and Construction Techniques: Establish quantitative factors relating the effects of design and construction techniques to the Maintenance Task Analysis Data. Also, uniform criteria are desirable relating maintainability levels and maintenance concepts to design and construction techniques; this includes repairable versus modular design, etc.

f. Maintainability Measurement and Demonstration: Studies are needed to establish ground rules and uniform criteria correlating maintenance personnel capability and training levels to the objectives and accept/reject criteria of test and demonstration plans.

Allied to research needs, there must be continual surveillance of advances in technology related to new devices and construction techniques to ensure that the maintainability techniques remain compatible and responsive to those innovations.

XII. Conclusions and Recommendations

A. Conclusions

1. For efficient operation, the interrelations between Maintainability, Reliability and Maintenance demand effective communcations and coordination between Operating, Maintenance and Logistic Support forces with the Design and Development activities.

2. Development Management has found the quantitative techniques for Reliability and Maintainability powerful tools for design and management decisions. For effective implementation of Cost Effectiveness Evaluation (over the total system life), Engineering Change Evaluation, Project Definition and Integrated Logistics Support, it appears that some of the very same design techniques may be equally applicable to Maintenance and Logistic Support cost and workload analyses (Reference 14, pp 29-33).

3. Experience data related to failures and downtime are not presently fully exploited for new design or for maintenance and logistics management.

4. The advent of certain advanced technology (such as electronics micro-circuitry and semiconductor integral circuits) establishes an immediate requirement for the reevaluation of maintenance and logistic support policies.

5. Though much has been accomplished in the Human Factors area, it remains as the principal variable and largely unknown factor effecting Reliability, Maintainability, Maintenance and Logistics Support.

B. Recommendations

It is recommended that:

1. Actions be taken to adapt established reliability and maintainability design techniques for maintenance, logistics support and spares procurement operations.

2. Action be taken to ensure:

a. The timely feedback of experience data (maintenance reporting, performance and malfunction reports, and failure reports) to design as well as to maintenance and logistic support functions;

b. The adequacy of the data content to permit reliability and maintainability assessment (time to failure data, maintenance task time data, etc.).

c. That this reporting be established as a requirement throughout development testing (--i.e., through Category 3 testing or equivalent Army, Navy testing) and also for at least the first year of operational use; and

d. That emphasis be placed on the surveillance of the major weapons systems as priority effort.

3. Efforts shall be made for early implementation of Paragraph VC of DoD Directive 4100.35 "Development of Integrated Logistic Support" relative to active participation of Logisticians (including Maintenance Engineering Personnel) in Development Milestone actions including (a) preparation of requirements documents, TDPs and contractual requirements, (b) reviews of contractor plans, engineering change proposals, system analyses, and (c) design reviews, development tests and inspections and approval demonstrations.

4. Steps should be taken to establish Periodic Reliability and Maintainability Status Recording for selected systems in the operational inventory (at least the Major Weapons Systems) for management visibility and for feedback to design for product improvement; also, to maintenance and logistics management. Recommend the Army and Navy review the recently initiated Air Force "IROS" (Improved Reliability of Operational Systems) program, covered by Air Force Regulation 400-46.

Similarly, the periodic assessments of reliability and maintainability made during development should be made available for maintenance and logistics planning.

5. Periodic audits of maintenance downtimes and maintenance loads related to specific systems should be conducted to determine the adequacy of methods being utilized and the degree of implementation of existing instructions.

6. Efforts should be initiated in the Military Departments to develop "Maintenance-Task-Time-Data Handbooks" from experience data that can be used by maintenance and logistic support management, and by designers for prediction of maintainability. These handbooks may be tailored to specific products; i.e., Tank andVehicular, Ordnance, Aircraft, Ships, Ground Electronics, Ballistic Missiles, etc.

7. Studies should be initiated to plan any revision of maintenance and logistic support policies in view of new advanced technology; such as, micro-electronics and semi-conductor integral circuits.

8. Continued efforts are recommended in the pursuit of solutions to the maintainability research needs discussed in the paper, with emphasis on studies related to measures of human capabilities and training levels, for correlation to maintenance tasks, logistics support, design and construction techniques and training.

REFERENCE

Reference (1) DoD Instruction 3200.6 "Reporting of Research, Development and Engineering Program Information"

" (2) MIL-STD-778 "Maintainability Terms and Definitions"

" (3) MIL-STD-721 "Definitions for Reliability Engineering"

" (4) Specification MIL-M-26512(USAF) "Maintainability Program Requirements for Aerospace Systems and Equipments"

" (5) DDC Report AD-404898 and AD-404899 Maintainability Engineering (Volumes I and II of RADC-TDR-63-85)

" (6) "DC Maintainability and Supportability Techniques"

a. DDC No. AD-245130 (OTS-PB163352)
b. DDC No. AD-249390 (OTS-PB163353)
c. DDC No. AD-249391 (OTS-PB163354)
d. DDC No. AD-249089 (OTS-PB163355)

NOTE: DDC (Defense Documentation Center)
OTS (Office Technical Services)

Reference (7) ARINC Report 267-02-6-420

" (8) MIL-M-2331A(Ships) "Maintainability Requirements for Ship/Shore Electronic Systems and Equipment

" (9) A Practical Reliability and Maintainability Model and Its Application, E. J. Althaus and W. D. Voegtlen Proceedings 11th National Symposium R&Q/C, January 1965

" (10) RAND Report No. RM-3645-PR(Abridged) "Optimum Check-out Intervals and Launch Capability of Ballistic Missiles"

" (11) Microelectronics In Defense Systems" dated 10 May 1965, J. M. Bridges, Special Assistant to DDRE for Command and Control.

" (12) "Reliability, Maintainability and Systems Effectiveness" dated 10 August 1964 by R. J. Mucci, ODDR&E, OAD (Engineering Management)

" (13) "Education for Maintainability" Keynote Address at Fifth EIA Workshop on Maintainability, May 5, 1964, by E. J. Engoron, ODDR&E, OAD (Engineering Management)

" (14) "Life Cycle Costing in Equipment Procurement" LMI Report dated April 1965, Task 4C-5.

MAINTAINABILITY

PREDICTION

RCA METHOD

1. NOMOGRAPH AND CHARTS
2. CHECK-OFF LISTS
   - A. - Scoring Physical Design Factors
   - B. - Scoring Design Dictates - Facilities
   - C. - Scoring Design Dictates - Maintenance Skills

These charts, scoring check lists and nomograph taken from AF Report RADC - TDR-62-156 "Maintainability Prediction Techniques" - Contract AF (30)(602) - 2057.

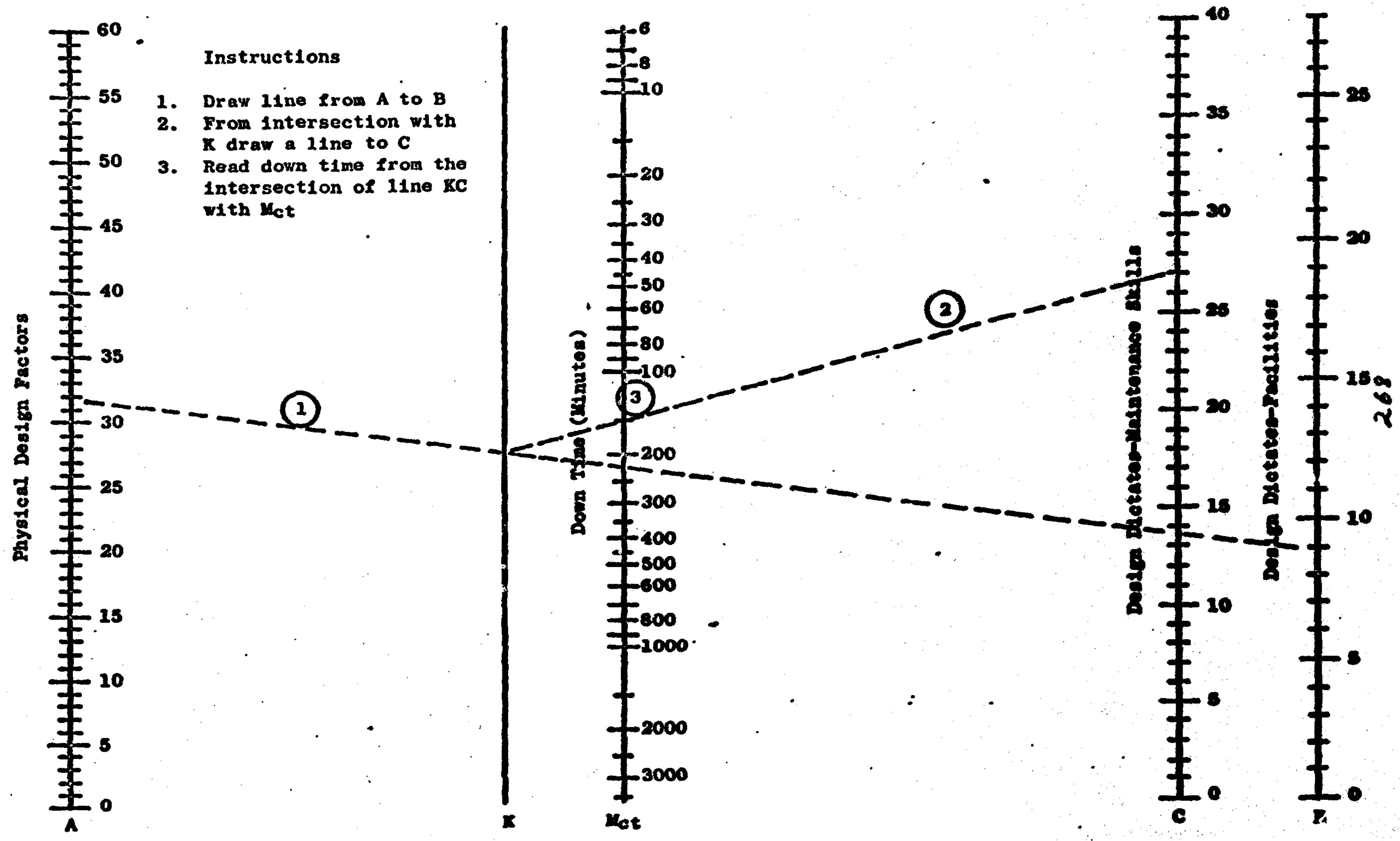

FIGURE 2.2 NOMOGRAPH - DOWN TIME

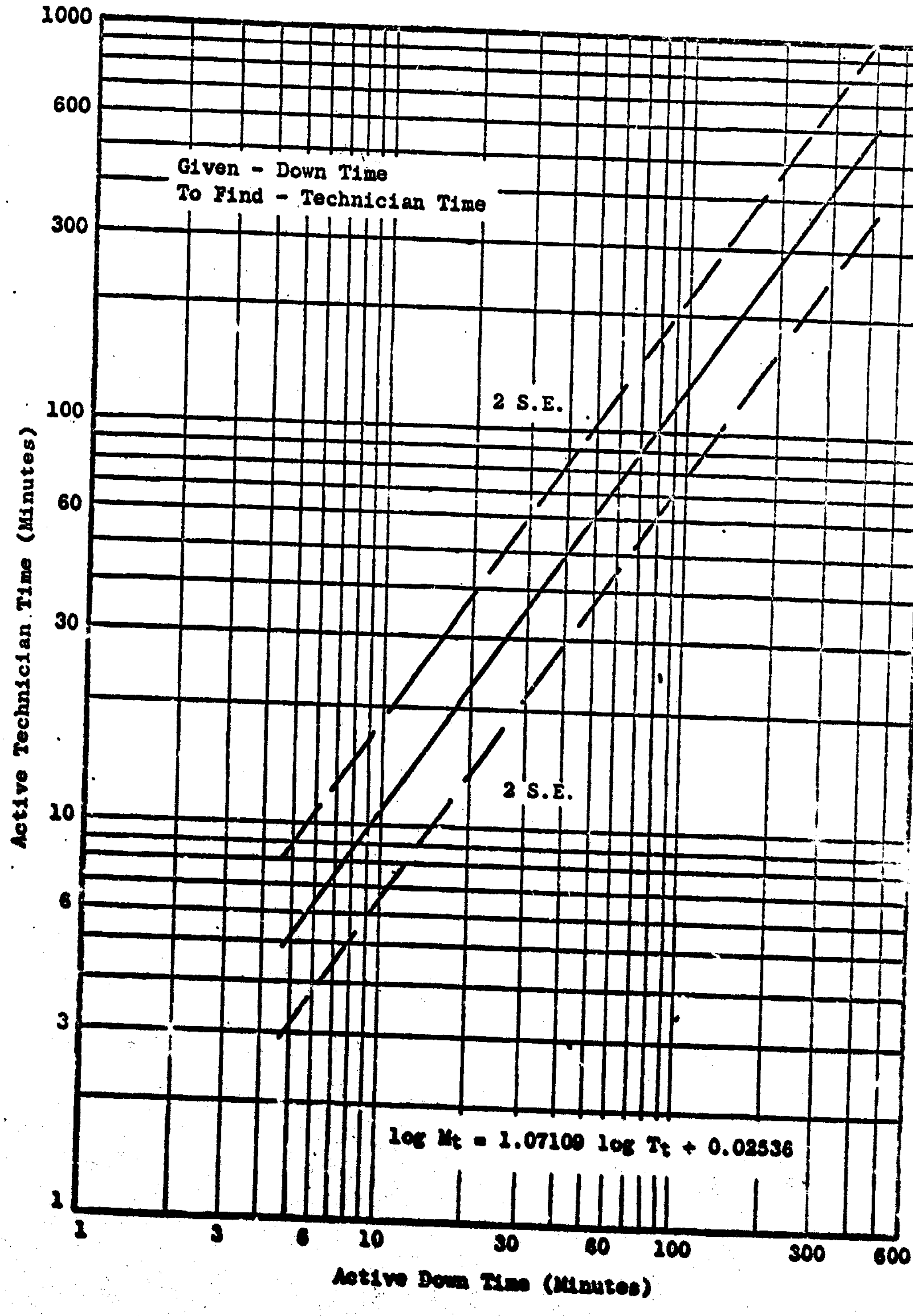

FIGURE 2.3 TECHNICIAN TIME VS. DOWN TIME

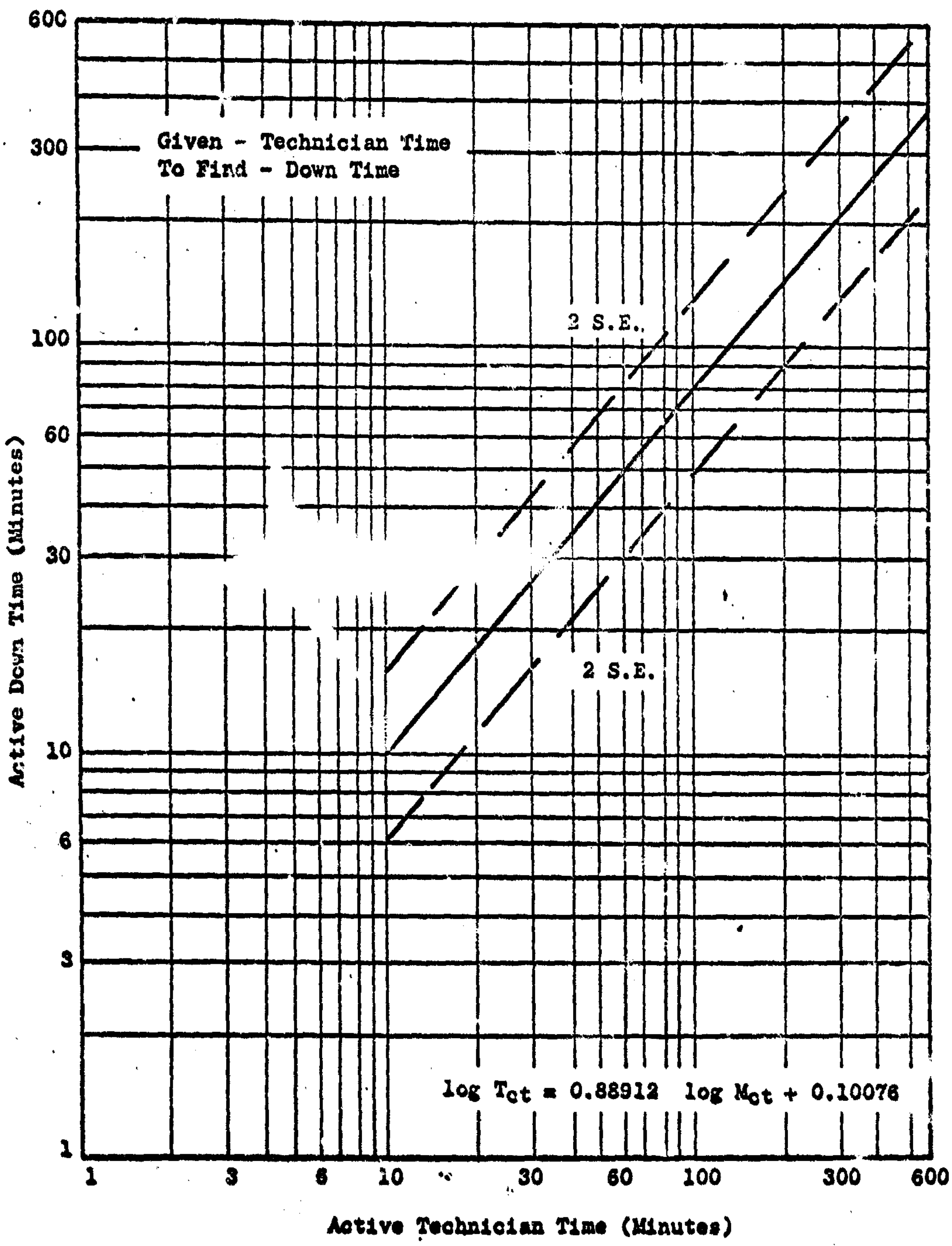

FIGURE 2.4 DOWN TIME VS. TECHNICIAN TIME

2.1.2 Checklist A, Scoring Physical Design Factors

1. Access (External)

   a. Access adequate both for visual and manipulative tasks (electrical and mechanical)....................................4

   b. Access adequate for visual, but not manipulative, tasks......2

   c. Access adequate for manipulative, but not visual, tasks......2

   d. Access not adequate for visual or manipulative tasks.........0

2. Latches and Fasteners (External)

   a. External latches and/or fasteners are captive, need no special tools, and require only a fraction of a turn for release..4

   b. External latches and/or fasteners meet two of the above three criteria...2

   c. External latches and/or fasteners meet one of the above three criteria...0

3. Latches and Fasteners (Internal)

   a. Internal latches and/or fasteners are captive, need no special tools, and require only a fraction of a turn for release..4

   b. Internal latches and/or fasteners meet two of the above three criteria...2

   c. Internal latches and/or fasteners meet one of the above three criteria...0

4. <u>Access</u> (Internal)

a. Access adequate both for visual and manipulative tasks (electrical and mechanical)....................................4

b. Access adequate for visual, but not manipulative, tasks......2

c. Access adequate for manipulative, but not visual, tasks......2

d. Access not adequate for visual or manipulative tasks.........0

5. <u>Packaging</u>

a. Internal access to components and parts can be made with no mechanical disassembly....................................4

b. Little disassembly required (less than 3 min.)...............2

c. Considerable disassembly is required (more than 3 min.)......0

6. <u>Units - Parts</u>

a. Units or parts of plug-in nature.............................4

b. Units or parts of plug-in nature and mechanically held.......2

c. Units of solder-in nature....................................2

d. Units of solder-in nature and mechanically held..............0

7. <u>Visual Displays</u>

a. Sufficient visual information on the equipment is given within one display area......................................4

b. Two display areas must be consulted to obtain sufficient visual information...2

c. More than two areas must be consulted to obtain sufficient visual information....................................0

8. Fault and Operation Indicators (Built-In Test Equipment)

a. Fault or malfunction information is provi. ' clearly and for rapid action...4

b. Fault or malfunction information clearly presented, but requires operator interpretation................................2

c. Fault or malfunction information requires no operator interpretation, but is not clearly presented.................2

d. Fault or malfunction information not clearly presented and requires operator interpretation........................0

9. Test Points (Availability)

a. Tas. did not require use of test points.....................4

b. Test points available for all needed tests..................3

c. Test points available for most needed tests.................2

d. Test points not available for most needed tests.............0

10. Test Points (Identification)

a. All test points are identified with required readings given...4

b. Some are suitably marked.....................................2

c. Points are not marked and test data is not given............0

11. Labelling

a. All parts labelled with full identifying information and all identifying information clearly visible....................4

b. All parts labelled with full identifying information, but some information hidden....................................2

c. All information visible, but some parts not fully identified..2

d. Some information hidden and some parts not fully identified..0

12. Adjustments

a. No adjustments or realignment are necessary to place equipment back in operation....................................4

b. A few adjustments, but no major realignments are required....2

c. Many adjustments or major realignments must be made.........0

13. Testing (In Circuit)

a. Defective part or component can be determined without removal from the circuit.....................................4

b. Testing requires removal.....................................0

14. Protective Devices

a. Equipment was automatically kept from operating after malfunction occurred to prevent further damage. (This refers to malfunction of such areas as bias supplies, keep-alive voltages, etc.)..................................4

b. Indicators warned that malfunction has occurred..............2

c. No provision has been made..................................0

15. Safety (Personnel)

a. Task did not require work to be performed in close proximity to hazardous conditions (high voltage, radiation, moving parts and/or high temperature parts)............4

b. Some delay encountered because of precautions taken..........2

c. Considerable time consumed because of hazardous conditions...0

2.2.2 Checklist B, Scoring Design Dictates-Facilities

1. External Test Equipment

   a. Task accomplishment does not require the use of external test equipment..4

   b. One piece of test equipment is needed.........................2

   c. Several pieces (2 or 3) of test equipment are needed.........1

   d. Four or more items are required...... 0

   ______

2. Connectors

   a. Connectors to test equipment require no special tools, fittings, or adapters...4

   b. Connectors to test equipment require some special tools, fittings, or adapters (less than two)..........................2

   c. Connectors to test equipment require special tools, fittings, and adapters (more than two).......................0

   ______

3. Jigs or Fixtures

   a. No supplementary materials are needed to perform task........4

   b. No more than one piece of supplementary material is needed to perform task.......................................2

   c. Two or more pieces of supplementary material are needed......0

   ______

4. Visual Contact

a. The activities of each member are always visible to the other member..4

b. On at least one occasion, one member can see the second, but the reverse is not the case..............................2

c. The activities of one member are hidden from the view of the other on more than one occasion.......................0

_____

5. Assistance (Operations Personnel)

a. Task did not require consultation with operations personnel..4

b. Some contact was required....................................2

c. Considerable coordination required...........................0

_____

6. Assistance (Technical Personnel)

a. Task required only one technician for completion.............4

b. Two technicians were required................................2

c. Over two were used...0

_____

7. Assistance (Supervisors or Contract Personnel)

a. Task completion did not require consultation with supervisor or contract personnel..................................4

b. Some help needed...2

c. Considerable assistance needed...............................0

_____

2.3.2 Checklist C, Scoring Design Dictates-Maintenance Skills

	Score
1. Arm, Leg, and Back Strength	____
2. Endurance and Energy	____
3. Eye-Hand Coordination, Manual Dexterity, and Neatness	____
4. Visual Acuity	____
5. Logical Analysis	____
6. Memory - Things and Ideas	____
7. Planfulness and Resourcefulness	____
8. Alertness, Cautiousness, and Accuracy	____
9. Concentration, Persistence, and Patience	____
10. Initiative and Incisiveness	____

TUBES[a]

AVERAGE TIME[d] (HOURS) TO PERFORM CORRECTIVE MAINTENANCE TASKS FOR ELIMINATING EQUIPMENT OR SYSTEM MALFUNCTIONS CAUSED BY TUBE FAILURE

FUNCTIONAL LEVELS: FOR DETERMINING LOCALIZATION AND ISOLATION TIME USE COLUMN BEGINNING WITH THE FUNCTIONAL LEVEL THROUGH WHICH FAILURE IS REMOVED[f]									CORRECTIVE MAINTENANCE TASKS					
									DIAGNOSIS		REPLACEMENT[b]		TEST	
9	8	7	6	5	4	3	2	1	LOCALIZATION	ISOLATION[c]	DISASSEMBLY	REASSEMBLY	ALIGNMENT	CHECKOUT[g]
SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	SUBASSEMBLY	STAGE	PART	.021[c]	.265[e]	.313	.438	.153	.175
NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	SUBASSEMBLY	STAGE	.023	.315	.231	.362	.077	.167
	NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	SUBASSEMBLY	.037	.394	.165	.282	.045	.150
		NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	.045	.506	.122	.191	.030	.140
			NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	.053	.636	.094	.134	.021	.130
				NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	.063	.778	.071	.090	.015	.124
					NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	.075	.907	.049	.061	.010	.103
						NONE	SYSTEM	SUBSYSTEM	.090	1.020	.032	.037	.007	.091
							NONE	SYSTEM	.107	1.303	.016	.017	.003	.052
								NONE	.125	1.546	.000	.000	.000	.006

PARTS[a,h]

AVERAGE TIME[d] (HOURS) TO PERFORM CORRECTIVE MAINTENANCE TASKS FOR ELIMINATING EQUIPMENT OR SYSTEM MALFUNCTIONS CAUSED BY PART FAILURE OTHER THAN TUBES OR FRONT PANEL FUSES.

FUNCTIONAL LEVELS: FOR DETERMINING LOCALIZATION AND ISOLATION TIME USE COLUMN BEGINNING WITH THE FUNCTIONAL LEVEL THROUGH WHICH FAILURE IS REMOVED[f]									CORRECTIVE MAINTENANCE TASKS					
									DIAGNOSIS		REPLACEMENT[b]		TEST	
9	8	7	6	5	4	3	2	1	LOCALIZATION	ISOLATION[c]	DISASSEMBLY	REASSEMBLY	ALIGNMENT	CHECKOUT[g]
SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	SUBASSEMBLY	STAGE	PART	[illegible]	.712[e]	[illegible]	1.334	.153	.175
NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	SUBASSEMBLY	STAGE	[illegible]	1.179	.328	.551	.077	.167
	NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	SUBASSEMBLY	[illegible]	1.417	.165	[illegible]	.045	.158
		NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	ASSEMBLY	[illegible]	1.569	.122	.191	[illegible]	.149
			NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	UNIT	[illegible]	1.700	.094	.134	.021	.135
				NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	GROUP	[illegible]	1.821	.071	.090	.015	.124
					NONE	SYSTEM	SUBSYSTEM	EQUIPMENT	[illegible]	1.935	.049	.061	.010	.103
						NONE	SYSTEM	SUBSYSTEM	[illegible]	2.022	.032	.037	.007	.091
							NONE	SYSTEM	[illegible]	2.100	.016	.017	.003	.052
								NONE	[illegible]	2.172	.000	.000	.000	[illegible]

Figure 3- Maintenance task times (cont'd.).

APPENDIX B

MAINTAINABILITY SPECIFICATIONS CONSOLIDATION

M = MAINTAINABILITY

TRI-SERVICE DOCUMENTS PLANNED	EXISTING SPECIFICATIONS
1. MIL - STD - 778 M TERMS AND DEFINITIONS	1. MIL - M - 55214 (EL) M REQTS. FOR ELECTRONIC EQUIPT.
2. MIL - STD - ______ M PROGRAM MGT.	2. MIL - M - 45765 (MI) M REQTS. FOR MISSILE SYST. & EQUIPT.
3. MIL - HBK - ______ M PREDICTION TECHNIQUES AND DATA	3. MIL - STD - 1228 (ARMY) M CRITERIA FOR TANK - AUTOMOTIVE MATERIEL
4. MIL - ______ M TEST & DEMONSTRATION	4. WR - 30 (WEPS) INTEGRATED MAINT. MGT.
	5. WS - 3099 (WEPS) M GENERAL SPEC.
	6. MIL - M - 23313A (SHIPS) M REQTS. SHIP/SHORE ELECTRONIC SYST. & EQUIPT.
	7. MIL - M - 2[illegible]303 (WEPS) SYST. READINESS/M AVIONIC SYST. DESIGN
	8. MIL - M - 26512C (USAF) M PROG. REQTS. FOR AEROSPACE SYST. & EQUIPT.

APPENDIX C

TITLE: AVCOM RELIABILITY AND MAINTAINABILITY PROGRAM

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NOTE: This paper was not presented orally at the 19 July 1965 Army Technical Meeting on Quantification of Maintainability

For
19 July 1965

RELIABILITY AND MAINTAINABILITY PROGRAM

By: Mr. D. D. Burchfield, USAAVCOM
Chief, Quality Assurance Office

In developing Army Aircraft Systems, the attainment of reliability and maintainability must be a primary objective.

Every detail of design and construction can affect the quality, reliability, and maintainability of a product. Goals must necessarily vary from one type system to another, depending upon the item and the performance required. Goals should be realistic and economically feasible.

Inherent reliability, optimum maintainability and required environmental characteristics must be designed in. At the present time, the Army needs aircraft designed for Army use, in Army environments.

Reliability and maintainability techniques provide a method of engineering discipline for prediction based on the design and means of evaluation. It is also another tool for achieving quality assurance throughout the product life cycle.

Because the terms reliability and maintainability are an integral part of each other and cannot be separated, this presentation will consider both and will not attempt to define either term, since they are adequately defined in Mil Standard publications.

The primary purpose of the AVCOM reliability and maintainability program is:

a. To establish a method to achieve reliability and maintainability as a normal design function on Army aircraft.

b. To insure that reliability and maintainability are treated as a design parameter of equal importance with other factors.

c. Provide customers with maximum reliability with minimum maintenance utilizing lowest skills level.

d. To alert the Commander or Project Manager to any reliability and maintainability problems.

The AVCOM program begins with the concept or QMR's or SDR's and must continue through the usage phase.

A. Contractor requirements are basic and are defined in the contract and work statement. The contractor's experience is utilized to the greatest extent.

PROGRAM IMPLEMENTATION (RFP)

THE CONTRACTOR'S RELIABILITY AND MAINTAINABILITY PROGRAM SHALL INCLUDE:

1. INDEPENDENT ORGANIZATION AND ASSESSMENT.
2. EFFECTIVE MANAGEMENT AND PLANNING.
3. DEFINITION OF PROGRAM ELEMENTS AND TASKS.
4. RELIABILITY AND MAINTAINABILITY ANALYSIS OF ALL DESIGN ASPECTS.
5. PREDICTION OF RELIABILITY VALUES ON MECHANICAL AND ELECTRONIC SYSTEMS, SUBSYSTEMS, AND COMPONENTS.
6. ANALYSIS OF ALL ENVIRONMENTAL CHARACTERISTICS TO ASSURE RELIABILITY AND PROPER MAINTENANCE CYCLES.
7. EVALUATION OF VALUE ENGINEERING PROPOSALS AND CHANGES TO PREVENT DEGRADATION OF QUALITY, RELIABILITY, AND MAINTAINABILITY.

8. HUMAN ENGINEERING ANALYSIS TO PROVIDE MAXIMUM OPERATOR CAPABILITY, COMFORT AND SAFETY INCLUDING INDICATORS AND/OR INSTRUCTIONAL MATERIELS FOR SAFETY, EASE OF MAINTENANCE, AND STANDARDIZATION OF INSTRUMENT AND EQUIPMENT LOCATIONS.

9. RELIABILITY AND MAINTAINABILITY DEMONSTRATION OF SPECIFIED VALUES, THROUGH TEST AND EVALUATION.

10. UP-TO-DATE STATUS OF PROGRAM EFFECTIVENESS THROUGH PROGRESS EVALUATION AND REPORTING.

11. DOCUMENTATION OF ACTIONS, INSPECTIONS AND TEST.

12. EFFECTIVE CORRECTIVE ACTION PROGRAM FOR PRODUCT AND DATA IMPROVEMENT.

13. FINAL CALCULATION OF RELIABILITY PERFORMANCE AND MAINTAINABILITY VALUES.

14. MINIMUM MAINTAINABILITY DOWN TIME, MAINTENANCE AND COMPONENT CHANGE TIME FOR GREATEST UTILIZATION OF AIRCRAFT (FOR AROUND THE CLOCK OPERATIONS).

ACCEPTABILITY BY GOVERNMENT

THE CONTRACTOR'S RELIABILITY AND MAINTAINABILITY PROGRAM SHALL BE SUBJECT TO REVIEW AND DISAPPROVAL BY THE GOVERNMENT.

B. The Reliability and Maintainability Program Plan is as follows:

1. Statement of the System Reliability and Maintainability Requirements.

Before any reliability and maintainability estimates can have any meaning the following terms have to be defined:

TERMS TO BE DEFINED (BY ARMY)

a. MISSION IN TERMS OF TIME (FLYING HOURS).

b. FAILURES (WHAT CONSTITUTES A FAILURE).

c. CONDITIONS OR ENVIRONMENT OF OPERATIONS.

d. MAINTAINABILITY AND MAINTENANCE DESIGN PARAMETERS.

2. AVCOM is presently contracting for an Integrated Logistic Support Plan to provide for maximum maintainability requirements as a normal logistics management function.

3. The following quantitative terms (examples) are defined for each aircraft system (as required for each system) commensurate with the state of the art.

EXAMPLE OF RELIABILITY AND
MAINTAINABILITY DESIGN REQUIREMENTS

RELIABILITY	MINIMUM	OBJECTIVE
SYSTEM	0.75	0.85
COMPONENTS AV. (N=10)	0.96	0.98
CONFIDENCE LEVEL	0.95	

FORMULA: CATASTROPHIC RELIABILITY $R = e^{-cT}$

MISSION RELIABILITY $R = e^{-mT}$

SYSTEM RELIABILITY $R = e^{-sT}$

WHERE c = CATASTROPHIC FAILURE RATE

m = MISSION FAILURE RATE

s = SYSTEM FAILURE RATE

T = MISSION TIME

e = 2.718...(A CONSTANT)

MAINTAINABILITY

a. **TURN-AROUND TIME - MAX. 30 MINUTES EXCLUSIVE OF REPAIRS AND CONFIGURATION CHANGE TIME**

b. **REACTION TIME (ALERT STATUS) - MAX. 10 MINUTES FOR BRINGING EQUIPMENT INTO OPERATION**

c. ORGANIZATIONAL LEVEL - 4.75 HOURS FLIGHT HOUR SCHEDULED AND OR UNSCHEDULED

FORMULA: $OM = \frac{\text{TOTAL MAINTENANCE HRS.}}{\text{TOTAL FLIGHT HRS.}}$

d. SCHEDULED INSPECTION TB-AVN 23-67 MINIMUM - 300 FLIGHT HOURS

FORMULA: SI = MIN.NUMBER OF FLIGHT HOURS BETWEEN INSPECTIONS

e. TIME REPLACEMENT COMPONENTS (DURABILITY)

1. DYNAMICS - 1200 HOURS TBO (OR INDEFINITE)
2. RETIREMENT LIFE (WEAR PARTS) (NONE OR MIN. 3600 HRS.)

f. TACTICAL AVAILABILITY 75% (24 HOUR REQUIREMENT) ARMY TO PROVIDE CONTRACTOR WITH PREDICTED RATE OF FLYING HOURS PER DAY AND AVERAGE FLYING HOURS PER MONTH. (NORMALLY AROUND THE CLOCK OPERATION).

FORMULA: $P(\text{AVAIL}) = 1-e^{-ut}(1-e^{-fT})$

WHERE u = AVERAGE TIME TO REPAIR

t = MAX. ALLOWABLE TIME TO REPAIR

T = MISSION TIME

f = FAILURE RATE

e = 2.718...(A CONSTANT)

C. Other factors which must be considered during design are:

1. PRODUCIBILITY - The contractor must, in the producibility engineering phase, institute a program to analyse and assure that the system component design is acceptable for quantity production and within present or improved state of the art, for production methods. Components and supply parts of a system must be interchangeable and/or replaceable, any changes which may affect these items must be approved by the Army Aviation configuration control board, which is a board for reviewing and approving engineering changes or modifications.

2. VALUE ENGINEERING - The contractor is required to establish a value engineering program directed at analyzing the functions of the subsystems and components to achieve the required function at the lowest overall costs consistent with performance requirements. The objective of this program is to reduce the costs before and during the qualification test stages, research, development, and test, evaluation, and production of the system. (In other words, get maximum performance and eliminate the gold plating!) For cost effectiveness, the optimum design, rather than "too much" or "too little" quality, is the objective.

ANALYSIS FOR VALUE ENGINEERING

a. ELIMINATE GOLD PLATING

b. MAXIMUM PERFORMANCE

c. AFFECT UPON RELIABILITY, QUALITY, ENVIRONMENTAL CHARACTERISTICS

d. COST EFFECTIVENESS STUDIES

3. HUMAN FACTORS - In any weapons system or aircraft program the contractor must establish a human factors program which is directed at analyzing the equipment, procedures, environment, and facilities associated with system functions which are identified as involving human performance; such as, minimizing visual sweep and standardizing operations in the aircraft operation. The objective of this program is to help realize maximum performance of the system - (including the personnel performance) without degradation of system quality or an increase in operating costs. This objective is accomplished by applying human factors engineering principles (during system definition and the acquisition phase) to reduce demands upon

manpower resources in terms of the number of personnel, the diversity of skills (to the lowest possible levels), minimize training, and increase the ability to execute operations with maximum safety; provide for the survival of the human component by applying basic human performance and safety criteria; and avoid the erroneous induction of poor features in the design selection and definition phases.

HUMAN FACTORS ENGINEERING ANALYSIS

a. ENVIRONMENTAL CHARACTERISTICS

b. SYSTEM FUNCTIONS

c. INSTRUCTIONAL AND OPERATING PROCEDURES (SIMPLIFICATION)

d. MINIMUM SKILL (MAINTENANCE & OPERATION LEVELS

e. STANDARDIZATION (AIRCRAFT TYPES) OF INSTRUMENTATION AND OPERATIONAL REQUIREMENTS

4. QUALITY CONTROL - The contractor must establish a program for control of the quality to enhance the Reliability and Maintainability program of the aircraft through complete Quality Control, inspection, tests, and records. The inspection procedures and tolerances submitted should be in accordance with applicable design specification requirements. Tests (conducted under the approved procedures) must be performed to assure that quality is maintained throughout the program. The prime contractor under MIL-Q-9858A is not only responsible for his quality assurance program, but also that of his subcontractors and vendors. The prime contractor is also responsbile for calibration of inspection and test equipment maintaining the quality of any government furnished equipment, as received, and during

installation and usage, until delivered to the government.

QUALITY CONTROL (MIL-Q-9858A)

a. SUPPORT FOR RELIABILITY AND MAINTAINABILITY PROGRAM

b. CONTRACTOR QUALITY PLAN

c. QUALITY OF TECHNICAL DATA (EVALUATION AND COLLECTION)

d. EVALUATION OF CONTRACTOR (QUALITY CONTROL AND PLANNING AND PRODUCTION DESIGN-CRITICAL ASSESSMENT)

e. TOTAL IMPLEMENTATION OF QUALITY PROGRAM

f. CONTRACT ADMINISTRATION OF QUALITY

g. AUDIT PROGRAM

h. SPECIAL INSTRUCTIONS FOR INSPECTION

i. QUALITY COSTS

j. INDUSTRIAL FABRICATION ENVIRONMENTAL CONTROL

k. CALIBRATION AND MEASUREMENT (METROLOGY)

NOTE: In Igor Bazovsky's book entitled, "Reliability Theory and Practice," comments on quality control place reliability in perspective as follows: "Reliability thus adds a new dimension to quality control work without subcontracting anything from traditional quality control work and methods. It extends quality control work into the time domain, and greatly increases the area of activity and responsibility of the quality control organization into a quality and reliability control organization."

5. TEST DEMONSTRATION is for the purpose of determining the effectiveness of the predicted design parameters.

DEMONSTRATION

a. EVALUATION OF RELIABILITY AND MAINTAINABILITY PREDICTIONS AND DETERMINE ACTUAL VALUES

b. IMPLEMENTATION OF TEST PROGRAM PLANS

c. AFFECT UPON PREDICTED DURABILITY (AVERAGE LIFE TO FAILURE)

d. SYSTEM COMPATIBILITY TESTS

6. ENGINEERING AND QUALITY ASSURANCE TEST PROGRAM (PRODUCT ASSESSMENT) (USATECOM, AVCOM AND CONTRACTOR)

a. TEST PLAN

b. SCHEDULE

c. SURVEILLANCE

d. REPORT A[illegible]TS

e. QUALITY AN[illegible] RELIABILITY IMP[illegible] [illegible] TO PRODUCTION)

f. CONFIRMATORY TEST

g. FOLLOW UP

h. DATA

7. TECHNICAL INTEGRATION - Technical integration is actually a management responsibility and requires the integration of all technical aspects for the overall system performance. This requires that management be constantly aware of the total technical responsibility and that he establish the management controls, necessary to accomplish the total program of cost effectiveness and also provide the government with a reliable, quality product as specified by the contract. The government looks over the contractor's shoulder, during technical integration, when he analyses system requirements to determine if

design compromise is to be made; to achieve priority-for-necessary-effectiveness of system performance, safety, acceptable maintenance levels, acceptable costs, size, durability, weight, and interchangeability.

TECHNICAL INTEGRATION (TRADE-OFF FACTORS)

ANALYSIS OF ACHIEVEMENT AND INTEGRATION

a. EFFECTIVENESS

b. SYSTEM PERFORMANCE

c. HUMAN FACTORS

d. MAINTENANCE

e. OVERALL COST EFFECTIVENESS

f. SIZE

g. DURABILITY

h. WEIGHT

i. INTERCHANGEABILITY

8. The overall Evaluation of Contractor's Performance must include:

EVALUATION OF CONTRACTOR-PROPOSAL AND AIRCRAFT PROGRAM (SUMMARY)

a. RELIABILITY

b. MAINTAINABILITY

c. PRODUCIBILITY

d. VALUE ENGINEERING

e. HUMAN FACTORS

f. TECHNICAL INTEGRATION

g. QUALITY CONTROL

Appendix I provides a check list for evaluating contractor Reliability and Maintainability contract proposals and programs.

D. Training:

1. Mr. Bazovsky said in his book, "Reliability Theory and Practice," "Before any serious reliability work can begin, an education in reliability principles, theory and methods must be offered to all engineering personnel. ---Graduate engineers require about twenty to forty class hours of theory, with examples of reliability problem solving by numerical calculations to establish a sound background in reliability theory and methods from which they can start to develop their own experience in actual reliability work without making grave mistakes."

2. In our estimation, this level of training is necessary for every engineer working in reliability. Therefore, we plan to have an intensive training program throughout the Army Aviation Command.

E. Summary:

We think we have the basic framework of a good sound reliability, maintainability, and quality program.

This work is progressing slowly.

We are in about the same position as most organizations, that of having a grave need of quality feedback data to pinpoint and analyze problems. TAERS should be most helpful in this area along with specific input from contractors.

APPENDIX I

RELIABILITY PROGRAM EVALUATION

CHECKLIST

(Each item to be answered yes or no.)

1. Reliability Program
   a. Is documented.
   b. Encompasses management and technical factors.
   c. Considers all phases of the life cycle.
   d. Interfaces and coordinates related QA activities.
2. Reliability Organization
   a. Identifies organization and personnel responsible for managing the over-all program.
   b. Clearly defines responsibilities and functions including policy, action, and authority.
   c. Relationship in chain of command defined.
3. Management and Control
   a. Detailed listing of specific tasks.
   b. Man-loading per task.
   c. Procedures to implement and control these tasks.
   d. Task description.
   e. Organizational unit responsible for executing each task.
   f. Method of control to insure execution of each task.
   g. Scheduled start and completion date of each task.

h. Milestone chart.

i. Definition of Interrelationships.

j. Estimation of times required for reliability program activities and tasks.

k. PERT is utilized.

4. Program Review

Program is organized and scheduled to permit status review, including status achieved, at preplanned steps or checkpoints.

5. Mathematical Models, Apportionment, Prediction Program

a. Mathematical models based on system analysis.

b. Apportion reliability over major system elements.

c. Initial prediction.

6. Reliability Requirement Studies

a. Provisions for preliminary and continuing studies of reliability requirements.

b. Definition of functional performance limits.

c. Duration of operation in time or cycles.

d. Environmental conditions of operational use.

7. Test Requirements for Development Qualification and Acceptance

a. Estimated achieved reliability of equipment by test.

b. Feedback data for reliability improvements.

c. Test Program

(1) Confirms adequacy of selection of components and parts.

(2) Determines capabilities and safety margins.

(3) Evaluates drift of component parts w/time.

d. Items having significant effect on inherent reliability are tested or validated early in development.

8. <u>Environmental Requirements for Equipment Design and Testing</u>

a. Tests under use-environment are used.

b. Environmental problem areas are identified.

9. <u>Component Parts Testing</u>

a. Component parts used in production equipment are assigned a reliability index.

b. MIL tests are used where applicable.

If contractor's test procedures are used, he presents justification of MIL testing unapplicability.

c. Test data is retained two years from contract completion.

10. <u>Maximum Preacceptance Operation</u>

a. Provides and maintains a list of items having critically limited useful life.

b. Methods of determining maximum allowable operating time are clearly defined and justified.

11. <u>Parts Reliability</u>

a. Uses parts with known reliability determined from current or previous testing.

b. Avoids duplication of testing.

c. Recognizes risks involved using data recorded under different use-environment.

d. Preferred parts list are maintained.

e. Reliability improvement program is included.

12. Furnished Equipment

a. Uses known or estimated reliability values.

b. Reports potential reliability problems and indicate and justifies system changes necessary for efficient system integration.

13. Critical Items

Provides for an effective method for identification, control and special handling of critical parts, components, or subsystems from design through final acceptance.

14. Supplier's and Subcontractor's Reliability Program

a. Supplier and subcontractor (S&S) achieved reliability levels are consistent with over-all system requirements.

b. Imposes quantitative reliability requirements and acceptance criteria on S&S.

c. Incorporates applicable portions of MIL-R-27542 in subcontract and purchase orders.

d. Surveillance of S&S activities include:

(1) Quality Control.

(2) Facilities examination.

15. Reliability Indoctrination and Training

Supplements basic training and indoctrination with regard to advancing technologies and requirements of the system.

16. Statistical Methods

a. Provides for optimum utilization of statistical planning and analysis.

b. Includes such methods as:

(1) Design of experiments.

(2) Analysis of variance.

17. Human Engineering

Human Engineering features are incorporated to minimize the possibility of degrading reliability through human error.

18. Effects of Storage, Shelf-Life, Packaging, Transportation, Handling and Maintenance

a. Determines by test or estimates the above effects on the reliability of the product.

b. Provisions that special requirements or limitations on above actions are made known to the U. S. Army.

19. Design Review

a. Periodic reviews are made of system design.

b. Denotes personnel participating in review and includes their authority.

c. Compares design with previously defined qualitative and quantitative requirements.

d. At least ten days' notice prior to scheduled formal design review is given.

e. Minutes of review are made available.

20. Manufacturing Control and Standards

a. Control of manufacturing processes.

b. Production monitoring.

c. Process Standards and Procedures.

d. Manufacturing personnel job tasks.

e. Reliability consideration for engineering changes.

21. Failure Data Collection, Analysis and Corrective Action

a. Has closed loop system for collecting, analyzing and recording all failures.

b. Describes reporting procedures including flow charts for: Analysis, feedback, and corrective action.

c. Recording differentiates equipment failure from human error in designing, processing, handling, transporting, storing, maintaining, and operating the equipment.

d. Includes provisions to assure effective corrective action.

e. Establishes audit to review all open reports.

22. Reliability Demonstration

a. General Plan

(1) Includes number of test articles or estimate of confidence level.

(2) Includes trade-off curves showing number of test articles and operating test time, or test effort versus confidence.

b. Specific Plans

(1) Includes revisions.

(2) Includes ground rules for classing success, failure, or exclusion of test.

(3) Applies all valid results from which measurement or assessment can be obtained.

(4) Includes Engineering tests and analyses to supplement statistical measures.

(5) Plans are submitted for approval as required to procuring activity.

23. Periodic and Final Reports

a. Provides for intervals not exceeding three months.

b. Provides accounting or progress on each task in program plan.

c. Includes charts and illustrations comparing:

objectives, minimum requirements, predictions, level of achieved reliability.

d. Includes final report in accordance with contract.

DESIGNING

FOR

MAINTAINABILITY

18 MAY 1965

NOTE: This paper was not presented orally at the 19 July 1965 Army Technical Meeting on Quantification of Maintainability

PRESENTED BY
COL. JOHN H. DAVIS
DEPUTY PRESIDENT

US ARMY MAINTENANCE BOARD
FORT KNOX, KENTUCKY

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DESIGNING FOR MAINTAINABILITY

IN ORDER TO DEAL ADEQUATELY WITH THIS SUBJECT, IT IS ESSENTIAL TO DEVELOP SOME DEFINITIONS FOR MAINTENANCE, MAINTAINABILITY, AVAILABILITY, RELIABILITY, AND EFFECTIVENESS. WE WILL DISCUSS THE PROCEDURES FOR SPECIFYING MAINTAINABILITY, THE IMPLEMENTATION OF A MAINTAINABILITY PROGRAM IN A CONTRACTOR'S FACILITY, THE ACTIVITIES OF A DESIGNER, AND LASTLY, A LOOK AT THE FUTURE FROM THE STANDPOINT OF MAINTAINABILITY.

ANYONE WHO HAS DEPENDED UPON, OWNED, OR POSSESSED PROPERTY HAS AT SOME TIME CONCERNED HIMSELF WITH THE PROBLEMS OF SUSTAINING HIS PROPERTY IN A CONDITION WHERE IT WILL PERFORM WITHIN CERTAIN LIMITS. THIS ACTIVITY MAY GENERALLY BE CALLED MAINTENANCE. DESIGNING FOR MAINTAINABILITY IS AN ENTIRELY DIFFERENT ACTIVITY. TO CLARIFY THESE TWO STATEMENTS, IT IS ESSENTIAL THAT WE FIRST EXAMINE MAINTENANCE. I WILL ATTEMPT TO DO THIS BY CATEGORIZING AND CLASSIFYING THE VARIOUS TYPES OF MAINTENANCE AND ELEMENTS OF MAINTENANCE. ONE CLASSIFICATION EMBODIES THE CONCEPT OF PREVENTIVE MAINTENANCE AND CORRECTIVE MAINTENANCE. PREVENTIVE MAINTENANCE IS PLANNED CARE AND SERVICING OF EQUIPMENT BY SYSTEMATIC INSPECTIONS, LUBRICATION, PROTECTION, AND, OF COURSE, CLEANING OF EQUIPMENT. CORRECTIVE MAINTENANCE, ON THE OTHER HAND, IS PERFORMED ON AN UNSCHEDULED BASIS TO RESTORE EQUIPMENT TO SATISFACTORY CONDITION AFTER A MALFUNCTION HAS OCCURRED. IT SHOULD BE EVIDENT THAT SINCE MALFUNCTIONS OCCUR RANDOMLY, THAT CORRECTIVE MAINTENANCE MUST BE DEALT WITH AS A RANDOM ACTIVITY.

LET US NOW EXAMINE SOME OF THE ELEMENTS OF MAINTENANCE, SPECIFICALLY

CORRECTIVE MAINTENANCE. AFTER A FAILURE HAS OCCURRED, IT MUST FIRST BE DETECTED OR EVIDENT TO SOMEBODY THAT IT HAS OCCURRED. THEN COMES THE PHASE OF FAULT ISOLATION. SOMEBODY MUST DETERMINE WHAT HAPPENED. THE NEXT LOGICAL STEP IS TO CORRECT THE FAULT. HOWEVER, THIS MAY NOT BE AS SIMPLE IN THE REAL WORLD AS IT SEEMS BECAUSE HERE IS WHERE WE BEGIN TO RUN INTO THE ADMINISTRATIVE DELAYS OVER WHICH THE DESIGNER HAS LITTLE OR NO CONTROL. IN PASSING, IT SHOULD BE RECOGNIZED THAT FAULT CORRECTION MAY BE CATEGORIZED AS "REMOVE AND REPLACEMENT," OR FIXING OR ADJUSTING THE OFFENDING PART, AND FINALLY THE CHECK-OUT ACTIVITY.

CHART 1 ON

THIS LITTLE CHART SHOWS THE RELATIONSHIP AMONG THESE ELEMENTS OF MAINTENANCE. IT IS IMPORTANT TO NOTE TWO ALTERNATIVE PATHS ON THE CHART.

CHART 1 OFF

LET US LOOK AT A CHART SHOWING THE DISTRIBUTION OF TIME TO PERFORM THESE ELEMENTS.

CHART 2 ON

PLEASE NOTE ITEM H "CONTINGENCY ITEMS," AND THAT THIS CONSUMES 38% OF THE TIME TO DO MAINTENANCE. THIS ELEMENT DOES NOT CONTRIBUTE PRODUCTIVELY TO MAINTENANCE SINCE IT CONSISTS OF ADMINISTRATIVE DELAYS. THE DATA IS BASED ON AN ANALYSIS OF 101 TASK MEASUREMENTS TAKEN ON THREE DIFFERENT EQUIPMENTS.

CHART 2 OFF

THERE ARE TWO OTHER CATEGORIZATIONS OF MAINTENANCE WHICH SHOULD BE MENTIONED IN PASSING. ONE OF THEM DEALS WITH WHERE THE MAINTENANCE IS

DONE OR BY WHOM IT IS DONE. IN THE ARMY WE CALL IT ORGANIZATIONAL, DIRECT SUPPORT, GENERAL SUPPORT, AND DEPOT. IN THE AIR FORCE IT IS CATEGORIZED AS ORGANIZATIONAL, INTERMEDIATE, AND DEPOT. THIS CATEGORIZATION REFLECTS SKILL LEVELS AND FACILITIES AVAILABLE. THE SECOND CATEGORIZATION REFERRED TO ABOVE IS WHETHER THE WORK IS DONE WITH THE SYSTEM OPERATING OR NOT OPERATING (I.E., A MISSILE). THIS DISCUSSION SO FAR DEALS WITH MAINTENANCE, BUT NOT MAINTAINABILITY, RELIABILITY, AVAILABILITY, OR EFFECTIVENESS.

NOW THE USER IS PRIMARILY CONCERNED WITH THE EFFECTIVENESS OF MATERIEL OR THE PROBABILITY THAT IT WILL DO THE JOB AT HAND. WE WILL DEFINE EFFECTIVENESS AS A PRODUCT OF RELIABILITY, AVAILABILITY, AND PERFORMANCE.

CHART 3 ON

CHART 3 OFF

TO SIMPLIFY OUR DISCUSSION, WE WILL ASSUME THAT THE FIGURE OF MERIT OR VALUE OF PERFORMANCE IS ONE, THAT IS TO SAY, WHEN THE EQUIPMENT IS FUNCTIONING PROPERLY, IT CAN DO WHAT IT WAS INTENDED TO DO. RELIABILITY IN THIS DEFINITION IS DEFINED AS THE PROBABILITY THAT THE ITEM WILL PERFORM ITS INTENDED TASK FOR A SPECIFIC LENGTH OF TIME (MISSION TIME) IN A SPECIFIED ENVIRONMENT WITH THE ASSUMPTION THAT IT WAS OPERATING PROPERLY AT THE BEGINNING.

CHART 4 ON

CHART 4 OFF

THE NEXT TERM WHICH NEEDS DEFINING IS AVAILABILITY. AVAILABILITY IS DEFINED AS USE-TIME DIVIDED BY USE-TIME PLUS MAINTENANCE TIME.

CHART 5 ON

PLEASE NOTE THAT WE CALL USE-TIME MTBF, WHICH IS MEANTIME BETWEEN FAILURES AND REPAIR TIME AS MTR, MEANTIME TO REPAIR. MTBF IS CALCULATED BY ADDING TIME TO THE FIRST FAILURE PLUS TIME TO THE SECOND FAILURE AND SO FORTH DIVIDED BY NUMBER OF FAILURES. MTR IS SIMILARLY CALCULATED. THIS FORMULA CAN BE REWRITTEN AS MTR EQUAL TO MTBF TIMES ONE OVER AVAILABILITY MINUS ONE. ALSO PLEASE NOTE THAT THESE DEFINITIONS INVOLVE PROBABILITIES SINCE THEY DEAL WITH RANDOM VARIABLES.

CHART 5 OFF

TO LAY A PROPER FOUNDATION FOR WHAT IS TO FOLLOW, LET US EXAMINE THE WORD PROBABILITY FOR THE MOMENT. THE PROBABILITY OF AN EVENT CAN BE EXPRESSED NUMERICALLY AS SOME VALUE EQUAL TO OR GREATER THAN ZERO AND LESS THAN OR EQUAL TO ONE. PROBABILITY CAN BE ILLUSTRATED BY MEANS OF PROBABILITY DISTRIBUTIONS AND WE WILL DEAL WITH THREE TYPES, EXPONENTIAL, NORMAL, AND LOG NORMAL.

THE EXPONENTIAL DISTRIBUTION REPRESENTS THE PROBABILITY OF AN EVENT OR FAILURE WHERE THE HAZARD RATE IS CONSTANT; THAT IS TO SAY, THE CHANCE OF ANY ITEM FAILING IS THE SAME AT ONE TIME AS ANOTHER. IT TYPIFIES THE PERFORMANCE OF EQUIPMENT AFTER THE INITIAL RASH OF FAILURES DUE TO IMPROPER ASSEMBLY, MATERIEL DEFECTS, ETC., AND BEFORE THE EFFECTS OF WEAR OUT TAKE PLACE.

CHART 6 ON (BATHTUB CURVE)

THIS IS REPRESENTED BY THE FLAT PART OF THIS CURVE.

CHART 6 OFF

CHART 7 ON

THIS IS THE EXPONENTIAL FUNCTION IN ITS SIMPLEST FORM. Y IS EQUAL TO e^{-x}. e IS THE BASE OF THE NATURAL LOGARITHMS AND IS APPROXIMATELY 2.718. THE AREA TO THE RIGHT OF X EQUAL TO 1 IS 37% AND THE AREA TO THE LEFT IS 63%.

CHART 7 OFF

NOW, LET US APPLY THIS BIT OF THEORY TO THE PROBLEM OF EXPRESSING QUANTITATIVELY THE ATTRIBUTE OF RELIABILITY.

CHART 8 ON

HERE WE SEE THE SAME FUNCTION EXCEPT THAT Y NOW REPRESENTS THE FREQUENCY OF FAILURE $f(t)$, THE INDEPENDENT VARIABLE, AND MTBF IS MEANTIME BETWEEN FAILURE OR "CHARACTERISTIC LIFE" AND IS CONSTANT IN ACCORDANCE WITH THE FLAT PART OF THE BATHTUB CURVE. AT A TIME t_1, THE NUMBER OF ITEMS WHICH HAVE FAILED IS REPRESENTED BY THE AREA UNDER THE CURVE TO THE LEFT OF t_1. THIS AREA CALLED $F(t)$ AND EQUAL TO $\int_0^t f(t)dt$ IS EQUAL TO $\int_0^t \frac{1}{MTBF} e^{-\frac{t}{MTBF}} dt$ IS EQUAL TO $-e^{-\frac{t}{MTBF}}\Big|_0^t$ IS EQUAL TO $1-e^{-\frac{t}{MTBF}}$. THIS IS A PLOT OF $F(t)$ AND THE AREA TO THE LEFT OF t_1 IS REPRESENTED BY THE HEIGHT OF $F(t)$. SINCE THIS REPRESENTS THE FAILED ITEMS, RELIABILITY IS REPRESENTED BY $1-(1-e^{-\frac{t}{MTBF}})$ WHICH IS EQUAL TO $e^{-\frac{t}{MTBF}}$. FOR EXAMPLE, IF MTBF IS EQUAL TO 60 HOURS AND MISSION TIME IS EQUAL TO FIVE HOURS, RELIABILITY FOR FIVE HOURS IS EQUAL TO $e^{-\frac{5}{60}}$ IS EQUAL TO $\frac{1}{e^{.083}}$ IS EQUAL TO $\frac{1}{1.087}$ = .92. PLEASE NOTE THAT $\frac{1}{MTBF}$ IS NECESSARY IN $f(t)$ SO THAT THE TOTAL AREA UNDER $F(t)$ WILL BE ONE SINCE PROBABILITY IS EQUAL TO OR GREATER THAN ZERO AND EQUAL TO OR LESS THAN ONE.

CHART 8 OFF

THE NEXT IS THE NORMAL DISTRIBUTION OR THE FAMILIAR BELL-SHAPED CURVE. IT EXEMPLIFIES A SITUATION WHERE THE HAZARD RATE IS INCREASING AND THE FAILURES ARE EQUALLY DISTRIBUTED ON BOTH SIDES OF AN MTBF.

CHART 9 ON

HERE IS THE NORMAL DISTRIBUTION IN ITS SIMPLEST FORM. Y IS EQUAL TO e^{-x^2}, $-\infty < x < \infty$. NOW LET'S ADAPT THIS SIMPLIFIED FUNCTION SO THAT IT IS USABLE. $f(t) = \frac{1}{\sqrt{2\pi}S} e^{-\frac{1}{2}\left(\frac{t-M}{S}\right)^2}$. AGAIN $f(t)$ IS SUBSTITUTED FOR Y AND $\frac{1}{\sqrt{2\pi}S}$ IS INCLUDED TO ASSURE THAT THE AREA UNDER THE CURVE IS EQUAL TO ONE. NOTE THAT WE HAVE CHANGED x^2 to $\frac{1}{2}\left(\frac{t-M}{S}\right)^2$ AND INTRODUCED A NEW PARAMETER S. ALSO THAT M WILL BE USED INSTEAD OF MTBF. USING $t-M$ INSTEAD OF t ENABLES US TO SHIFT THE CURVE FROM BEING CENTERED ABOUT ZERO TO THE POINT M ON THE X AXIS.

CHART 9 OFF

CHART 10 ON

M IS CALCULATED AS FOLLOWS. M IS EQUAL TO $\frac{1}{n}\sum_{i=1}^{n} x_i$ IS EQUAL TO $\frac{x_1 + x_2 + \cdots + x_n}{n}$. NOW LET'S DISCUSS THE PARAMETER S. S IS EQUAL TO THE STANDARD DEVIATION. S IS A MEASURE OF VARIANCE OR SPREAD. S^2 IS EQUAL TO VARIANCE. S^2 IS CALCULATED AS FOLLOWS:

S^2 IS EQUAL TO $\frac{\sum_{i=1}^{n}(x_i - M)^2}{n-1}$ IS EQUAL TO $\frac{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}{n(n-1)}$.

CHART 10 OFF

CHART 11 ON

TO ILLUSTRATE WITH SOME SPECIFIC NUMBERS. READ FROM CHART.

CHART 11 OFF

CHART 12 ON

THIS CHART FURTHER ILLUSTRATES THE SIGNIFICANCE OF S.

*ONE S ON EITHER SIDE OF M INCLUDES APPROXIMATELY 68% OF THE AREA.

*TWO S ON EITHER SIDE OF M INCLUDES APPROXIMATELY 95% OF THE AREA.

*THREE S ON EITHER SIDE OF M INCLUDES 99.74% OF THE AREA.

TO THE RIGHT IS A PLOT OF $F(t)$. HERE AGAIN THE HEIGHT OF $F(t)$ REPRESENTS THE AREA UNDER $f(t)$ TO THE LEFT OF SOME t.

CHART 12 OFF

CHART 13 ON

THE LOG NORMAL DISTRIBUTION IS THE ONE THAT IS FUNDAMENTAL TO MAINTAINABILITY AND IT IS A SKEWED CURVE. IT IS GENERALLY REPRESENTATIVE OF TIME, t, TO MAKE REPAIR. IF t IS A RANDOM VARIABLE WHICH HAS A LOG NORMAL DISTRIBUTION, THEN LOG t WILL HAVE A NORMAL DISTRIBUTION. MATHEMATICALLY, A VARIABLE t HAS A LOG NORMAL DISTRIBUTION IF $f(t)$ IS EQUAL TO $\frac{1}{\sqrt{2\pi}\,\mathrm{LOG}\,S}\, e^{-\frac{1}{2}\left[\frac{\mathrm{LOG}\,t-\mathrm{LOG}\,M}{\mathrm{LOG}\,S}\right]^2}$, $0 < t < \infty$.

TO REPEAT - IF t IS A RANDOM VARIABLE WHICH HAS A LOG NORMAL DISTRIBUTION THEN LOG t WILL HAVE A NORMAL DISTRIBUTION.

CHART 13 OFF

CHART 14 ON

$$\mathrm{LOG}\,M = \sum_{i=1}^{n} \mathrm{LOG}\,x_i, \quad (\mathrm{LOG}\,S)^2 = \frac{\sum (\mathrm{LOG}\,x_i - \mathrm{LOG}\,M)^2}{n-1}$$

CHART 14 OFF

CHART 15 ON

HERE IS AN ACTUAL PLOT OF TIMES TO REPAIR. NOTE THE LOG NORMAL SHAPE AND THAT M OR MTR (MEAN VALUE) IS 2.29 HOURS AND S IS 2.23 HOURS.

CHART 15 OFF

LET US NOW REVIEW THE LAST FEW COMMENTS BY MEANS OF A SPECIFIC EXAMPLE.

CHART 16 ON

AN AIRBORNE COMMUNICATION CENTRAL IS TO BE DEVELOPED TO MEET A SPECIFIED EFFECTIVENESS OF .90; THAT IS, IT MUST BE CAPABLE OF OPERATING ON DEMAND NINE TIMES IN TEN THROUGHOUT A FIVE HOUR MISSION. INITIAL STUDIES INDICATE THAT A RELIABILITY FOR A FIVE HOUR MISSION OF .92 IS FEASIBLE. THUS, AN AVAILABILITY REQUIREMENT OF APPROXIMATELY .98 MUST BE MET TO SATISFY THE EFFECTIVENESS REQUIREMENT. THIS IS DETERMINED BY DIVIDING AVAILABILITY BY RELIABILITY AND PERFORMANCE - ASSUMING PERFORMANCE = 1. NOW REMEMBER THAT AVAILABILITY IS EQUAL TO MTBF DIVIDED BY MTBF PLUS MTR OR MTR IS EQUAL TO MTBF TIMES ONE OVER AVAILABILITY MINUS ONE. ASSUMING THE COMMUNICATIONS CENTRAL HAS A FAILURE DISTRIBUTION DESCRIBED BY THE EXPONENTIAL, THAT IS WITH A CONSTANT HAZARD RATE OR CONSTANT MEANTIME BETWEEN FAILURE, WE CALCULATE MTBF TO BE 60 HOURS. APPLYING THIS IN THE FORMULA FOR MEANTIME TO REPAIR, WE CALCULATE MTR EQUAL TO 1.2 HOURS. THIS IS THE BASIC MEASURE OF MAINTAINABILITY THAT THE EQUIPMENT MUST BE DESIGNED TO ACHIEVE IN ORDER TO SATISFY THE 90% EFFECTIVENESS FOR A FIVE HOUR MISSION WITH 92% RELIABILITY FOR FIVE HOURS.

CHART 16 OFF

UP TO THIS POINT, WE HAVE DERIVED AND USED IN AN EXAMPLE THE BASIC ENGINEERING MODELS FOR EFFECTIVENESS, AVAILABILITY, RELIABILITY, AND MAINTAINABILITY. LET ME EMPHASIZE, HOWEVER, THAT IT REPRESENTS A GROSS OVERSIMPLIFICATION. FOR INSTANCE, IN THE MODELS WE HAVE USED ONLY THE MEANS TO REPRESENT THE ACTUAL PROBABILITY DISTRIBUTIONS INVOLVED. CONSEQUENTLY OUR RESULTS ARE ONLY IN TERMS OF MEANS OR AVERAGES. WE DEVELOPED THE STANDARD DEVIATION AS A MEASURE OF THE SPREAD OF A DISTRIBUTION AND SHOWED ITS SIGNIFICANCE. IT WOULD THEREFORE BE NECESSARY

TO EMPLOY MORE COMPLEX MODELS IN ORDER TO ACTUALLY KNOW JUST WHAT THE AVAILABILITY WOULD BE. FURTHER, WE HAVE DEALT WITH ONLY AN INADEQUATELY DEFINED STATISTIC MTR. IN ACTUALITY MTR IS A COLLECTION OF DISTRIBUTION OF THE DETERMINANTS OF MAINTENANCE AS DISCUSSED EARLIER.

CHART 17 ON

THIS SHOULD GIVE YOU SOME APPRECIATION OF THE COMPLEXITY OF MTR.

CHART 17 OFF

SPECIFYING MAINTAINABILITY

WITH THIS TECHNICAL BACKGROUND LAID, LET US NOW DISCUSS THE SUBJECT OF SPECIFYING MAINTAINABILITY. THE UNDERLYING PRINCIPLE HERE IS THAT YOU WILL GET ONLY WHAT YOU CONTRACT FOR AND ARE WILLING TO PAY FOR. AND MOST IMPORTANT OF ALL --- PAY TO HAVE DEMONSTRATED THAT YOU ARE GETTING WHAT YOU CONTRACTED FOR.

TO REVIEW IN DETAIL THE MILITARY SPECIFICATIONS AVAILABLE TODAY DEALING WITH MAINTAINABILITY IS IMPOSSIBLE IN THE TIME REMAINING. HERE IS A PARTIAL LIST.

CHART 18 ON

CHART 18 OFF

LET US REVIEW THE NEEDS OF TODAY DEVELOPED BY MR. JOHN E. LOSEE OF REPUBLIC AVIATION WITH RESPECT TO THIS SUBJECT.

FIRST FROM THE STANDPOINT OF THE CUSTOMER -

CHART 19 ON

1. QUANTITATIVELY ACHIEVABLE GOALS SHOULD BE SPELLED OUT BY THE CUSTOMER, OR DEVELOPED BY THE CONTRACTOR AND APPROVED BY THE CUSTOMER.

2. ALL LEVELS OF MAINTENANCE SHOULD BE COVERED BY THE M SPECIFICATIONS.

3. DOCUMENTATION OF THE M ELEMENTS SHOULD BE MADE SIMULTANEOUSLY AT THE TIME OF DESIGN REVIEW.

4. TRADE-OFFS SHOULD BE MADE IN TERMS OF DOWNTIME AND DOLLARS AS LONG AS THE UPPER BOUND OF THE SUPPORT RESOURCE CAPABILITY IS NOT EXCEEDED.

5. TECHNIQUES AND DATA USED IN M MUST BE STANDARDIZED IF WE ARE TO BE ABLE TO COMPETE AND BE EVALUATED ON A COMPETITIVE BASIS.

6. M TO BE EFFECTIVE SHOULD START AT THE CONCEPTUAL STAGE AND FOLLOW THROUGHOUT PRODUCT IMPROVEMENT.

7. SPECIFICATIONS SHOULD STATE THEIR SCOPE CLEARLY AND NOT TRY TO BE "ALL THINGS" TO ALL PRODUCTS.

CHART 19 OFF

HERE IS AN EVALUATION MATRIX OF THESE NEEDS VS THE LIST OF SPECIFICATIONS.

CHART 20 ON

CHART 20 OFF

CHART 21 ON

NOW HERE ARE THE NEEDS FROM THE CONTRACTORS STANDPOINT.

CHART 21 OFF

PROGRESS SO FAR IS EXEMPLIFIED BY THIS LIST

CHART 22 ON

OF PROJECTS WITH CONTRACTUAL MAINTAINABILITY REQUIREMENTS.

CHART 22 OFF

IMPLEMENTATION

TO ASSURE THAT MAINTAINABILITY OBJECTIVES ARE ACHIEVED, A MAINTAINABILITY PROGRAM MUST BE IMPLEMENTED TO RUN CONCURRENT WITH EQUIPMENT

DESIGN, DEVELOPMENT, PRODUCTION, AND FIELD OPERATION. SUCH A PROGRAM IS ESTABLISHED TO MEET THE REQUIREMENTS OF MILITARY SPECIFICATIONS CALLING FOR MAXIMUM EQUIPMENT AVAILABILITY AND REDUCED MAINTENANCE COSTS. THE FOLLOWING DESCRIBES THE ORGANIZATION, PROGRAM TASKS, AND MAJOR MILESTONES IN A COMPREHENSIVE MAINTAINABILITY PROGRAM.

THE MAINTAINABILITY MANAGEMENT CONTROL FUNCTION MUST PROVIDE FOR INTEGRATION OF EFFORTS AND OPERATIONS UP THROUGH HIGH ORGANIZATIONAL LEVELS. THE MAGNITUDE AND SPECIALIZED NATURE OF MOST LARGE MAINTAINABILITY PROGRAMS PREVENT THEIR EFFICIENT ACCOMPLISHMENT AS AN ADDITIONAL DUTY OF THE EXISTING STAFF OF ENGINEERS, SUPERVISORS, AND MANAGERS. TO BE EFFECTIVE, SUCH A PROGRAM MUST BE LED BY A SPECIAL GROUP IN WHICH IS VESTED THE RESPONSIBILITY FOR THE MAINTAINABILITY EFFORT, ORGANIZATION, AND RULES. PERSONNEL TRAINED IN MAINTAINABILITY TECHNOLOGY SHOULD BE EMPLOYED IN EACH PHASE OF THE PROGRAM FROM PRELIMINARY PLANNING THROUGH FINAL FIELD EVALUATION. IT IS IMPORTANT THAT SPECIFIC ASSIGNMENTS BE MADE TO ACCOMPLISH THE NECESSARY TASKS DURING THE DEVELOPMENT CYCLE, AND THAT THESE TASKS BE COORDINATED IN EACH STAGE OF EQUIPMENT GROWTH.

HERE IS A SHORT LIST OF THE TYPES OF PERSONNEL NECESSARY TO A CONTRACTOR.

CHART 23 ON

MAINTAINABILITY ENGINEER

MAINTENANCE SERVICE SPECIALIST

DESIGN ANALYST

DATA ANALYST

MAINTAINABILITY MONITOR

CONSULTANTS

STATISTICIAN

MATHEMATICIAN

HUMAN FACTORS SPECIALIST

CHART 23 OFF

ACHIEVING TIME OBJECTIVES OF A MAINTAINABILITY PROGRAM INVOLVES A NUMBER OF TASKS. EACH IS A MAJOR REQUIREMENT IN ASSURING A COMPREHENSIVE PROGRAM. THEY WILL, OF COURSE, VARY IN SCOPE CONSISTENT WITH THE PARTICULAR END ITEM.

CHART 24A ON

READ FROM CHART.

CHART 24A OFF

CHART 24B ON

READ FROM CHART.

CHART 24B OFF

ACTIVITIES OF A DESIGNER

THE MAINTAINABILITY REQUIREMENT OF A SYSTEM MUST FIRST BE APPORTIONED AMONG THE SUBSYSTEMS, THEN THE COMPONENTS, ETC. IN OTHER WORDS A DETERMINATION MUST BE MADE BY ENGINEERING MANAGEMENT IN THE CONTRACTORS FACILITY AS TO HOW MUCH EACH SUBSYSTEM, COMPONENT, ETC. WILL BE ALLOWED TO CONTRIBUTE TO THE OVERALL MAINTENANCE REQUIREMENT OF THE SYSTEM.

THIS SAME TYPE OF APPORTIONMENT MUST, OF COURSE, BE DONE FOR RELIABILITY, COST, AND WEIGHT, TO ASSURE THAT THE SYSTEMS ARE WITHIN CONTRACTURAL RESTRAINTS. IN THIS WAY EACH DESIGNER HAS A SO CALLED BUDGET FOR EACH OF THESE ATTRIBUTES THAT HE MUST DESIGN TO.

WITH RESPECT TO MAINTAINABILITY THE DESIGNER MUST CONSIDER THE FOLLOWING:

CHART 25 ON

THE MAINTENANCE CONCEPT

THE MAINTENANCE ENVIRONMENT

FACILITIES AVAILABLE

COMMON AND SPECIAL TOOLS

SKILL LEVEL OF MAINTENANCE PERSONNEL

OPERATION USE OF SYSTEM

REACTION TIME

TURN AROUND TIME

RELIABILITY

HUMAN FACTORS

TEST EQUIPMENT

THESE REPRESENT THE CONSTRAINTS IMPOSED UPON THE DESIGN. CONSEQUENTLY THEY MUST BE UNEQUIVOCALLY AND UNAMBIGUOUSLY STIPULATED CONTRACTUALLY IF THE USERS NEEDS ARE TO BE SATIATED. OBVIOUSLY, TRADE-OFFS AMONG THESE RESTRAINTS ARE NECESSARY IF THE DESIGN IS TO REPRESENT THE CURRENT STATE OF THE ART. IT THEREFORE FOLLOWS THAT THE RELATIVE VALUE OF THESE TRADE-OFFS MUST ALSO BE UNEQUIVOCALLY AND UNAMBIGUOUSLY STIPULATED.

CHART 25 OFF

NOW IN ADDITION TO THE ROOM TO MANEUVER AS EXEMPLIFIED BY THE CONTRACTUALLY STATED ACCEPTABLE TRADE-OFFS, THE DESIGNER HAS A GROUP OF DESIGN FEATURES THAT HE IS FREE TO MANIPULATE USUALLY WITHOUT CONTRACTUAL RESTRAINT. SOME OF THESE ARE:

CHART 26 ON

FAULT INDICATORS

TEST POINTS

EXTERNAL TEST EQUIPMENT

ACCESS

ADJUSTMENTS

LABELING

COLOR CODING

PROTECTIVE DEVICES

MURPHY LAW FEATURES

CIRCUIT DESIGNS

COMPONENT SELECTION

LUBRICANTS, FUELS, COOLANTS, ETC.

MATERIEL

MATERIEL FINISHES

MATERIEL HEAT TREATMENT

FASTENERS

CONNECTORS

PACKAGING

MODULES

THE LIST IS INTERMINABLE.

CHART 26 OFF

NOW I WANT TO GIVE YOU ONE CHART THAT EXEMPLIFIES THE IMPORTANCE OF THE DESIGNER IN THIS WHOLE PROCESS.

CHART 27 ON

THERE IS LITTLE I CAN SAY TO EMPHASIZE THIS OTHER THAN THAT THE WHOLE WORLD OF REQUIREMENTS MUST FLOW THROUGH THIS MAN'S EYES, EARS, BRAIN, AND HANDS TO PRODUCE THE LINE ON THE PAPER AND THE WORDS IN THE TECHNICAL REPORTS THAT DETERMINE JUST EXACTLY WHAT THE EQUIPMENT WILL BE LIKE. YES, HE DOES HAVE A FEW TOOLS AT HIS DISPOSAL. A SLIDE RULE, A DRAFTING MACHINE, PENCILS, ERASERS, PAPER, A LIBRARY OF ENGINEERING HANDBOOKS, STANDARD PARTS CATALOG, MATERIALS SPECIFICATIONS, AND OCCASIONALLY A COMPUTER. AND IT IS WITH THESE AND HIS PERSISTENCE, PATIENCE, EXPERIENCE, AND BRAIN, THAT HE PRODUCES OUR CARS, GUNS, AND SPACECRAFT AND KEEPS THEIR MAINTAINABILITY WITHIN THE CONFINES OF THE LOG NORMAL DISTRIBUTION OF TIME TO REPAIR.

DURING THE YEARS SINCE 1946, A GREAT MANY EFFORTS HAVE BEEN MADE TO PORTRAY DO'S AND DON'TS IN WHAT WAS FIRST EASE OF MAINTENANCE AND LATER BECAME MAINTAINABILITY. THE AUTOMOTIVE DIVISION, DEVELOPMENT AND PROOF SERVICE DEVELOPED SEVERAL VOLUMES OF HANDBOOKS FOR COMBAT AND TACTICAL VEHICLE DESIGN, AND LATER THE ORDNANCE TANK-AUTOMOTIVE COMMAND DEVELOPED A SERIES OF DESIGN HANDBOOKS. FOR ORDNANCE DURING ITS EXISTENCE, THESE EFFORTS CULMINATED IN A SERIES OF ABOUT 50 ORDNANCE ENGINEERING DESIGN HANDBOOKS WITH A BASIC MANUAL FOR MAINTENANCE (HOLD UP). HERE IS ANOTHER UNDER AMC FOR THE MISSILE COMMAND. THIS IS ONE OF OVER 75 OF THESE NEWER ISSUES. IF YOU CHANCE TO EXAMINE THESE, YOU WILL NOTE A WIDE DIFFERENCE IN APPROACH.

REGARDLESS OF APPROACH, THE REALLY CRITICAL POINT IS WHAT DID YOU FORCE THE CONTRACTOR TO DO? REMEMBER MY EARLIER COMMENTS ABOUT THE MAINTAINABILITY SPECIFICATION? YOU MUST CONTRACT FOR WHAT YOU WANT. YOU HAVE TO BE ABLE TO STATE WHAT YOU WANT, AND YOU MUST DETERMINE THAT YOU RECEIVED IT. (EXAMPLE OF DETAILS AND CALL OUT DRAWINGS.)

CHART 27 OFF

A LOOK AT THE FUTURE

MAINTAINABILITY HAS LAGGED RELIABILITY IN ITS EVOLUTIONARY DEVELOPMENT BECAUSE IT IS MORE COMPLEX AND BECAUSE THE HUMAN ELEMENT IS MORE PREDOMINANT. IT IS IN THE AREAS OF PREDICTION AND DESIGN THAT THE GAP BETWEEN THE TWO DISCIPLINES IS SO APPARENT. AT THE PRESENT TIME, THERE ARE NO SUBSTANTIAL HANDBOOK TYPE DATA AVAILABLE, PARTICULARLY IN THE MECHANICAL AND ELECTRO-MECHANICAL FIELDS. FOR INSTANCE, THERE IS NO REFERENCE AVAILABLE TO A DESIGNER TO DETERMINE HOW LONG IT WOULD TAKE TO REMOVE AND REPLACE AN OIL PUMP IN A TANK ENGINE. THE INFLUENCING PARAMETERS HAVE NOT BEEN IDENTIFIED AND INTERRELATED. I WOULD PREDICT THAT THIS PROBLEM WILL NOT SEE A START OF A SOLUTION UNTIL 1967 AND BE COMPLETELY SOLVED UNTIL 1970.

PREVENTIVE MAINTENANCE CAN EITHER IMPROVE OR DEGRADE THE MAINTAINABILITY OF AN EQUIPMENT, DEPENDING PRINCIPALLY UPON THE DISTRIBUTION OF LIFE TIMES UNDERLYING THE PARTS REPLACED. PRESENT PRACTICE WITH REGARD TO THE USE AND SCHEDULING OF PREVENTIVE MAINTENANCE IS BASED UPON LITTLE MORE THAN GUESS-WORK. THE NEED EXISTS FOR A STUDY TO IDENTIFY THE PART TYPES AND MAINTENANCE TASKS WHICH SHOULD BE SUBJECTS OF PREVENTIVE MAINTENANCE AND THE CONDITIONS (INCLUDING TIME) UNDER WHICH SPECIFIC MAINTENANCE ACTIONS SHOULD BE PERFORMED. IT SHOULD INCLUDE:

(A) THE COLLECTION, AS REQUIRED, ANALYSIS AND ORGANIZATION OF GENERAL GUIDELINES CONSISTING OF DEGRADATION CHARACTERISTICS OF PARTS WHICH ARE AMENABLE TO PREVENTIVE MAINTENANCE SCHEDULES.

(B) DEVELOPMENT AND COMPILATION OF A COMPREHENSIVE SCHEDULE OF MEAN-TIME-TO-REPAIR FOR EACH TYPE OF PREVENTIVE MAINTENANCE TASK.

(C) USE OF THE INFORMATION DEVELOPED IN (A) AND (B) TO ESTABLISH THE VALUE OF K IN THE RELATIONSHIP PREVENTIVE MTR = K TIMES CORRECTIVE MTR.

1966 IS A REASONABLE DATE FOR SOLUTION OF THIS PROBLEM WITH RESPECT TO ELECTRONIC EQUIPMENT AND 1969 FOR MECHANICAL EQUIPMENT.

PAST STUDIES HAVE SHOWN THAT THE TIME DEVOTED TO DIAGNOSIS OF FAILURE IS BY FAR THE BIGGEST PART OF THE TOTAL DOWNTIME INTERVAL, EXCEPT FOR

ADMINISTRATIVE DELAYS. WITH SYSTEMS BECOMING MORE COMPLEX AND WITH THE INCREASING APPLICATION OF MICROELECTRONIC CIRCUITS, THERE IS A NEED FOR THE DEVELOPMENT AND APPLICATION OF NEW APPROACHES TO SOLVING THIS PROBLEM.

IN FAULT LOCATION WE NEED SIMPLIFICATION AND STANDARDIZATION. WE NEED TO SURVEY THE VARIOUS APPROACHES TO FAULT LOCATION AND TO IDENTIFY, FOR INTERIM STANDARDIZATION, THOSE WHICH OFFER ADEQUATE CAPABILITY IN MOST SIMPLE FORM. DATA DERIVED FROM MAINTAINABILITY PREDICTION AND RELIABILITY STUDIES SHOULD BE USEFUL IN IDENTIFYING EQUIPMENT AREAS IN GREATEST NEED OF FAULT LOCATION. CRITERIA SHOULD ALSO BE DEVELOPED TO ENABLE THE DESIGNER TO KNOW WHAT THE OPTIMUM DEPTH OF PENETRATION OF FAULT LOCATION IS; HOW FAR INTO THE EQUIPMENT'S "INNARDS" SHOULD HE GO? (MODULAR DESIGN)

FAILURE PREDICTION, OR CATCHING SOMETHING BEFORE IT FAILS, WILL BECOME MORE IMPORTANT AS DEGRADATION AND DRIFT FAILURES BEGIN TO PREDOMINATE. NEW DIAGNOSTIC TOOLS ARE NEEDED TO DETERMINE THOSE PARAMETERS WHICH ARE PRECURSORS OF DRIFT FAILURES, AND RAPID METHODS FOR THEIR MEASUREMENT. THIS IS PARTICULARLY TRUE OF THE NEW TECHNOLOGY OF MICROELECTRONICS.

ALTHOUGH THERE HAVE BEEN MANY STUDIES OF VARIOUS THEORETICAL APPROACHES TO OPTIMUM FAULT LOCATION AND AUTOMATIC CHECKOUT TECHNIQUES, FEW, IF ANY, HAVE BECOME CONVERTED TO OPERATIONAL HARDWARE. THIS IS BECAUSE THERE ARE EITHER NO QUANTITATIVE MAINTAINABILITY REQUIREMENTS TO BE MET, OR TIME AND COST CONSTRAINTS PREVENT THE DESIGN OF THE OPTIMUM MAINTENANCE SYSTEM. AS SYSTEMS INCREASE IN COMPLEXITY AND QUANTITATIVE MAINTAINABILITY REQUIREMENTS BECOME THE RULE RATHER THAN THE EXCEPTION, WE SHALL SEE GREATER APPLICATION OF THE TOOLS OF FAILURE DIAGNOSIS THAT HAVE BEEN LANGUISHING ON THE SHELF. IF THE TECHNOLOGY CONTINUES TO EVOLVE AS RAPIDLY AS IT HAS OF LATE, THIS AREA MIGHT FIND ITSELF "LEAPFROGGED" BY THE DESIGNER'S ABILITY TO DESIGN AROUND FAILURES THROUGH APPLICATION OF TECHNIQUES SUCH AS REDUNDANCY AND ADAPTIVE MECHANISMS.

REDUNDANCY HAS BEEN THE SUBJECT OF EXTENSIVE STUDY DURING THE PAST FEW YEARS. MATHEMATICAL MODELS CORRELATING RELIABILITY WITH VARIOUS FACTORS SUCH AS NUMBER OF REDUNDANT ELEMENTS, EQUIPMENT LEVEL (EQUIPMENT, SUBASSEMBLY, MODULE, ETC) OF APPLICATION, ETC., HAVE BEEN DEVELOPED TO HIGHLY SOPHISTICATED DEGREES. UNFORTUNATELY, LIKE THE WEATHER, ALTHOUGH MUCH HAS BEEN SAID ABOUT IT THERE ARE FEW CONCRETE EXAMPLES OF ANYBODY DOING ANYTHING ABOUT IT. SIMILAR TO FAULT LOCATION, THERE ARE TECHNIQUES, ON-THE-SHELF, CRYING TO BE USED. THEY WILL NOT BE USED, HOWEVER, UNTIL THE COMBINED EFFECTS OF INCREASED SYSTEM COMPLEXITY AND HIGHER RELIABILITY REQUIREMENTS OVERTAKE THE RELIABILITY THAT ONE CAN ATTAIN FROM SIMPLEXED COMBINATIONS OF COMPONENT PARTS. MOST REDUNDANCY TECHNIQUES USED TODAY CONSIST OF THE SIMPLE "BACK-UP" TYPE IN WHICH SPARE UNITS ARE PROVIDED FOR RAPID REPLACEMENT OF THOSE THAT HAVE FAILED. PREDOMINANTLY, TODAY IT WILL PROBABLY REMAIN THE MOST OFTEN USED FORM OF REDUNDANCY, AS LONG AS IMPROVEMENTS IN RAPID FAULT LOCATION AND ECONOMICAL MODULE REPLACE-MENT ARE ABLE TO MAINTAIN SYSTEM AVAILABILITY AT A REASONABLE LEVEL. HOWEVER, THERE WILL COME A TIME WHEN EITHER THE HUMAN IS NOT AVAILABLE TO REPLACE THE FAILED COMPONENT OR THE TIME TAKEN TO LOCATE THE FAILURE AND REPLACE THE FAILED COMPONENT IS CONSIDERED EXCESSIVE. IT IS THEN THAT THE MORE SOPHISTICATED TECHNIQUES OF REDUNDANCY WILL BEGIN TO BE APPLIED IN ORDER TO TAKE THE HUMAN OUT OF THE MAINTENANCE "LOOP".

THE NEXT OBVIOUS STEP WOULD BE TO WIRE THE SPARES INTO THE CIRCUIT - EITHER IN SERIES OR PARALLEL DEPENDING UPON THE PREDOMINANT FAILURE MODE OF THE ELEMENT - AND HAVE SOME METHOD OF SWITCHING IN THE SPARE ELEMENT WHEN THE ORIGINAL ONE FAILS. IN THE IDEAL CASE OF 100% RELIABILITY OF THE

SWITCHING ELEMENT, WE GET THE SITUATION DEPICTED HERE,

CHART 28 ON

WHERE WE HAVE PLOTTED THE PROBABILITY OF AT LEAST ONE ELEMENT SURVIVING AGAINST THE RATIO OF DESIRED OPERATING TIME TO MTBF OF THE SIMPLEXED ELEMENT. EVEN IN THE IDEAL CASE, IT CAN BE SEEN THAT THE NUMBER OF UNITS REQUIRED FOR A GIVEN RELIABILITY MAY BE IMPRACTICAL OR UNECONOMICAL IF THE DESIRED MISSION TIME IS MUCH HIGHER THAN THE MTBF OF THE SIMPLEXED UNIT.

CHART 28 OFF

WHEN ONE ADDS TO THIS THE FACT THAT ANY FAULT SENSING AND SWITCHING ELEMENT HAS A FINITE FAILURE RATE, ONE RAPIDLY REACHES THE POINT OF DIMINISHING RETURNS IN TERMS OF PRACTICAL APPLICATION OF THIS APPROACH TO ACHIEVE LARGE INCREASES IN RELIABILITY.

BY 1970, REDUNDANCY WILL BE COMBINED WITH CRUDE SELF-REPAIR SO THAT AS A BLOCK FAILS, THE FAILURE IS NOTED, AND THE FUNCTIONAL BLOCK IS AUTOMATICALLY REPLACED, E.G., LIKE CIGARETTE PACKAGES IN A VENDING MACHINE. ON THE OTHER HAND, IF ENOUGH BLOCKS WERE IN A REDUNDANT CONFIGURATION, THEY MIGHT BE PERMITTED TO FAIL AT A FINITE RATE (LIKE BODY CELLS) UNTIL SOME DANGER POINT WERE REACHED, AT WHICH TIME THE FAILED ELEMENTS MIGHT ALL BE REPLACED WITHOUT CAUSING SYSTEM FAILURE.

TO SUMMARIZE, WE HAVE DISCUSSED THE VARIOUS CATEGORIZATIONS AND DETERMINANTS OF MAINTENANCE; SHOWN THE MATHEMATICAL RELATIONSHIPS AMONG MAINTAINABILITY, AVAILABILITY, RELIABILITY, AND EFFECTIVENESS; AND EMPHASIZED THE DIFFERENCE BETWEEN MAINTENANCE AND MAINTAINABILITY. FURTHER, WE HAVE DEVELOPED THE THREE MOST IMPORTANT PROBABILITY DISTRIBUTIONS - EXPONENTIAL,

NORMAL, AND LOG NORMAL, AND HAVE SHOWN THEIR RELATIONSHIP TO RELIABILITY, MAINTAINABILITY, AVAILABILITY, AND EFFECTIVENESS. WE HAVE DISCUSSED THE IMPORTANCE OF THE PARAMETERS - MEAN AND VARIANCE IN DESCRIBING PROBABILITY DISTRIBUTIONS. WE HAVE DISCUSSED THE IMPLEMENTATION OF A MAINTAINABILITY PROGRAM FROM THE STANDPOINT OF A CUSTOMER AND A CONTRACTOR. FURTHER WE HAVE DESCRIBED THE ACTIVITIES OF A DESIGNER IN A CONTRACTOR'S FACILITY AND HAVE EMPHASIZED HIS IMPORTANCE IN THE ACQUISITION OF NEW MATERIEL. AND LASTLY WE HAVE DISCUSSED SOME OF THE PROBLEM AREAS IN THE FIELD OF MAINTAINABILITY ENGINEERING AND MADE PREDICTIONS AS TO WHEN THESE MAY BE SOLVED.

THANK YOU.

MAINTENANCE FLOW DIAGRAM

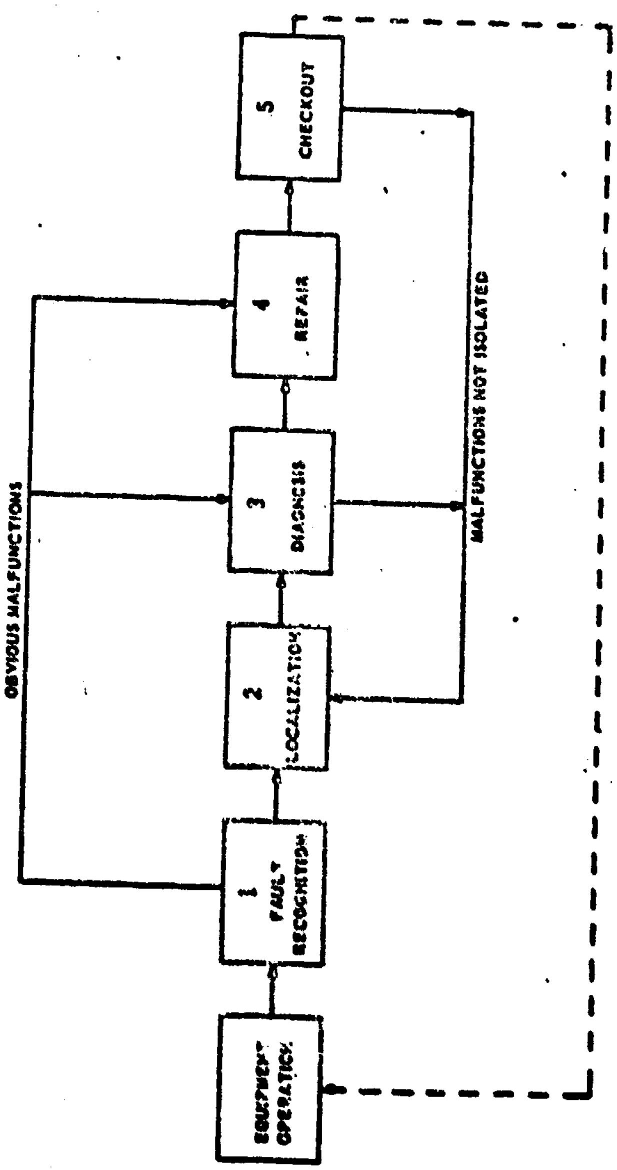


CHART 1

ELEMENT CONTRIBUTION OF MAINTENANCE TIME

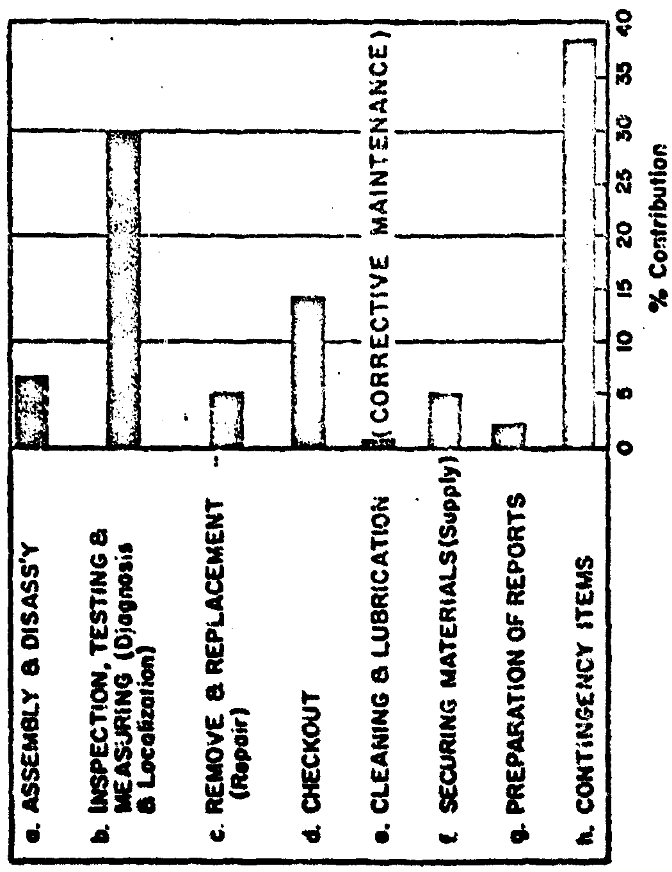


Chart 2

EFFECTIVENESS = RELIABILITY X AVAILABILITY X PERFORMANCE

Chart 3 325

CLASSICAL RELIABILITY DEFINITION

RELIABILITY IS THE  THAT A DEVICE WILL

PERFORM ITS ASSIGNED 

FOR A PRESCRIBED

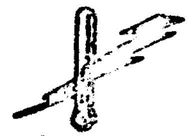
 UNDER THE  FOR WHICH IT WAS DESIGNED

Chart 4

$$\text{AVAILABILITY} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTR}}$$

$$\text{MTR} = \text{MTBF}\left(\frac{1}{A} - 1\right)$$

Chart 5

Chart 6

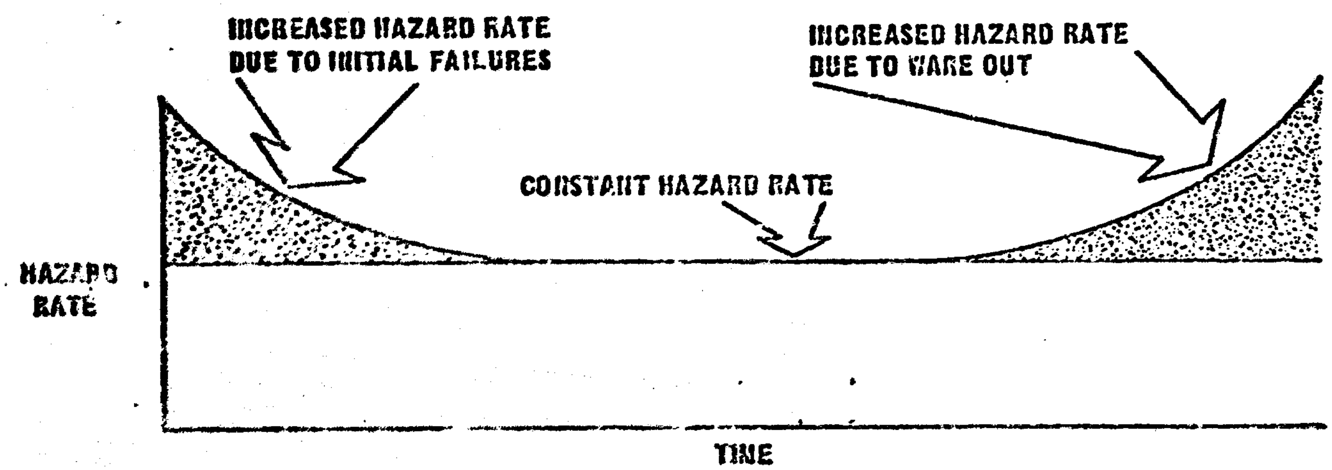
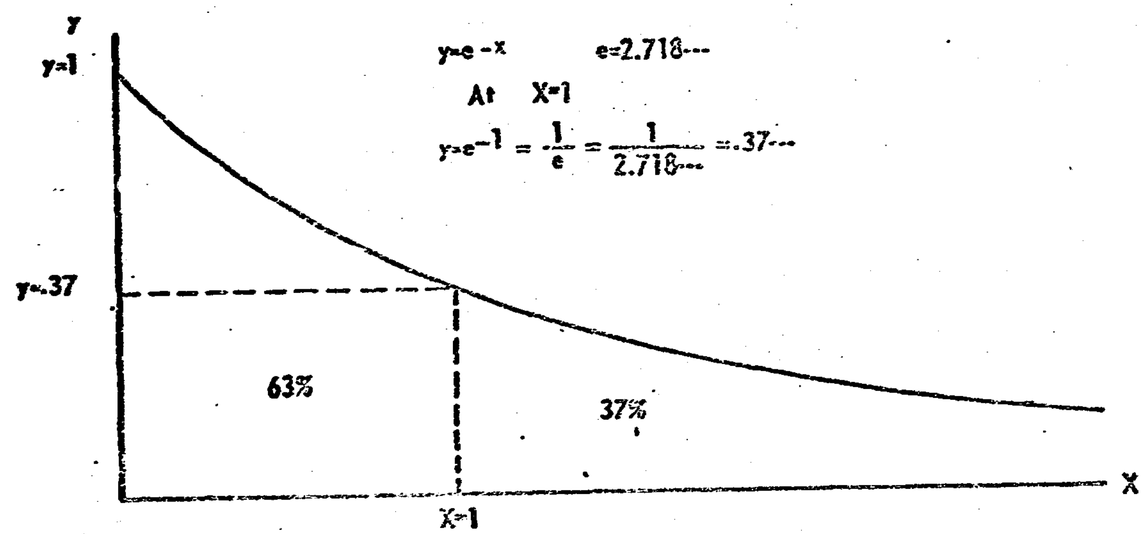

INCREASED HAZARD RATE
DUE TO INITIAL FAILURES
INCREASED HAZARD RATE
DUE TO WARE OUT
CONSTANT HAZARD RATE
HAZARD
RATE
TIME

Chart 7

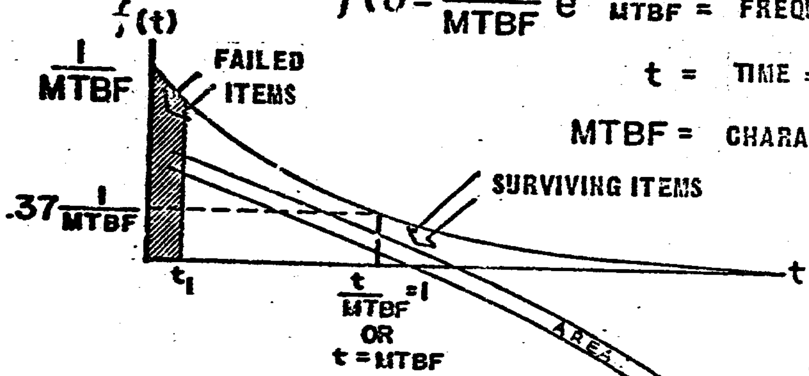


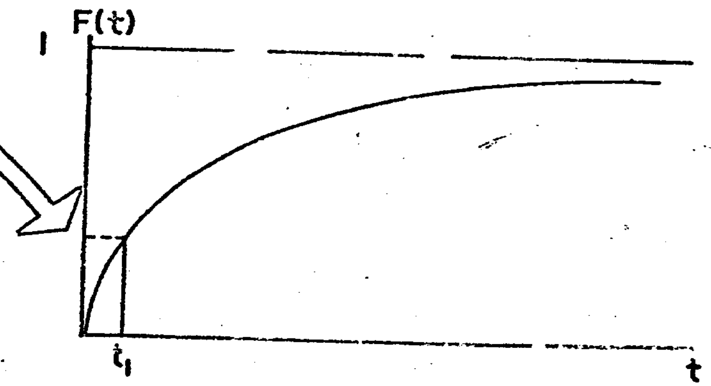
EXPONENTIAL FUNCTION

$$f(t) = \frac{1}{MTBF} e^{-\frac{t}{MTBF}} = \text{FREQUENCY OF FAILURE}$$

t = TIME = INDEPENDENT VARIABLE

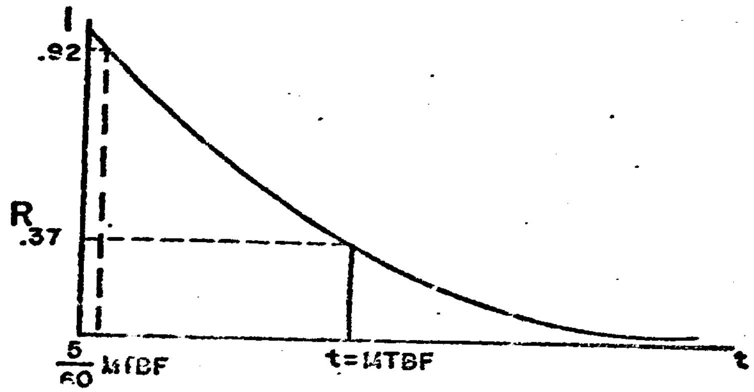
MTBF = CHARACTERISTIC LIFE (CONSTANT)





$$F(t) = \int_0^t f(t)\,dt = \int_0^t \frac{1}{MTBF} e^{\frac{1}{MTBF}}\,dt =$$

$$= -e^{-\frac{t}{MTBF}} \Big|_0^t = 1 - e^{-\frac{t}{MTBF}}$$



$$R = 1 - F(t)$$
$$= 1 - (1 - e^{-\frac{t}{MTBF}})$$
$$= e^{-\frac{t}{MTBF}}$$

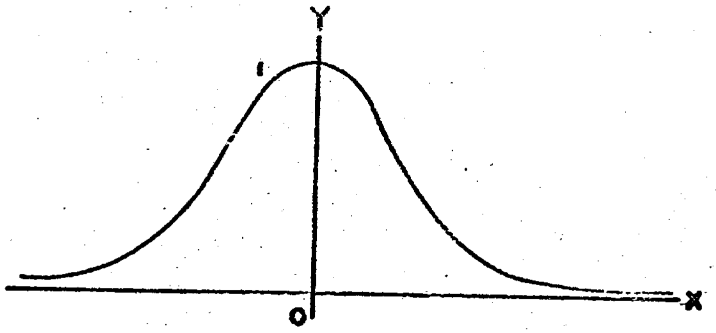
1 = MTBF = 60 HRS

MISSION TIME (t) = 5 HRS

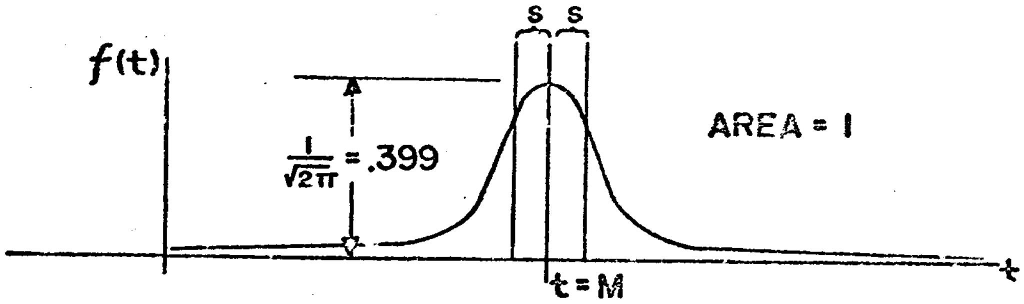
$$R_2 = e^{-\frac{5}{60}} = \frac{1}{e^{.083}} = \frac{1}{1.087} = .92$$

Chart 9

$$Y = e^{-x^2} \qquad -\infty < x < \infty$$



$$f(t) = \frac{1}{\sqrt{2\pi}\, s}\, e^{-\frac{1}{2}\left(\frac{t-M}{s}\right)^2}$$



$$M = \frac{1}{n} \sum_{i=1}^{n} x_i = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

S = STANDARD DEVIATION

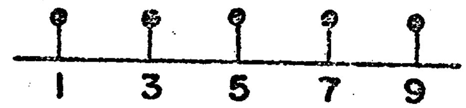
S IS A MEASURE OF VARIANCE OR SPREAD

S^2 = VARIANCE

$$S^2 = \frac{\sum_{i=1}^{n} (x_i - M)^2}{n-1} = \frac{\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}{n(n-1)}$$

Chart 10

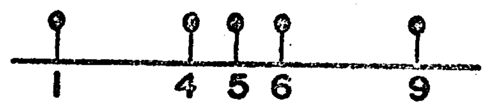
$$X = 1\ 3\ 5\ 7\ 9$$



$$M = \frac{1+3+5+7+9}{5} = \frac{25}{5} = 5$$

$$S^2 = \frac{(1-5)^2+(3-5)^2+(5-5)^2+(7-5)^2+(9-5)^2}{5-1} = \frac{40}{4} = 10 \qquad S = \sqrt{10}$$

$$X = 1\ 4\ 5\ 6\ 9$$



$$M = \frac{1+4+5+6+9}{5} = \frac{25}{5} = 5$$

$$S^2 = \frac{(1-5)^2+(4-5)^2+(5-5)^2+(6-5)^2+(9-5)^2}{5-1} = \frac{34}{4} = 8\tfrac{1}{2} \qquad S = \sqrt{8\tfrac{1}{2}}$$

$$X = 1\ 2\ 5\ 8\ 9$$

$$S = \sqrt{12\tfrac{1}{2}}$$

Chart 11

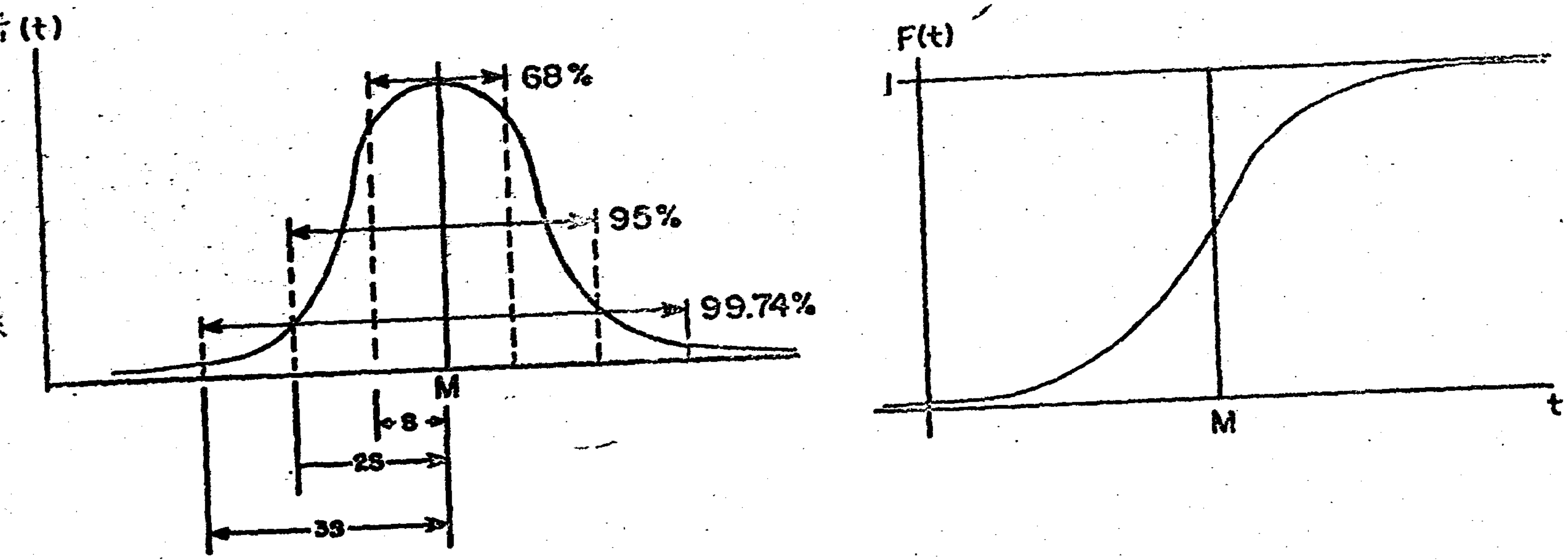


Chart 12

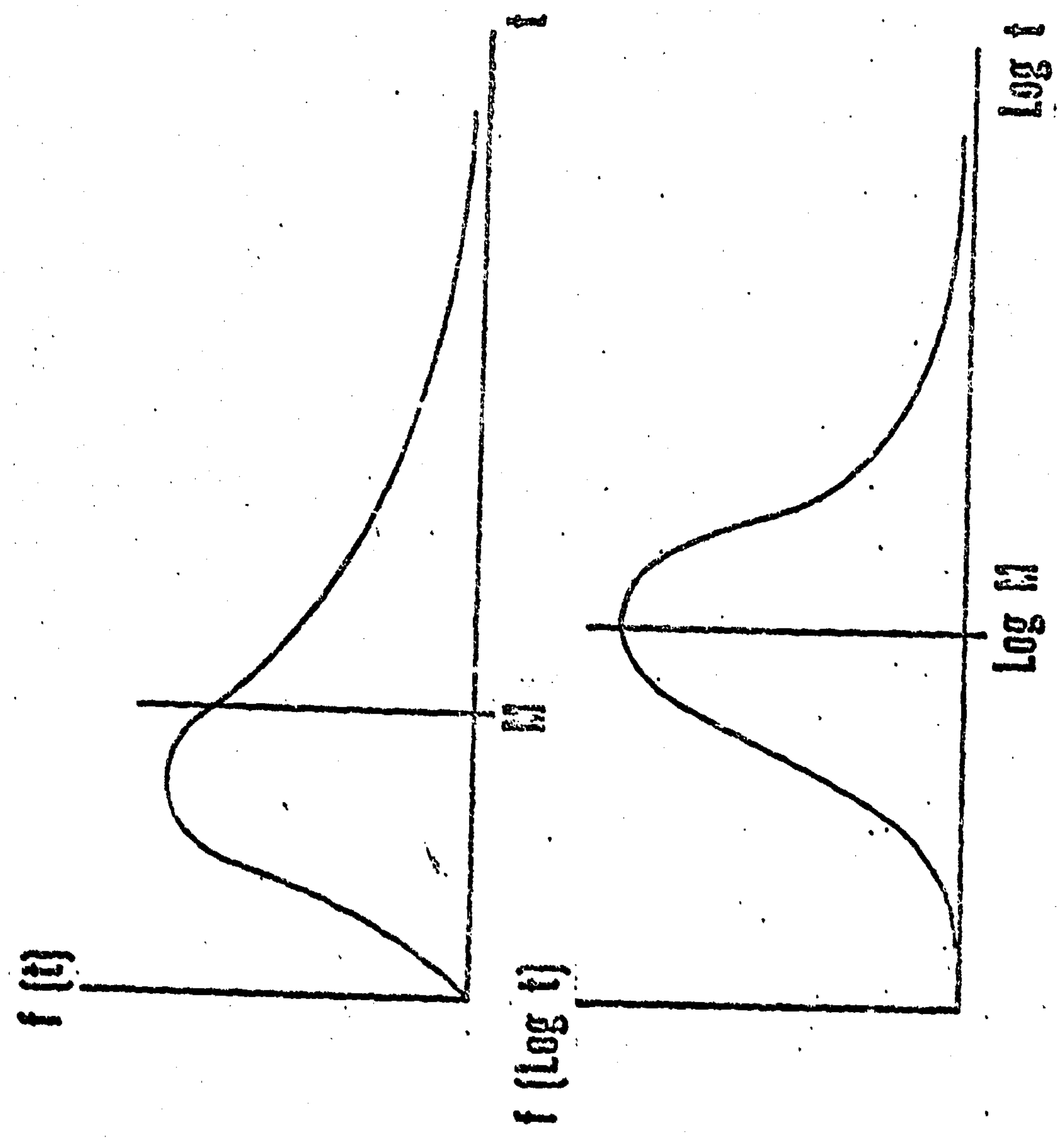


Chart 13

$$\text{Log } M = \sum_{i=1}^{n} \text{Log } X_i = \frac{\text{Log } X_1 + \text{Log } X_2 + \cdots + \text{Log } X_n}{n}$$

$$(\text{Log } S)^2 = \frac{\sum_{i=1}^{n} (\text{Log } X_i - \text{Log } M)^2}{n-1}$$

$$= \frac{(\text{Log } X_1 - \text{Log } M)^2 + (\text{Log } X_2 - \text{Log } M)^2 + \cdots + (\text{Log } X_n - \text{Log } M)^2}{n-1}$$

Chart 14

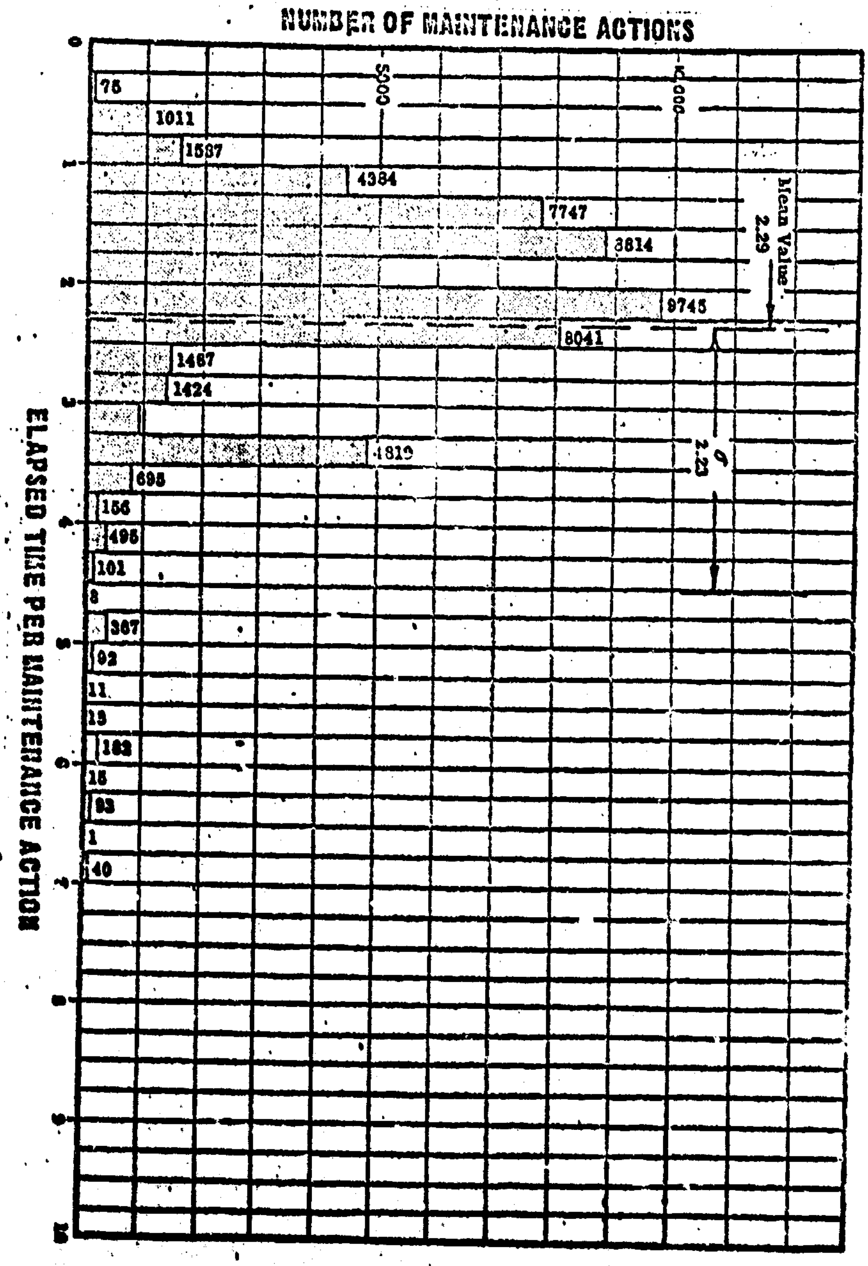

NUMBER OF MAINTENANCE ACTIONS
ELAPSED TIME PER MAINTENANCE ACTION
5000
10,000
Mean Value 2.29
σ 2.23
75
1011
1537
4384
7747
8814
9745
8041
1467
1424
1819
695
156
495
101
8
367
92
11
13
182
15
93
1
40

Chart 15

REQUIRED:

EFFECTIVENESS, $E = .90$

GIVEN:

RELIABILITY FOR 5 HRS, $R_5 = .92$

PERFORMANCE, $P = 1$

AVAILABILITY, $A = \frac{E}{R\,P} = \frac{.90}{.92 \times 1} = .98$

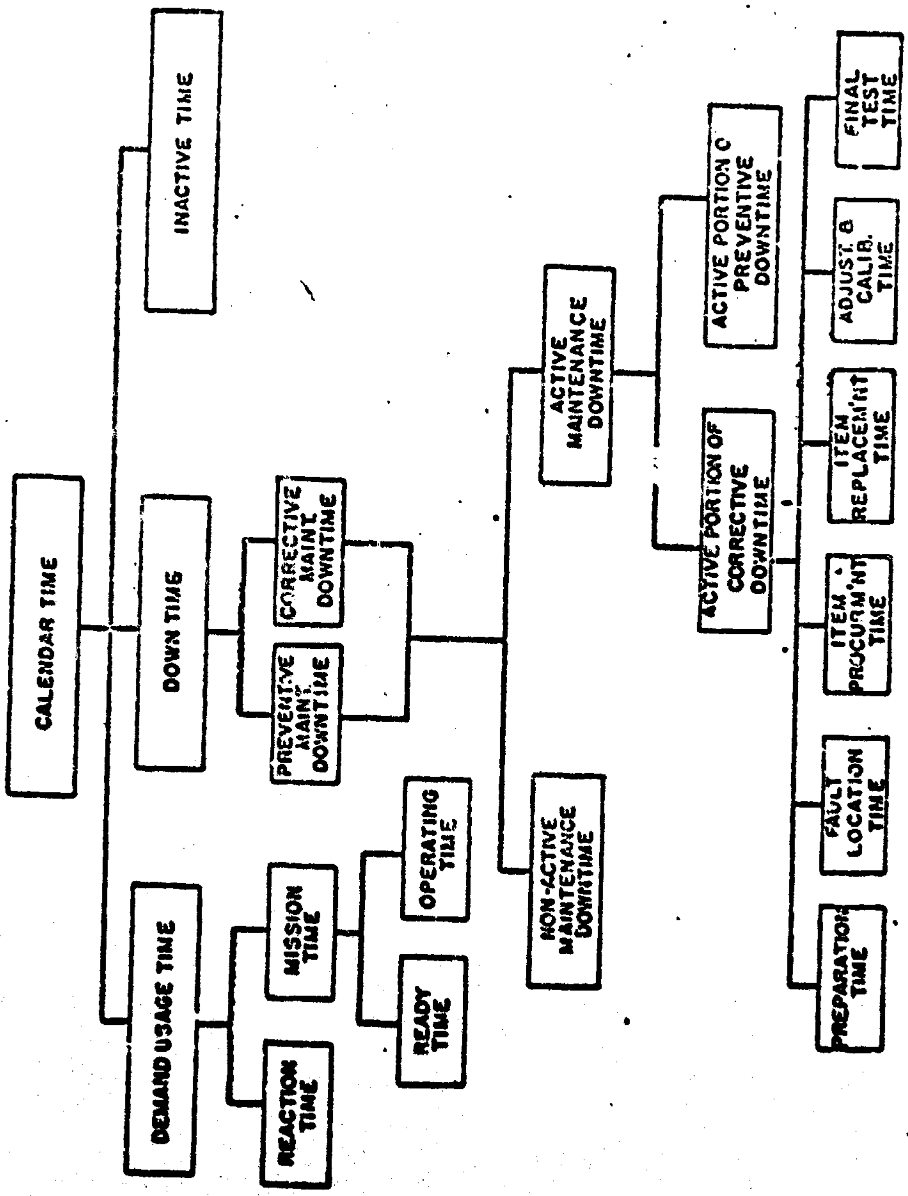
$R_5 = .92 = e^{-\frac{5}{MTBF}}$

$MTBF = \frac{5}{Lg\left(\frac{1}{.92}\right)} Lg\, e = \frac{5}{.0835} = 60$ HRS

$MTR = MTBF\left(\frac{1}{A} - 1\right) = 60\left(\frac{1}{.98} - 1\right)$

$= 1.2$ HRS.

Chart 16



Operation Profile

Chart 17

Table 1 - M Specifications Available from Defense Agencies

Number	Title	Issue Date
MIL-M-26512 (USAF)	Maintainability Program Requirements for Aerospace Systems and Equipment	13 Dec 1963
MIL-M-23313A (SHIPS)	Maintainability Requirements for Shipboard and Shore Electronic Equipment and Systems	7 Oct 1963
MIL-M-45765 (MI)	Maintainability Requirements for Missile Systems and Equipment	1 Apr 1963
MIL-M-55214 (EL)	Maintainability Requirements, General for Electronic Equipment	8 Feb 1963
MIL-S-23603 (WEP)	System Readiness/Maintainability Avionic Systems Design General Specifications For	1 Mar 1963
MIL-M-9933 (USAF)	Maintainability & Reliability Program Quick Reaction Capability Electronic Equipment General Specification For	20 June 1962
WR-30 (BUWEPS)[1]	Integrated Maintenance Management for Aeronautical Weapons, Weapon Systems and Related Equipment	1 May 1963
WS-3099	Bureau of Naval Weapons, Department of the Navy, Naval Weapons Specification, Maintainability, General Specification For	13 Nov 1962

[1] Not a true M specification - yet too important to overlook.

Chart 18

1 QUANTITATIVELY ACHIEVABLE GOALS SHOULD BE SPELLED OUT BY THE CUSTOMER OR DEVELOPED BY THE CONTRACTOR AND APPROVED BY THE CUSTOMER

2 ALL LEVELS OF MAINTENANCE SHOULD BE COVERED BY THE M SPECIFICATIONS

3 DOCUMENTATION OF THE M ELEMENTS SHOULD BE MADE SIMULTANEOUSLY AT THE TIME OF DESIGN REVIEW

4 TRADEOFFS SHOULD BE MADE IN TERMS OF DOWNTIME AND DOLLARS AS LONG AS THE UPPER BOUND OF THE SUPPORT RESOURCE CAPABILITY IS NOT EXCEEDED

5 TECHNIQUES AND DATA USED IN M MUST BE STANDARDIZED IF WE ARE TO BE ABLE TO COMPETE AND BE EVALUATED ON A COMPETITIVE BASIS

6 M TO BE EFFECTIVE SHOULD START AT THE CONCEPTUAL STAGE AND FOLLOW THROUGHOUT PRODUCT IMPROVEMENT

7 SPECIFICATIONS SHOULD STATE THEIR SCOPE CLEARLY AND NOT TRY TO BE "ALL THINGS" TO ALL PRODUCTS

Chart 19

DOES THE SPECIFICATION REQUIRE		MIL-M-9933	MIL-M-23313A	MIL-M-26512C	MIL-M-45165	MIL-M-55214	MIL-S-23603	WR-30	WS-3099
Achievement of Stated Goals	Clocktime	-	X	X	X	-	X	X	-
	Mantime	-	-	X	-	-	-	X	X
	Personnel	-	-	X	-	-	-	-	-
	Equipment (AGE)	-	-	X	-	-	X	-	-
	Facilities	-	-	X	-	-	X	-	-
	Cost	-	-	X	-	-	-	-	-
	Program Phasing	-	-	X	X	-	X	X	X
M Analysis for All Levels of Maintenance	On-Equipment	-	X	X	X	X	X	X	X
	Field shops	-	-	X	-	X	X	X	-
	Overhaul	-	-	-	-	X	-	X	-
Listing of Programmed Resources by Major Task and Work Center	Personnel	-	-	-	-	X	-	X	-
	Equipment	-	-	X	X	X	-	X	-
	Facilities	-	-	-	-	X	-	X	-
	Consumables	X	-	X	-	X	-	X	-
	Clocktimes	X	X	-	X	X	X	X	-
	Tech Data	-	-	-	-	X	-	X	-
Development of Cost Data	Clock Time	-	-	-	-	-	-	-	-
	Personnel	-	-	-	-	-	-	-	-
	Equipment	-	-	-	-	-	-	X	-
	Facilities	-	-	-	-	-	-	-	-
	Consumables	-	-	-	-	-	-	X	-
	Special tech data	-	-	-	-		-	-	-
Specified Procedures for: (Intra-Spec. Only)	Prediction	-	-	X	-	X	X	-	X
	Documentation	-	X	X	X	X	X	X	X
	Trade Off	-	-	-	-	-	-	-	-
	Demonstration	-	X	X	X	-	X	-	-
	Non-compliance	-	X	-	-	-	X	-	X
	Costing	-	-	-	-	-	-	-	-
Observance During:	Conceptual	-	-	X	-	-	X	X	X
	Development	X	X	X	X	X	X	X	X
	Production	X	X	X	X	-	X	X	X
	Product Improve.	-	X	X	X	-	X	X	X
Application to Only:	Electronics	X	X	-	-	X	X	X	[illegible]
	Mechanical	-	-	-	-	-	-	X	[illegible]
	Primes	-	-	X	X	-	-	X	[illegible]
	General	-	-	X	X	-	-	X	[illegible]

Evaluation Matrix

Chart 20

1 WHAT IS M? DOES MY CUSTOMER UNDERSTAND IT EXACTLY THE SAME AS WE DO?

2 IS IT REALLY QUANTITATIVE? CAN THE CUSTOMER TRULY EVALUATE OUR EFFORT?

3 IS THE M PROCEDURAL PROGRAM SUFFICIENTLY ADVANCE[illegible] TAKE A FIXED PRICE CONTRACT?

4 CAN WE ACCEPT ANY PENALTY CLAUSE FOR NONCONFORM[illegible] TO QUANTITATIVE CONTRACTUAL M REQUIREMENTS?

5 CAN WE APPORTION THE PENALTY CLAUSE TO OUR VENDO[illegible]

6 SHOULD THE M PROGRAM BE INTEGRATED WITH PERSONNEL SUBSYSTEM, SPARES, AGE, ETC

7 WILL ANY GFAE THAT WE MIGHT USE BE SUBJECTED TO OUR M PROGRAM?

8 IS THE M PROGRAM ADAPTABLE TO COST EFFECTIVENESS REVIEW?

Chart 21

Chart 22

AGENCY	SPECIFICATION	PROJECT	STATUS	AWARD CONTRACTOR
	MIL-M-26512			
USAF		F5T28	On contract-stated requirement	Northrop
USAF		SLAM (Un. er Proj. LASV)	Contractor required to produce a M prediction	Chance Vought
USAF		C-141	on contract - M provisions stated as a goal	Lockheed
USAF		Titan II	on contract	Martin-Denver
USAF		BCW	on contract	Republic Aviation
USAF		MMRBM	on contract for Guidance System only	General Precision
BUSHIPS	MIL-M-23313	AN/SPS 49 & 50	on contract	Raytheon
BUSHIPS		AN/BQQ-1	Not yet on contract	Raytheon
BUSHIPS		LORAN C	on contract	Collins
BUSHIPS		VLF Commu	on contract	Westinghouse
BUSHIPS		Automatic F. ctronic Degauss..g E. uip.	Technical Shipboard M evaluation under way	Vickers/Kearfott
ARMY	MIL-M-55214	AN/C..C 105 108	on contract - 105 compl. 108 in work now	General Dynamics
ARMY	(SCL 4301D)	A., "SG-	Internal effort - not covered by contract	Martin-Orlando
ARMY		Proje.. R. D.	- on PDP contract - expected on Development contract	RCA/Martin-Orlando
BUWEPS	(WR-30 & MIL-M-26512B)	F-111	on contract	General Dynamics
BUWEPS	WR-30	F-4II		McDonnell
BUWEPS		CH53A	on contract	Sikorsky
BUWEPS		EX 10 Torp		Contractor not yet selected
BUWEPS		VAL	on contract	LTV
BUWEPS		COIN		Contractor not yet selected
BUWEPS		F-8	on contract	LTV
BUWEPS		Phoenix (F-1.. Navy)	on contract - (combined goals and requirements)	Hughes
BUWEPS	XPP-148	P3A (XPP-148)	on contract	Lockheed
BUWEPS		A5 (XPP-148)	on contract	North American
BUWEPS		E2A (XPP-148)	on contract	Grumman
BUWEPS		CH46 (XPP-148)	on contract	Boeing - Vertol
BUWEPS		A-6 (XPP-148)	on contract	Douglas
	WS-3099			United Aircraft

Project with M Requirements

Chart 23

- MAINTAINABILITY ENGINEER
- MAINTENANCE SERVICE SPECIALIST
- DESIGN ANALYST
- DATA ANALYST
- MAINTAINABILITY MONITOR
- CONSULTANTS
    - STATISTICIAN
    - MATHEMATICIAN
    - HUMAN FACTORS SPECIALIST

Chart 24A

A. [illegible]/S[illegible] PLANNING PHASE

B. PROPOSAL PHASE

1. MAINTAINABILITY OBJECTIVES
2. MAINTAINABILITY PARTICIPATION
3. MAINTAINABILITY DOCUMENTATION

C. DEVELOPMENT PROGRAM PHASE

1. PROGRAM PLAN
2. MATHEMATICAL MODEL
3. DESIGN POLICY MANUAL
4. SPECIFICATIONS REVIEW
5. PREDICTION AND ANALYSIS
6. TRAINING
   a. OBJECTIVES
   b. ORGANIZATION
   c. SPECIFICATIONS
   d. ANALYSIS AND [illegible]
   e. DESIGN POLICY MANUAL
   f. TEST DEMONSTRATION
   g. FAILURE AND MAINTENANCE REPORTING AND ANALYSIS
7. HUMAN FACTORS ENGINEERING
8. CHANGE CONTROL
9. DESIGN REVIEWS
10. DESIGN TRADE-OFFS
11. VENDORS PROGRAM
12. EVALUATION AND IMPROVEMENT
    a. EVALUATION OF TEST AND FIELD DATA
    b. IMPROVEMENT RECOMMENDATION

D. PRODUCTION PHASE

1. QUALITY CONTROL
2. MODIFICATION AND CHANGE CONTROL

E. OPERATIONAL PHASE

1. INITIAL DEPLOYMENT STAGE
2. FIELD OPERATING STAGE
   a. CORRECTIVE MAINTENANCE
   b. PREVENTIVE MAINTENANCE

Chart 248

THE MAINTENANCE CONCEPT	REACTION TIME
THE MAINTENANCE ENVIRONMENT	TURN AROUND TIME
FACILITIES AVAILABLE	RELIABILITY
COMMON AND SPECIAL TOOLS	HUMAN FACTORS
SKILL LEVEL OF MAINTENANCE PERSONNEL	TEST EQUIPMENT
OPERATION USE OF SYSTEM	

Chart 25

FAULT INDICATORS	LUBRICANTS, FUELS, COOLANTS, ETC.
TEST POINTS	MATERIEL
EXTERNAL TEST EQUIPMENT	MATERIEL FINISHES
ACCESS	MATERIEL HEAT TREATMENT
ADJUSTMENTS	FASTENERS
LABELING	CONNECTORS
COLOR CODING	PACKAGING
PROTECTIVE DEVICES	MODULES
MURPHY LAW FEATURES	•
CIRCUIT DESIGNS	•
COMPONENT SELECTION	•

Chart 26

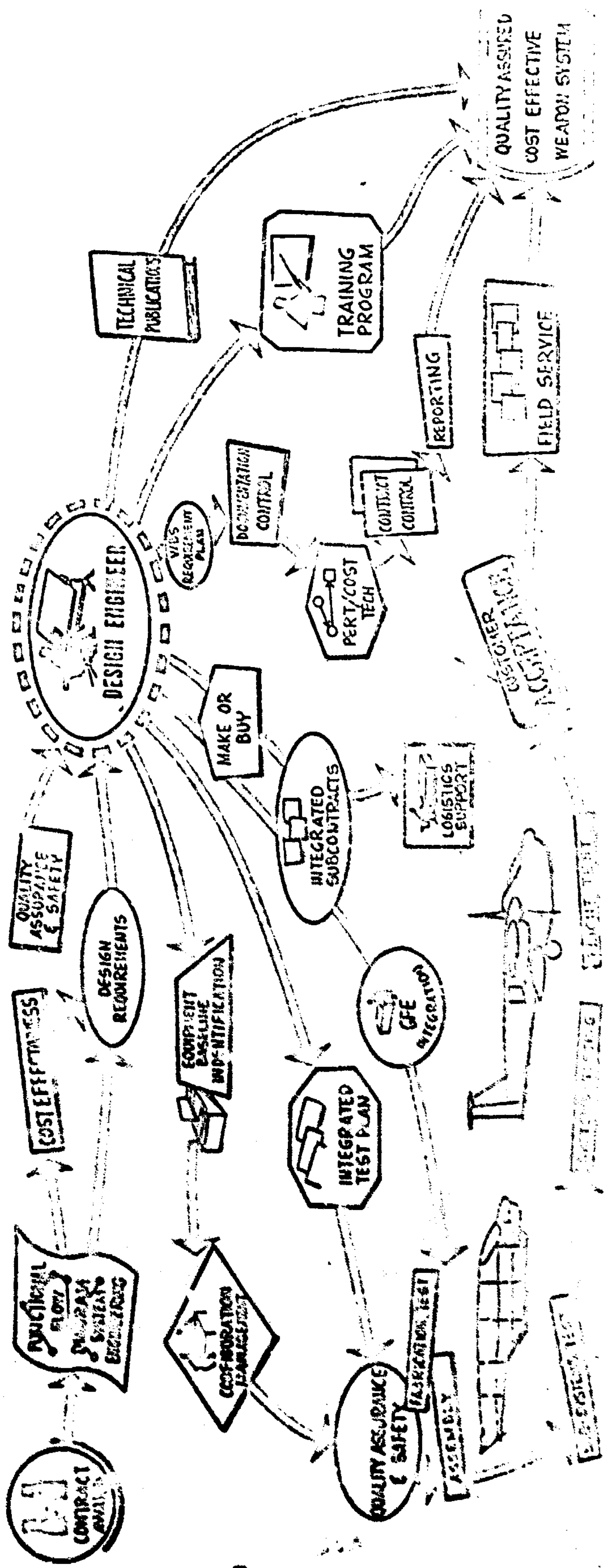
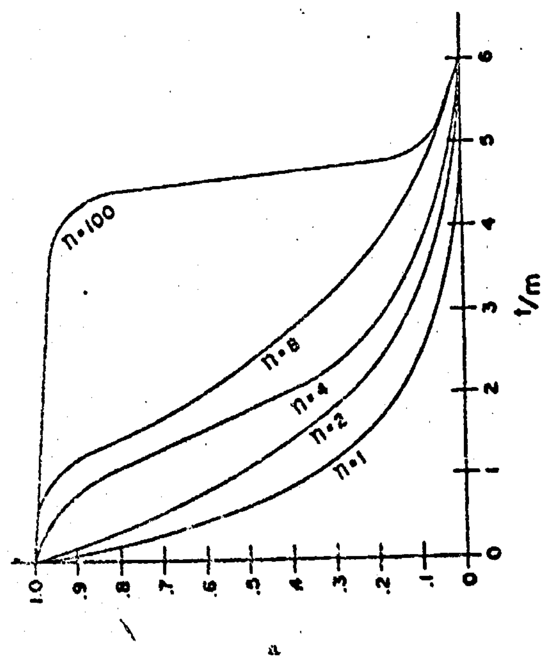

CONTRACT
COST EFFECTIVENESS
QUALITY ASSURANCE & SAFETY
DESIGN REQUIREMENTS
CONFIGURATION MANAGEMENT
INTEGRATED TEST PLAN
GFE INTEGRATION
MAKE OR BUY
INTEGRATED SUBCONTRACTS
LOGISTICS SUPPORT
DESIGN ENGINEER
PERT/COST TECH
DOCUMENTATION CONTROL
CONTRACT CONTROL
REPORTING
FIELD SERVICE
TECHNICAL PUBLICATIONS
TRAINING PROGRAM
QUALITY ASSURED
COST EFFECTIVE
WEAPON SYSTEM
CUSTOMER
QUALITY ASSURANCE & SAFETY
ASSEMBLY

Chart 27



Reliability of redundant components

Chart 28

DEPARTMENT OF THE ARMY

U.S. ARMY MOBILITY EQUIPMENT CENTER

Maintainability Engineering Program

in the

Equipment Development Phases

FORT BELVOIR, VIRGINIA

DESCRIPTION OF WORK PERFORMED
MAINTAINABILITY

1. Maintainability. Maintainability is expressed as the combined features that have been designed into an end item which facilitates the accomplishment of checking, adjusting, troubleshooting, servicing, repair and overhaul with minimum time, skill and resources in the planned maintenance environment; all of which through evaluation and test is expressed quantitatively to determine whether the item meets quantative maintainability requirements.

2. Authority.

AR 11-25	Reduction of Lead Time
AR 700-20	Type Classification of Materiel
AR 700-35	Product Improvement of Materiel
AR 705-5	Research & Development of Materiel
AR 705-26	Maintainability Program for Materiel & Equipment
MOCOM REG 705-1	Specific "In-Process" Review Points in Materiel Research & Development
MOCOM REG 715-8	Management, PEMA 4900 Production-Base Support Program
ERDL REG 705-3	Preparation of Certificate to Support Type Classification of Materiel
ERDL REG 705-4	In Process Reviews During Development
ERDL REG 705-14	Interdepartmental Participation in the Development and Standardization of Engineer Materiel

3. Work Sources.

R & D Schedule

In Process Review Schedules

Army Materiel Program (AMP)

Production Engineering Measures Contracts

4. Procedures.

a. In-Process Review Evaluations.

At each item review phase, as listed in the ERDL In-Process Review Schedule, maintainability engineers and technicians analyze the item and prepare an evaluation report on the adequacy of the maintainability characteristics of the item. Maintainability engineers and technicians contact project engineers and review available requirements statements, concept layouts, drawings, specifications, test data and equipment hardware in order to provide to the project engineers a maintainability evaluation which contains as appropriate, maintainability requirements, predictions, trade-off improvement change recommendations and/or comments and interpretations on the maintainability contents of the reviewed documents. The maintainability program follows the equipment development phases as outlined in the following paragraphs.

(1) QMR or SDR Phase.

The QMR or SDR is an approved statement of a military need for a new item, system or assemblage, the development of which is believed feasible. These documents indicate the general overall equipment life and maintainability requirements of the items to be developed including such performance and availability characteristics as allowable downtime, Mean-Time-Between-Failure (MTBF), mission time, turn-around-time, allowable corrective and preventive maintenance, available maintenance skills etc. These documents, in draft form, are reviewed by maintainability engineers and technicians and comments and interpretations submitted as to the practical validity of these requirements and highlight the maintainability problem areas.

(2) Engineering Design Phase.

This phase includes concept studies, feasibility studies, Technical Development Plans (TDP's) and engineering design. These documents are reviewed by maintainability engineers and technicians and comments and recommendations are made as to the maintainability suitability of the proposed designs.

(3) Engineering Prototype Phase.

The engineering and/or service test prototype stage includes procurement and test of the test model. The Purchase Description is reviewed by maintainability engineers and technicians to assure that appropriate maintainability requirements and tests are included and when required technical assistance is provided in monitoring the contractors maintainability effort. Similar assistance is provided for Production Engineering Measures contracts. When the prototype model is available, it is completely disassembled under simulated field conditions and a formal "Maintainability Study" is conducted on the item as outlined in paragraph 4b below.

b. Maintainability Engineering Studies.

In-house maintainability studies are performed on selected items of equipment where it is anticipated that major breakthroughs in maintainability can be made. The selected item is completely disassembled under simulated field conditions and a formal "Maintainability Study" is conducted on the item by maintainability engineers and technicians using the "Trade-Off" technique as developed by the National Security Industries Association, Maintenance Advisory Committee, Maintenance Reliability and Maintainability Panel. The "Trade-Off" technique is such that each particular design feature change that is desirable from a maintainability standpoint is considered individually on a "team basis" and evaluated, or "traded-off", through a numerical value weighting system, in terms of the effect of the change upon any and all end-item weighted functional parameters. This completed study provides the project engineer with a means to conveniently make a decision on the relative merits or demerits of each proposed maintainability improvement change.

c. In addition to the maintainability effort directly connected with the equipment development cycle, the maintainability function includes certain other activities as covered by the following paragraphs.

(1) Maintainability Data File.

Maintainability data on equipment and components is collected for future dissemination and use on other developments. Equipment and component maintainability studies and test results are made available to designers of other equipment as appropriate. This data will be correlated and assimilated into the data systems developed or approved by the Army. The data includes obtainable feed-back data from users for use in upgrading next generation equipment maintainability and for evaluating the effort that was conducted during the development cycle.

(2) Training.

Through attendance at seminars sponsored by other Government Agencies and commercial companies and by participation in the "Maintainability Team Evaluations" project engineers are afforded the opportunity to broaden the maintainability effort.