The Mean-Time-Before-Failure and the Failure-Rate are numerical factors used in the evaluation and acceptance of complex automatic systems.

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Reliability of Photogrammetric Equipment

(*Abstract on page 832*)

INTRODUCTION

THE GENERAL NATURE of the highly complex problem of reliability is the subject of this paper, together with the steps by The U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency to solve it, and some of the results obtained so far; but no attempt is made here to present a strict mathematical solution.

Actually reliability is by no means a new concept and has been with us in one guise or another for a long time, as possibly best epitomized by the renowned "One Horse Shay," the components of which all disintegrated simultaneously after it had been in use exactly one hundred years.

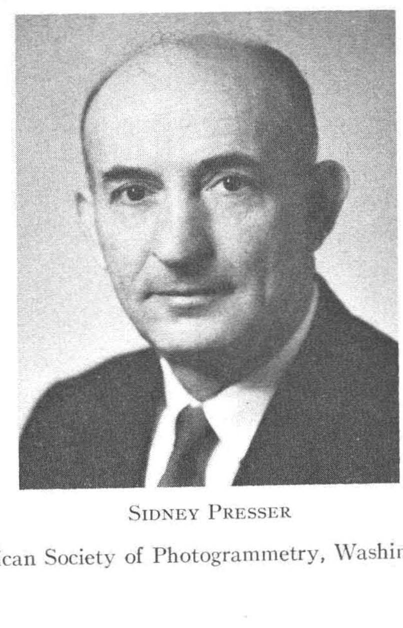
While photogrammetric equipment such as Multiplex, Kelsh and the first order plotting instruments, in use for the past three or more decades cannot be said to quite match the remarkable failure rate achieved by the "One Horse Shay," conventional photogrammetric equipment, nevertheless, presents few problems from the standpoint of reliability, as failures are usually either the result of abuse, or accidental damage, or of a nature that can easily be remedied by replacement of a simple component such as a projector lamp, light bulb or simple transformer.

The venture of The Corps of Engineers into the field of Automatic Mapping has radically changed this salutary condition and has created a marked awareness of the importance of reliability, because of the unusual complexity of the Semi-Automatic and Automatic Mapping Systems, some of which comprise tens of thousands of components

AUTOMATIC SYSTEMS

The importance of reliability was rather forcefully demonstrated in the first Automatic Mapping System tested by The Corps of Engineers, the integrated Mapping System shown in Figure 1. This system was so named, since it was designed to produce simultaneously an orthophoto and a contour manuscript. Major failures such as those of the high voltage line and line drop unit were considered to be, in reliability parlance, of a catastrophic nature. These failures were directly attributable to a violation of reliability principles as evinced by use of electronic components of dubious reliability.

The next Automatic Mapping System developed for and tested by The Corps of



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Engineers was the Automatic Stereomapping System. As can be seen in Figure 2 it is essentially an automated Kelsh-type plotter. This system proved to be somewhat more satisfactory from the standpoint of reliability but still required an inordinate amount of maintenance and considerable redesign to ensure uninterrupted performance.

The third system, which is still undergoing testing, the Automatic Map Compilation System, Figure 3, is a considerably more sophisticated system than the previous two mentioned and utilizes a high speed digital computer to ensure fully automated operation. Numerous failures of the computer and other components have indicated that the initial reliability of this sytem left much to be desired. Since this system was designated a laboratory experimental model; modifications were made and the reliability has been greatly improved.

ABSTRACT: *The trend towards automation has produced electronically oriented mapping systems of increasing complexity and sophistication. While the acquisition of the necessary skill to operate this equipment is of some concern, maintenance poses a problem of greater magnitude. It is therefore of paramount importance to insure initially that the equipment is designed with a high degree of reliability in order to minimize failures and to avoid the necessity for excessive preventive maintenance. Criteria are formulated which are stipulated in design requirements of GIMRADA to insure attainment of the necessary degree of reliability, and the reliability results obtained thus far are encouraging. The approach is from a practical rather than theoretical standpoint; and only rudimentary mathematics is employed.*

Reliability Criteria

The failure of the initial Automatic Mapping Systems to provide a satisfactory measure of reliability became progressively of greater concern to the Photogrammetry Division, and consequently steps were taken early in 1962 to formulate some definitive criteria which could be incorporated into the design requirements for equipment in order to ensure a workable degree of reliability. These criteria which were eventually compiled for incorporation into Purchase Descriptions, to be used in developmental contracts, were quite specific and of a length which does not lend itself to full presentation in this paper. In brief, these criteria are based on the premise that reliability is the probability that a device will perform, without failure, a specific function under given conditions for a given period of time. Expressed as a simple mathematical formula reliability becomes $R=e^{-t/T}$ where t is the duration of an operation or mission and T is the MTBF (Mean Time Between Failures). It can readily be seen that reliability increases exponentially with Failures). It can readily be seen that reliability increases exponentially with an increase of the MTBF or a decrease in the duration of the mission.

Specifically, the requirement stipulated a fixed value, in hours, for the Mean Time Between Failures (MTBF) and provided a means for estimating a theoretical value as well as demonstrating in a practical manner that the required MTBF had been attained to a 90 per cent confidence level. The theoretical value was to be estimated by employing the criteria shown in Table 1.

Contractor Requirements

The contractor was also required to make a study of the life characteristics of special critical parts and subassemblies, whose failure would cause complete disability or serious degradation of equipment performance and to submit periodically as applicable preliminary interim and final reliability estimates based on the latest component count as determined from the revised or modified design configurations.

When the final reliability estimate as given in hours of MTBF is computed to be significantly less than the number of hours stipulated in the contract, the contractor is required to modify the design of the equipment and submit a new estimate indicating that the failure rate is of an acceptable level.

Since it was also encumbent upon the contractor to demonstrate to a 90 per cent confidence level by actual testing that the required reliability has been provided, the testing was to be accomplished in accordance

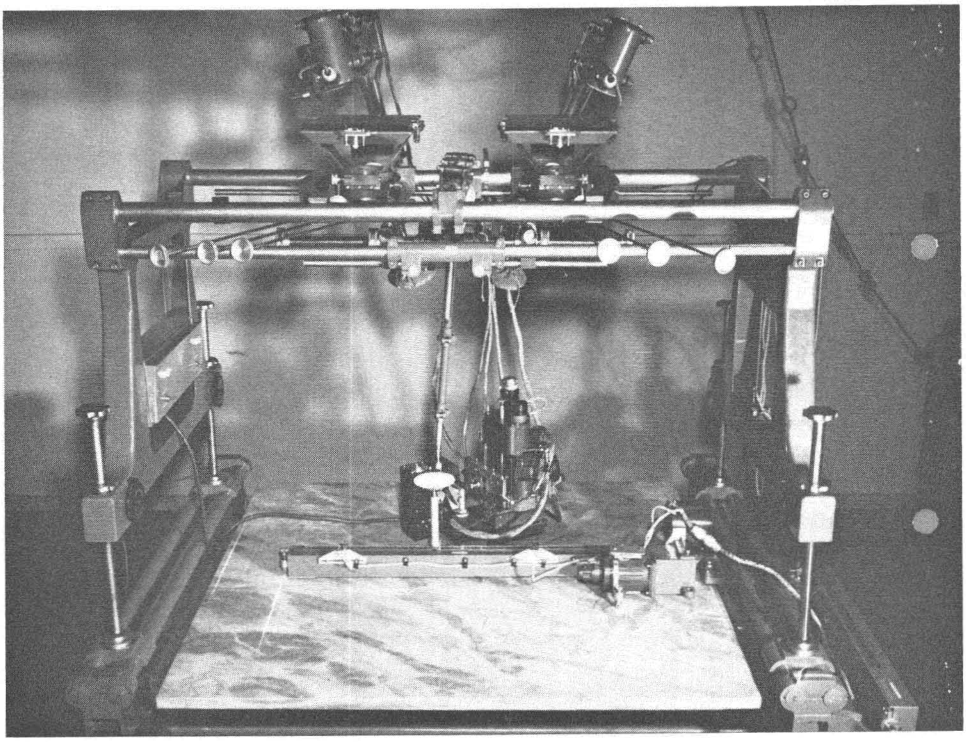

FIG. 1. Integrated Mapping System

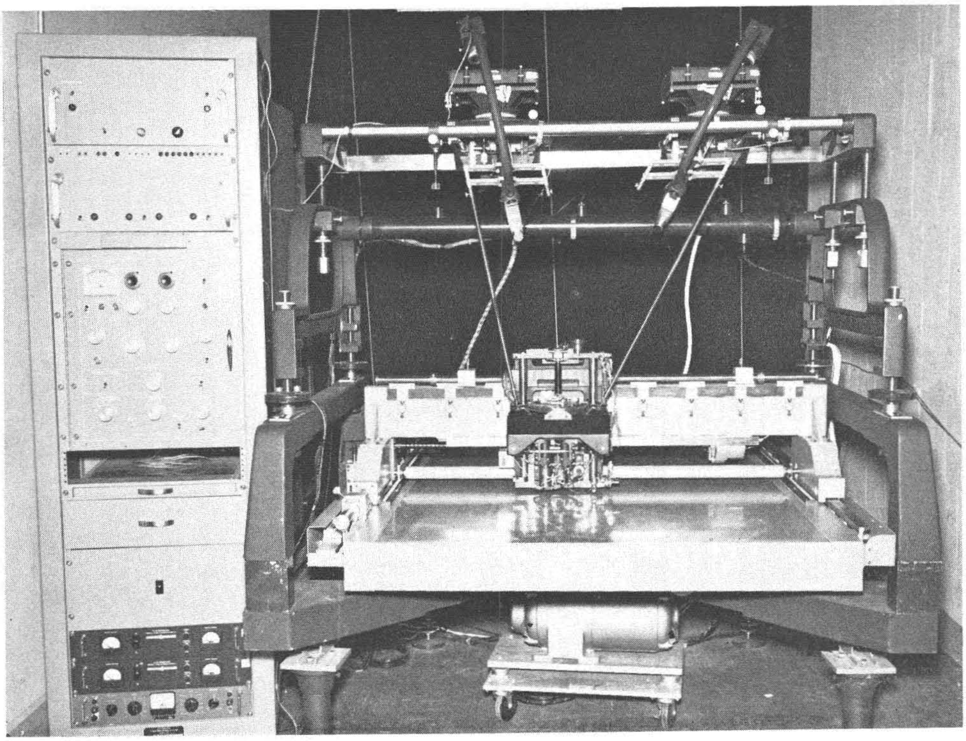

FIG. 2. Automatic Stereomapping System

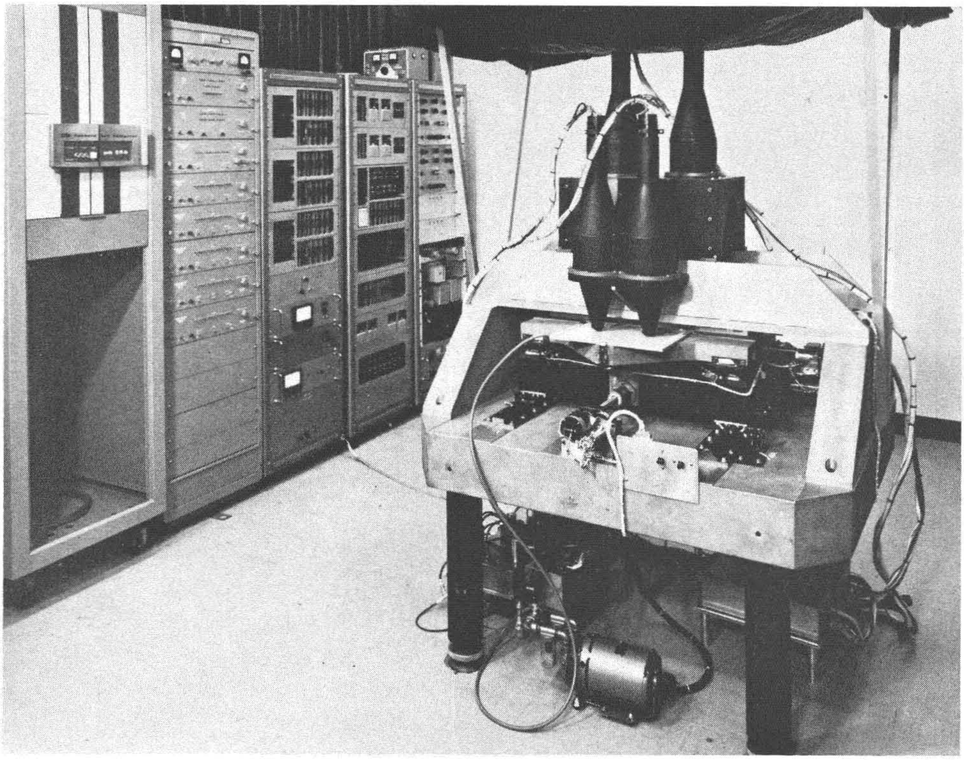

FIG. 3. Automatic Map Compilation System

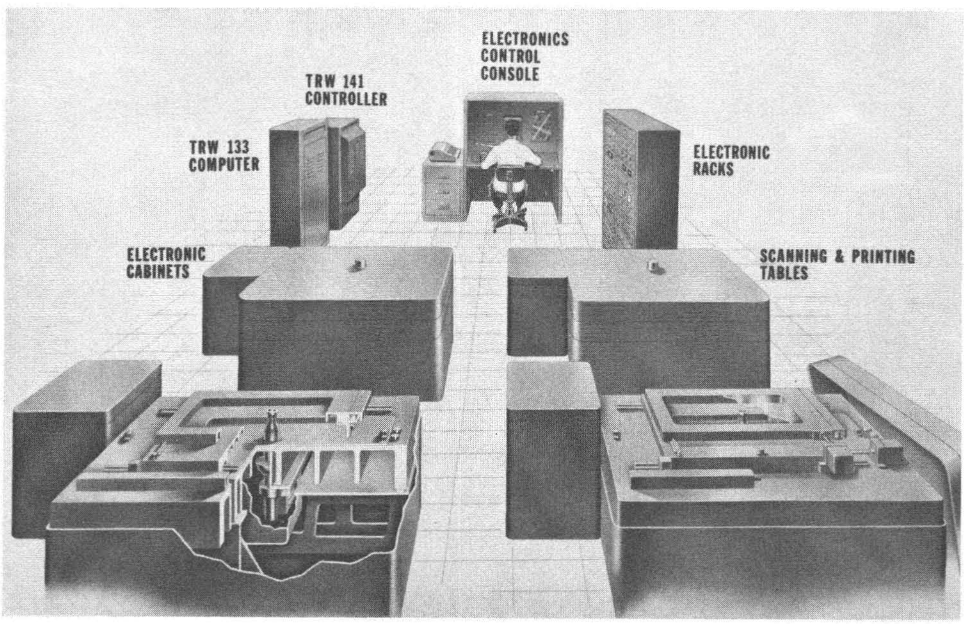

FIG. 4. Universal Automatic Map Compilation Equipment

TABLE 1

ORIGINAL CRITERIA FOR ESTIMATING MTBF

MTBF = 1/F.R.
F.R. $= 10^{-6} (30 N_t + 15 N_m + 2 N_s + 0.5 N_c)$

MTBF = Mean time between failures
F.R. = Failure rate
N_t, N_m, N_s and N_c are total number of tubes, relays, semi-conductors and capacitors respectively.

with the conditions shown in condensed form in Table 2.

To illustrate, if the requirement for the Mean Time Between Failures was established as 100 hours, theoretically the equipment could be accepted after it had been tested for only 300 hours, provided only one failure occurred during those 300 hours of testing. As can be seen from Table 2, if the number of failures that occurred during the 300 hours is more than one, but less than eight, the test must be continued until only an acceptable number of failures has occurred within a specified time, such as five failures within 565 hours, or seven within 703, etc., at which time the equipment would be accepted and the test terminated.

Conversely the equipment would be rejected if eight failures occurred before 332 hours of testing had elapsed.

RELIABILITY TESTING

Since prolonged testing is costly and could also cause delays in delivery of equipment the reliability test is usually limited to 1,500 hours provided this exceeds three times the required MTBF and the number of failures which have occurred within that time indicate that a continuation of the test is justified, or in other words the number of failures are less than would require rejection.

When time is exceptionally critical and an accumulation of testing time equal to three times the MTBF is not feasible, the equipment is accepted when the number of independent failures is no greater than two times the ratio of accumulated test time to required MTBF, and the final reliability estimate is greater than the required MTBF. For example, if the required MTBF is 125, and the estimated MTBF is greater than this number, the equipment could be accepted under critical time conditions, with 250 hours of testing time provided not more than four independent failures occurred during this time.

A preliminary reliability estimate based on the requirements specified above was prepared for a semi-automatic coordinate reader comprising about 35,000 components by Nuclear Research Institute, a division of Houston Fearless. The result as summarized in Table 3 below, indicated an MTBF of only 24 hours, or less than one-fourth the stipulated 100 hours which was required. The contractor questioned the validity of the factors used in the formula for determination of the failure rate, since he believed that the design of his equipment was of a configuration which indicated an MTBF in excess of 100 hours.

TABLE 2

FAILURE RATE TESTING (ACCEPT-REJECT CRITERIA)

Multiples of MTBF	*Acceptance*	*Continuation of Testing*	*Rejection*
3.00	1	2–7	8
3.32	1	2–7	8
3.58	2	3–8	9
4.01	2	3–8	9
4.27	3	4–9	10
4.70	3	4–9	10
4.96	4	5–10	11
5.39	4	5–10	11
5.65	5	6–11	12
6.08	5	6–11	12
6.34	6	7–12	13
6.77	6	7–12	13
7.03	7	8–13	14
7.46	7	8–13	14
7.72	8	9–14	15
8.15	8	9–14	15
8.41	9	10–14	15
9.10	10	11–14	15
9.79	11	12–14	15
10.30	14	—	15

CRITERIA MODIFICATION

A study performed at GIMRADA verified NRI's contention as it was found that the weighting factors used in the formula had been based on data which had become obso-

TABLE 3

INITIAL MTBF FOR S.A.C.R.

Component	*Number*	*Factor*	*F.R.$\times 10^{-6}$*
Resistors, etc.	20,173	0.5	10,087
Semi-Conductors	14,358	2	28,716
Tubes	21	30	630
Relays & Motors	155	15	2,325
F.R.			$=41,758\times 10^{-6}$
MTBF = 24 Hours			

lete and which actually indicated a failure rate of components 4 to 20 times greater than the current accepted value for such items as transistors, diodes and capacitors.

New criteria for reliability estimating were subsequently prepared by the Photogrammetry Division, Geodesy, Intelligence and Mapping Research and Development Agency, based on data given in MIL-HDBK-217, "Reliability Stress and Failure Rate for Electronic Equipment" and when used by NRI, a more realistic estimate which exceeded the requirement of 100 hours for the MTBF was obtained.

The new formula for computing the MTBF and the new failure rate criteria for derated electronic parts and other components of electronic systems are summarized in Tables 4, 5, and 6.

In addition the parameters, such as operating temperature and population type proportions, on which the failure rates were based were spelled out in detail and a stipulation was made that, where different conditions were encountered, adjustments of the failure rates should be made based on applicable failure rates tabulated in MIL-HDBK-217. Failure rates for parts or components for which no provision is made in MIL-HDBK-217 must be based on experience factors available at the time computations are made or derived from a study made by the contractor.

An Example

The Universal Automatic Map Compilation Equipment developed for GIMRADA by The Bunker-Ramo Corporation is the most complex mapping system devised to date, and will probably not be exceeded in complexity and resultant versatility for some time to come. Reliability estimates for this system which comprises about 70,000 components have consistently indicated a compatibility with the required MTBF at 100 hours, and are summarized in Table 7.

The single figure given in the 5th Interim Reliability Report indicates that the design had at reporting time (Oct, 1964), been finalized to the point where a firm parts count could be obtained and definite operating parameters assumed. The figure of 111 hours indicates a strong probability that when tested the equipment will meet the reliability specified in the contract.

Since estimating and reporting reliability of equipment puts an extra burden on a contractor and consequently increases the cost to the Government, the requirements for detailed estimating and reporting are normally incorporated only in the procurement of equipment of unusual complexity. In other cases a simple provision stipulating that the equipment shall attain a high reliability, consistent with similar equipment is resorted to. A determination as to whether detailed or a general requirement should be used can only be made after a thorough evaluation of all the circumstances involved and no hard and fast rule is feasible. Normally, cost is the

Table 4

Revised MTBF Formula

$$\text{MTBF} = \frac{10^5}{-\text{F.R. in } \%/1{,}000 \text{ hours}}$$

F.R. = Failure Rate

Table 5

F.R. of Derated Components, %/1,000 Hours

Component	*0.1 Rating*	*0.5 Rating*
Diodes	.0100	.0210
Transistors	.0200	.0560
Capacitors	.0040	.0150
Resistors	.0014	.0030

Table 6

F.R. of Sample Non-derated Components

Component	*F.R.*
Connector	.020
CRT Scanner	4.100
Electron Tube	1.500
Limit Switches	.050
Photomultiplier	0.200
Servomotor	1.140

Table 7

Reliability Estimates for UAMCE

Report	*MTFB in Hours*
Preliminary	25.8–107.3
1st Interim	71.1–145.5
3rd Interim	73.5–160.5
5th Interim	111

most important consideration and detailed provisions would be seldom justified in procurement of an item or system the estimated cost of which would be less than $100,000.

Summary

In conclusion it can be stated that this paper touches only lightly upon the subject of reliability, and it is hoped that the over-simplifications, which have been resorted to in order to make this extremely complex subject more comprehensible to those who have not been previously exposed to it, will be forgiven.

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