

MEASURING THE RELIABILITY OF EQUIPMENTS
IN OPERATING ENVIRONMENTS

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A few years ago, "reliability" was a jargon word. Today we find it in the vocabulary of the informed lay public. News magazines and newspapers use the term frequently in articles on missiles and other equipments.

As operations researchers, we subscribe to the scientific principle that knowledge derives ultimately from measurement. The purpose of this paper is to discuss some of the concepts and problems pertinent to the measurement of reliability.

The definition of reliability must be well understood by those concerned with measuring it. "Reliability" encompasses five concepts: a probability; an aggregate; an environment; a set of criteria; a time interval. (See Reference 1 for a detailed discussion.) A "barefoot" definition that illustrates these points is: "Reliability is the chance that something does what it is supposed to do, when and where it is supposed to do it."

It is evident from the definition above that there are infinitely many reliabilities that describe the behavior of a particular aggregate. The so-called "storage life" of an equipment involves the probability that the equipment passes a specified test after a specified amount of time in a specified environment. For different testing procedures (visual inspection, continuity check, static operation, etc.) the value of "storage life" will be different.

Let us visualize a particular aggregate as an entity which is "born" (accepted into an operational inventory), "grows up" (installation and debugging at an operational site), "matures" (performs useful tasks, preventive and corrective maintenance occurs), and "dies" (removed from operational inventory for overhaul, or undergoes a destructive mission, such as a launching).

Many reliability measurement systems concentrate too heavily on the "death" of the individual aggregate. This is certainly important for inventory calculations. However, a major portion of the cost of an operating inventory of equipment in being over a period of time results from maintenance requirements generated during the "life" of the aggregate. Therefore, it is important to measure the reliability of equipments for environments, criteria, and time intervals which are appropriate to aggregate "life situations", such as checkouts, storage, etc. (Failure models appropriate to this concept are discussed in References 2 and 3.)

Many attempts have been made to measure the reliability of aggregates on the basis of data collected for other purposes, for example, data on the issues of aggregates from a stockage point. However, issues from a stockage point are caused by many factors other than malfunctions of operating aggregates: changes in operating policies, mandatory replacements, anticipated consumption, "hoarding," alternative uses, and so forth, (See Reference 4 for a discussion of this problem.) It can readily be seen that inferences on reliability made from data recorded for other purposes are, at best, of limited value and in many cases misleading.

In general, the measurement of reliability should be absolute, rather than relative. It is of some value to know that aggregate "A" had twice as many malfunctions as aggregate "B", but very little manipulation can be performed from such data. The significance of changes in relative reliability is difficult, if not impossible, to perceive.

There are many types of operating environments to which an aggregate is exposed during its life span: transportation; storage; turn-on (off); ground operation; in-flight operation; and maintenance. (See Reference 2) A reliability

measurement system must be flexible enough to permit recording of life events in terms of the operating environments which significantly affect a particular aggregate. The flexibility should work in another direction also, and permit dropping from the data recording system those environments which are found to be of little or no significance in the reliability history of a particular type of aggregate. Flexibility in these two directions implies that the reliability measurement system should permit addition to the data recording of environments which are to be tested for significance. Finally, the system should permit facile selection and revision of the criteria of successful performance of the aggregate.

Reliability factors are highly interdependent with operations, maintenance, and supply activities since it is the exercise of the equipment in these environments that exposes the equipment to the occurrence of malfunctions. Therefore, a reliability measurement system set up separately and in parallel to existing operations, maintenance, and supply systems will result in a high degree of redundancy in data collecting and processing. Cost considerations dictate that every consideration should be given to designing the reliability measurement system to be consolidated with the data system(s) which record(s) the operations, maintenance, and supply actions related to the equipments: (See Reference 5 for a more detailed discussion of these considerations.)

Data systems in general should adhere to the principle of simplicity of data input. This is particularly true of an operational reliability measurement system which usually requires that data elements be generated at a large number of operating locations by many individuals at different times. Insofar as feasible the operations of referencing, classification, arithmetic, summarization and analysis should not be performed by the agent who originates

data elements. As opposed to the situation in the development and testing phase, the reliability history of an equipment in its operational phase is observed by individuals who are not trained or oriented in scientific methods; who do not appreciate the need for complete and accurate data which will be used elsewhere for analysis and planning. Further, it is usually more efficient to forward data elements from several operating sites, batch them, and have the above mentioned operations performed by specialists.

Before being accepted for further processing, the data should be checked for accuracy and completeness. The latter problem deserves special note, since it includes checking for data which has not been submitted. The magnitude of this problem can be judged from reported experience by Western Electric, ARINC Research Corporation, and many other organizations, on reliability reports from unmonitored operational points. The experience is that an information loss of 70 per cent or more occurs under circumstances where no operating site data discipline is encountered.

Two of the most important alternatives in estimating equipment reliability are (1) analysis of the reliability history of relatively large aggregates of equipment: missile, ground guidance; ground checking, etc., (2) analysis of the reliability history of relatively small aggregates of equipment: tubes; resistors; gyros; etc., combined with synthesis to obtain estimates of the reliability of the larger aggregates. Each of these approaches results in vastly different reliability measurement systems. Approach number (1) results in a system which monitors the operational history of a relatively few major individual complex aggregates. Approach number (2) results in a system which monitors the operational history of a relatively large number of individual simple sub-aggregates.

The second approach appears to be desirable during the development and initial operation of equipments, when the total number of equipments in the inventory is small, and therefore the total number of individual sub-aggregates is not too great. At this time in the life span of the equipment, moreover, monitoring of the sub-aggregates is extremely desirable, so that the redesign that is usually necessary to achieve fully operational status can be based on the measured reliability behavior of sub-aggregates. This also results in better predictions of the ultimate system reliability.

However, as the equipment reliability and performance improves, redesign is (or should be) terminated or deferred, and as the operational inventory increases, the numbers of individual sub-aggregates becomes very large, and the complete monitoring of these would impose a severe data burden on operating personnel. In addition to which, since extensive redesign during this phase of equipment usage is undesirable, a complete reliability history of all the sub-aggregates is unnecessary -- the reliability history needed for follow-on provisioning, etc., can well come from a sampling of sub-aggregates rather than complete monitoring.

Also, during this period emphasis shifts to complete monitoring of the reliability history of the large aggregates of equipment, since the emphasis is now on the employment of the equipment rather than its development. Planning shifts to alternative employment and support policies for aggregates, rather than redesign within aggregates.

An approach to this problem that merits investigation can be briefly described as: (1) Define several "standard" operating environments for large aggregates; (2) Describe stresses on each sub-aggregate of interest for each "standard" environment; (3) Record only the reliability history of aggregates

in terms of standard environments and exceptions, (4) Correlate these estimates to "bench" reliability.

Finally, let us note some of the difficulties that face a reliability measurement system. One of the most vexing problems is the classification of malfunctions in terms of degradation of the effectiveness of the equipment. A malfunction can be defined (Reference 1) as a state of equipment performance which produces operator dissatisfaction. It is apparent that there are degrees of dissatisfaction, ranging, say, from mild annoyance to complete disgust. However, we cannot ignore the human factor in the definition of a malfunction, since each instance of dissatisfaction generates a maintenance action. Even those maintenance actions which conclude that no "real" malfunction existed result in the consumption of maintenance resources: skilled manpower, test equipment, parts (used in the testing process), and test facilities. Of course, many malfunctions can be more objectively defined, and then operator dissatisfaction has correspondingly less of a subjective component to it.

Another factor which poses a problem to the reliability measurement system is that of the fragmentation and recomposition of aggregates. As parts and major assemblies are received, repaired, operated, and replaced, the composition of the individual aggregate changes over time, so that knowledge of the time history of configuration must be made available to the consumer of the data collected in the reliability measurement system. Now, some degree of configuration knowledge must be maintained continuously for other purposes, such as operations planning; therefore, it does not seem to be desirable to establish a separate data requirement on this for reliability purposes only, but to consolidate the perhaps more detailed reliability measurement needs

with operational measurement needs and have each consumer of the data draw upon the same file.

Another problem of importance is the magnitude of the data processing workload. The application of sampling methods to the measuring of reliability of equipment populations can alleviate this to some degree. In the past, there has been such a paucity of data on equipment reliability that additional data always seemed to be desirable. However, due partially to the implications of present and near future high volume, high speed data processing equipment, data systems planning has reached the point where there is a possibility of collecting too much data, including reliability data. The concepts of statistical decision theory (Reference 6) are very appropriate to this problem in considering the cost and value of information in determining the extent of the sampling effort required.

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