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SOME PROPOSED RESEARCH ACTIVITIES PERTAINING TO RELIABILITY

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ACTIVITIES PERTAINING TO RELIABILITY

Contributed by the Staff of the
Reliability Evaluation Division
Sandia Corporation
Albuquerque, New Mexico

Presented by R. O. Frantik

Introduction

The purpose of this paper is three fold; first, to outline the major problems that have appeared in reliability research at Sandia Corporation, second, to note the progress which has been made to date, and third, to generalize from our experience. It is our purpose to advertise, to some extent, the progress that Sandia Corporation has made in reliability research. Correspondingly we seek information which may contribute to the solution of the problems which are to be described.

Before proceeding with this topic, a few comments concerning the Reliability Evaluation Division of Sandia Corporation may be of interest.

Two years ago, at the symposium at Corona, I outlined the weapon development process followed at Sandia and indicated the role of the reliability group in this process.[1] Since that time, the name of the division has been changed from the Component Analysis Division to the Reliability Evaluation Division. The division is now under the Director of Systems Development rather than under the Director of Research. There has been no essential change in personnel in the division.

Our efforts now are directed more or less exclusively toward reliability considerations. The administrative change puts the division more closely in contact with both the producer and the consumer of reliability data within Sandia Corporation.

One of the major projects in the division is directed toward setting up machine methods for collecting, recording, and sorting data to feed into statistical studies in the evaluation of reliability. As these data become available, more effort must be expended in deriving the necessary statistical methods for their conversion into reliability estimates. The time and manpower directed toward reliability research has increased substantially since the Statistical Research Division is working in direct collaboration with the Reliability Evaluation Division.

It should be mentioned that problems peculiar to the human engineering aspects of reliability are not considered in this paper. Such studies make a substantial and important contribution to the overall weapon or missile system reliability. However, because of the time restrictions here and because human engineering problems are considered at other symposia, this topic is not pursued in this paper.

General Areas For Reliability Research

The objective of reliability research is to derive the necessary mathematical, statistical, and laboratory methods required in the following four general activities:

I. The evolution of a component or system design which incorporates optimum reliability.*

II. The production of a component or a system which preserves (and possibly improves) the reliability characteristics of the design.

III. The maintenance and evaluation of reliability characteristics in stockpile and in use.

IV. The provision of bases for decisions by management or by the military where matters of reliability are involved.

The result of a particular reliability research project often will apply to more than one of these four categories.

In some cases the problems discussed later are assigned arbitrarily to one of the four categories.

The research activities of the Reliability Evaluation Division generally are directed toward the derivation of mathematical and statistical tools. Research into laboratory methods usually is confined to the statistical design of experiments aspect of a given problem.

Reliability Research Problems in Development

First, let's consider the major problems that arise in connection with the evolution of a component or a system design. Among these problems are:

1. Analysis of the design in an attempt to predict the most probable modes of failure.

2. Determination of the test procedures which yield the maximum amount of reliability information and re-evaluation of the procedures as testing progresses.

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* The term optimum reliability means maximum reliability consistent with other system requirements.

3. Investigation of means of decreasing test costs in time and money.

4. Investigation of methods for estimating the use environment and for extrapolating reliability estimates into the use environment.

5. Application of the methods of Boolean matrix theory to the estimation of reliability in the analysis of circuit designs.

6. Investigation of methods for stating reliability specifications.

Work on the first two of these six problems has proceeded on somewhat of a routine, non-research basis at Sandia. Proposed circuit designs are usually examined by the Reliability Division for the purpose of making a priori reliability estimates. In these examinations unsuspected modes of failure frequently are uncovered. General guide lines for applying the "physics of failure" approach to the design of a test program have been suggested by Leslie E. Ball. However, we know of no generally accepted procedure for the prediction of individual modes of failure particularly where a combination of environmental factors is involved.

Procedures for specific types of tests and for tests at particular stages in the design to stockpile process have received considerable attention. The design to stockpile sequence of events is usually long and sometimes quite complex. We believe that at least a sound philosophy or preferably a statistically sound procedure should be developed for apportioning time, money, and equipment to the series of tests required in this sequence of events. Such a procedure should yield more accurate reliability estimates and decrease the long range costs of the over-all test program.

The fact that reliability varies with environmental factors is well known, but this knowledge rarely embraces more than the qualitative aspects of such variation. Rules-of-thumb are offered occasionally as rough methods for approximating environmental effects. Since a reliability estimate with no indication of its accuracy is of little value except for purposes of comparison, the use environment must be estimated with sufficient accuracy to allow incorporation of reasonable factors of safety into the weapon design. Furthermore, statistical and laboratory procedures need to be developed for estimating the functional relationships between reliability and the various environmental variables. Some theoretical consideration of this problem appears in a Sandia document[2] which considers the special case in which the environment is a random variable. Another approach appears to lie in the application of extreme value theory to the probability of occurrence of severe environments and environmental combinations.

The analysis of circuit designs in the early stages of development is one function of the Reliability Evaluation Division. The methods currently used have been explained in a Sandia Corporation document[3]. A second document[4] illustrates some shortcut aids in the use of these methods. We hope to be able to apply Boolean matrix theory in deriving a method for more rapid circuit reliability evaluations. So far we have done little more than note an example or two which holds some promise for such an approach. Aside from establishing the necessary rules of operation, the main problem appears to

be the conversion of a square matrix which describes circuit operation into a matrix with component reliability estimates which may be evaluated by machine methods. We believe this problem holds sufficient promise to warrant an early attack.

The valuable contributions of Robert Lusser have gone far in the development of methods for stating reliability specifications. However, we believe that a complete theory must develop the relationships between interval estimates of the system reliability and the interval estimates of component reliability. Such relationships are fairly readily found for point estimates of reliability but point estimates rarely, if ever, carry any quantitative measure of their accuracy. Two Sandia studies[5,6] make a start on this problem, but much remains to be done. The first of these studies considers the error density functions of systems (with operating time as the independent variable) in terms of the error density functions of the components. The second of these studies considers the general theory of confidence intervals and uses simple two-element systems for examples. This problem may appear trivial on the surface, but for complex systems we do not know today what confidence statement could be made for a system based upon known confidence statements for the components.

The problem of writing specifications also applies to test equipment. Insofar as the normal density function applies to test set errors and to errors in product performance, this problem has been considered by the Reliability Evaluation Division[7].

Reliability Research In Production

Now, I should like to consider a few problems that appear to arise more frequently in the production stage of the system than in any of the other three general categories mentioned near the beginning of this paper. Some of these problems are:

1. The derivation of methods for using quality control and acceptance inspection data in the prediction of reliability. The suggestion of changes that will result in the data taken being more useful in deriving reliability estimates.

2. The derivation of procedures for measuring the effect of testing at various stages of production, storage, and use upon the predicted reliability in use.

3. The investigation of the theory of life curves and its application to the reliability aspects of weapon and missile components.

4. The derivation of improved sampling plans.

5. Further inquiry into the theory of testing for intermittent failures.

6. Further study of the use of confidence intervals. The study and application of the theory of confidence regions.

7. The development of criteria for making a choice between competing programs and between suppliers.

In the course of extending our data collection system, we expect to learn the extent to which quality control and acceptance inspection data can be used in estimating reliability. We are using some of these data presently. By comparing these data with data from later tests and inspections, some indication of the effects of certain environments may be obtained.

The effects of testing on reliability are closely akin to the types of life curves which may characterize many components. Therefore, in general, these two problems may be considered together. The theory of the initial failure and chance failure life curve combination has been extensively treated. However, as Marcus Acheson effectively points out, there are many other types of life curves. Where the theory of life curves applies, the effects of testing require that we learn more about the life curves of particular components as an aid in determining whether testing has an adverse effect on reliability.

Presently known sampling plans require inordinately large sample sizes for reasonable assurance of quality of highly reliable devices. Samples of 50 per cent or more of a lot are required in some cases. Such large samples are patently costly. Millions of dollars could be saved by successful research into new sampling techniques. However, new sampling plans must be examined for their effect on the amount and quality of information generated for a reliability evaluation program. The general theory of sequential sampling is well known. New sampling plans might be based on sequential procedures. Reliability people face a real problem in determining what AQL levels to specify to get one-shot devices of stated required reliability across many lots. They also face a difficult problem in stating acceptable consumers and producers risks. Certain types of failures on some types of equipment appear intermittently. The theory of the detection of intermittent failures has been developed in the Reliability Evaluation Division as it applies to acceptance sampling.[8,9] Further work remains to be done on the effects of intermittent failures as they pertain to final reliability estimates.

Many of our reliability estimates are stated in terms of confidence intervals. The theory of confidence intervals has been studied extensively at Sandia.[6] However, as mentioned earlier in this paper, we have yet to determine the relationships between confidence intervals for components and those for the system.

Graphs and nomographs have been constructed for the determination of confidence intervals where the binomial distribution applies and where the probability of failure is expected to be small.[10] These graphs have also been of value in making preliminary estimates of sample sizes required to demonstrate the attainment of specified reliability values.

In many situations we are interested in greater detail than a simple success-or-failure model provides. For example, a bomb may detonate prematurely, it may detonate properly, or it may fail to detonate. In such a trichotomy of events, confidence intervals can be derived for the probability of each event if only the marginal density functions are considered. However, we believe that such

a situation could be described more accurately by probabilistic methods which avoid such a piecemeal approach. Perhaps the theory of confidence regions could be developed and applied in such situations.

Numerous tests exist for making choices between products or systems where special conditions apply. We know of no test that can be applied in situations where the effectiveness of a product (for example) depends on several parameters, some of which favor one design (or supplier), while other parameters favor another design. We feel that this problem is amenable to the techniques developed for use by the systems analysts. We believe it is desirable that such tests be comprehendible by those people who make such decisions.

Reliability Problems In Stockpiling and Use of Weapons

In the maintenance and evaluation of reliability in stockpile and in use three major problems arise:

1. The derivation of methods for using surveillance data in confirming or amending earlier estimates of reliability and in extrapolating reliability estimates into the use environment.

2. The investigation of the role of reliability in determining stockpile requirements.

3. The derivation of methods for using reliability estimates in decisions to or not to retrofit.

The first of these problems is a continuation of the more general problem of keeping an up-to-date estimate of reliability beginning with the original study of the system design. As the data collection program of the Reliability Evaluation Division matures, it is expected that greater effort will be expended on the analysis of this particular type of data.

The determination of stockpile requirements is a complex problem which generally requires input data available only to high military circles. In general such problems can be treated only in terms of unknown parameters. However, some aspects of this problem appear in connection with the first problem of the next section.

The problem of the best time to retrofit a weapon type has been considered at Sandia but no solution has been found as yet. Insofar as retrofitting may be justified because it improves reliability, this problem may be considered in connection with the first problem in the next section.

The Provision of Bases For Decisions

The general problem of providing bases for decisions by management or by the military where matters of reliability are involved overlaps some of the problems discussed in the preceding category. In addition to these, the following problems have appeared:

1. The derivation of methods for estimating the value of improvements in reliability in terms of money, time, or other measures of value.

2. The study of relationships between reliability and performance capability, accuracy, vulnerability, operability, etc.

With regard to the problem of evaluating improvements in reliability we have suggested some elementary methods for determining lower limits for the dollar value of reliability improvements. When these lower limits are sufficiently high, they are of some value in indicating a decision. When a decision is not indicated by these elementary means, a more detailed evaluation must be made and one immediately is confronted with the lack of input data.

The problem of studying the relationships between reliabilty, performance, capability, etc., is properly the business of the Systems Evaluation Department. Under the present organization, the Reliability Evaluation Division would contribute only to the reliability phases of such a problem. In the past this division, under a different organization, has contributed to one such study with respect to a particular weapon. The solution to such a problem usually lies in the derivation of an over-all "worth equation". This worth equation supposedly serves as a decision function where a choice between two or more weapons or versions of the same weapon is involved. Such decisions depend upon many factors for which quantitative measures do not yet exist. Hence, the value of any general worth equation derived to date is in our estimation a matter of considerable doubt.

Some General Problems

In addition to the problems already discussed in this paper there are others of a more general nature. It is possible that game theory, search theory, and information theory can be applied to problems of interest in reliability research. In the past the Reliability Evaluation Division rarely has had more than two people at work on problems of the type outlined earlier in this paper at any one time. Therefore, our efforts have been directed to problems and methods which have shown early promise for a useful solution. In the immediate future we hope to add to the research potential of the division. As such people are added we hope to do some research of a more exploratory nature.

In retrospect it appears that we have solved few of our problems. However, we believe that real progress has been made when our major problems have been recognized. We hope that additions to our reliability research staff will allow us to attack an increasing number of these problems. Although we of the Reliability Evaluation Division of Sandia Corporation do not expect to solve all of these problems unassisted, we hope that our major contributions to future reliability symposia will lie in the domain presented here.

An Appeal

This paper has presented some proposed research activities pertaining to reliability in the context of the work being done by Sandia Corporation. However, we believe that these problems are not peculiar to our company. We have attempted in this paper to bring focus on the nature and extent of the research needed to accomplish the major tasks which face reliability people, i.e., we have attempted to define the problem areas. We strongly

urge that the infancy of reliability efforts everywhere be recognized and that these infant efforts be bolstered by support of the research required. To this end it is recommended that the various military services and manufacturers make these important problems known to universities and other research agencies and if necessary support this research by contract or endowment.

I would like to make another plea and recommendation regarding communication. Within the AEC family there is a classified journal on reactor technology. It seems possible to me that a similar journal on reliability problems and data exchange could be sponsored by the DOD.

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