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THEORETICAL COMPARISON CRITERIA FOR SOFTWARE RELIABILITY MODELS

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ABSTRACT

A set of criteria is proposed for the comparison of software reliability models. The intention is to provide a logically organized basis for determining the superior models and for the presentation of model characteristics. It is hoped that in the future, a software manager will be able to more easily select the model most suitable for his/her requirements from among the preferred ones.

KEYWORDS

Model comparisons, predictive validity, software failures, software reliability.

1. INTRODUCTION

The measurement of software reliability has become increasingly important because of both the impact of software failures and the development costs of reducing them. One wishes to select the "best" value of reliability, in a tradeoff with other product characteristics, and then track a software component or system during test and operation to determine f the goal has been achieved, and if not, when it will be. A number of models have been proposed for characterizing software reliability and its dependence on various variables related to the software product and the software development process[1]-[4].This proliferation, although permitting the exploration of many possibilities, has resulted in confusion on the part of the software manager or engineer. It may or may not be possible to do this, but it should at least be feasible to reduce the number of models and provide some guidance for selecting one among the educed set. Some attempts have been made to compare some of the different models. These attempts, while laudable, have generally been handicapped by lack of satisfactory data or lack of agreement in the software reliability community as to the evaluation criteria to be employed. Recently there has been a substantial improvement in the quality of failure data that are available [6]. Consequently, it seemed highly desirable to determine if a consensus could be reached among software reliability researchers on the evaluation criteria to be used. This paper represents a comparison criteria based on theoretical concept that is predictive validity, capability, applicability, quality of assumption. Comments from many reviewers who are involved in the software reliability field have also been incorporated. It is hoped that this effort will facilitate model comparisons.

Some background information applicable to all models may be appropriate at this point. The generally accepted definition of software reliability is the probability of failure free operation of a software component or system in a specified environment for a specified time [7].A failure is any departure of program output (taken in the most general sense; includes control signals, commands, transmitted data, printout, displays, etc.) from requirements as the program is executed. The term "environment" reflects the operational profile of the program; i.e., the relative probabilities of occurrence of various types of runs, which are characterized by their input states. If a program is used in different environments, the reliability may be different for each environment. It is assumed that input states are presented randomly to the program in accordance with the relative probabilities indicated. This assumption is generally realistic with respect to programs in the operational phase. It is also generally realistic for programs in test except that the probabilities may be altered to increase testing efficiency (in which case an adjustment must be made to the reliability by using the testing compression factor [2].

Reliability refers to the consistency of a number of measurements taken using the same measurement method on the same subject. If repeated measurements are highly consistent or even identical, then the measurement method or the operational definition has a high degree of reliability. If the variations among repeated measurements are large, then reliability is low. For example, if an operational definition of a body height measurement of children (e.g., between ages 3 and 12) includes specifications of the time of the day to take measurements, the specific scale to use, who takes the measurements (e.g., trained pediatric nurses), whether the measurements should be taken barefooted, and so on, it is likely that reliable data will be obtained. If the operational definition is very vague in terms of these considerations, the data reliability may be low. Measurements taken in the early morning may be greater than those taken in the late afternoon because children's bodies tend to be more stretched after a good night's sleep and become somewhat compacted after a tiring day. Other factors that can contribute to the variations of the measurement data include different scales, trained or untrained personnel, with or without shoes on, and so on.

A software reliability model is a representation of a random process through which software reliability [or a directly-related quantity such as mean-time-to-failure (MTTF) or failure rate] is characterized as a function of time and properties of the software product or the development process. It specifies the general form of the dependence of software reliability on the variables mentioned. The specific form is determined from the general form by statistical inference procedures, which are usually based on the known failure data. A model generally has a statistical inference procedure associated with it. A model may be applied to a software module, subsystem, or system, although reasonable predictive validity may not be attainable for a small software component with a resultant small sample of failures. Note that models that do not consider time are excluded by definition from consideration, although such models may provide some insight. Models can be expressed in terms of either calendar time or execution time; models expressed in execution time incorporate the effects of varying workload. This paper does not address the relationship between the reliabilities of software components and the reliability of a software or software-hardware system (e.g., a distributed system).

2. COMPARISON CRITERIA

It is recommended that software reliability models be compared on the basis of the criteria discussed in this section. It will be noted that some of these criteria are general ones that apply to all types of models; however, they are described and discussed here in the specific context of software reliability. Only "intrinsic" criteria have been selected; it is assumed that such attributes as documentation quality and human interface quality depend on the implementation and are not characteristic of the model per se. The criteria can be used for assessment (determining the absolute worth of a model) as well as comparison. Comparison should be done with relation to a variety of software systems; it does not appear likely that the evaluation of the models will be application-dependent, but one must watch for this possibility. The data must, of course, be collected with care; it would not be reasonable to compare models with poor quality data, or worse, data of unequal quality. However, as will be noted in Section 2.4, tolerance to or capability to compensate for certain types of poor data is a desirable quality in a model. It is expected that comparisons will cause some models to be rejected because they meet few of the criteria discussed in this paper. On the other hand, there may or may not be a clear choice between the more acceptable models. The relative weight to be placed on the different criteria may depend upon the context in which the model is being applied. However, the criteria have been ranked in approximate order of importance (rank is indicated by the section numbers). When comparing two models, all criteria should be considered simultaneously (i.e., models should not be eliminated by one criterion before other criteria are considered, with the possible exception of models whose predictive validity is grossly unsatisfactory).[5] is not expected that a model must satisfy all criteria to be useful.

The Problem

Before we examine the used in modeling, we need to specify clearly what question we are trying to answer. Too often, we believe, there has been an unthinking use of classical reliability concepts which were originally developed for hardware systems. It may be that some ideas from hardware reliability will be appropriate for software, but a positive justification must be made in each case in order not to end up with quantified nonsense. Perhaps the most common example is the wide use of mean time between failure (MTBF) as a measure of software reliability.

2. 1. PREDICTIVE VALIDITY

Predictive validity is the capability of the model to predict future failure behavior during either the test or the operational phases from present and past failure behavior in the respective phase. The ultimate goal is to predict operational failure behavior from failure behavior in either test or operational phases or both. However, the relationship between test and operational behavior needs to be understood more fully before prediction across the test/operational boundary can be made with high confidence. Predictions are normally made during a period in which the software is being maintained (at least some portions of failures are being corrected).

Ideally, one would like to determine that predictive validity is "adequate" in some absolute sense. However, no criterion for determining adequacy has been established at present. At best, one should keep in mind the differences between models that should be larger than sources of error (especially measurement error) before any advantage can be attributed to one model over another. There are two general ways of viewing predictive validity, based on the two equivalent approaches to characterizing the failure random process, the failure interval approach and the number of failures (counting process) approach. Various methods (some representing approximations to predictive validity) may be applied; it has not been determined if one is superior at the present time. In the failure interval approach, the failure random process is characterized in times (execution or calendar) between failures T_1', T_2', - - (in this section we will follow the customary practice of indicating random variables by upper case letters and their realizations by lower case). The description of the random process is provided by the cumulative distribution functions (cdf's). All other quantities such as MTTF (if it exists), failure rate, reliability, etc. may be obtained from these. Typically, each model has also implicitly incorporated a procedure for making inferences about the parameters of the cdf's from the failure data $t_1', t_2', \ldots . t_m'$.

The predictor distribution for the random variable T*i*, which incorporates model and inference procedure, may be written.

$$\hat{F}(t_1', t_2', \ldots\ldots\ldots\ldots, t_m') \qquad \text{------ (1)}$$

Assumption used:

i= failure interval

m= number of failure interval (i>m)

Let k = i-m. (Prediction length) ------- (2)

Cases:

m fixed , k varies

m varies, k fixed

Here i varies in both the cases.

In the former case, we are examining predictions of various lengths using a fixed sample size. In the latter case, we are examining prediction of a fixed length based on different sample sizes. It is recommended that predictive validity be checked from both viewpoints. If one model has equal predictive validity with another but attains this capability earlier (i.e., for a smaller failure sample), it may be superior.

The number of failures approach may yield a method that is more practical to use than the failure interval approach. In this approach, the alternative characterization of the failure random process is employed, where the random process is described by {M (t), t > 0},

Where M(t) represents the number of failures experienced by time t.

Such a counting process is characterized by specifying the distribution of M(t), including the mean value function μ(t).

Assumption

q=failures have been observed at the end of test time t_q.

te= failure data up to time (t_e>t_q)

These variables are used to estimate the parameters of μ(t).

Then, the number of failures by tq can be predicted by substituting the estimates of the parameters in the mean value function to obtain $\hat{\mu}(t_g)$ which is compared to the actually observed number q. This will be repeated for various values of t_e.

The predictive validity can be checked visually by plotting the relative error {($\hat{\mu}$ (t_q) - q)/q} against the normalized test time t_e/t_q. The error will approach zero as t_e approaches t_q. If the points are positive (negative), the model tends to overestimate (underestimate). Numbers closer to zero imply more accurate prediction and hence the better model.

The use of normalization enables one to overlay relative error curves obtained from different failure data sets. For an overall conclusion as to the relative predictive validity of models, we may compare plots of the medians (taken with respect to the various data sets). The model which yields the curve that is the closest to zero will be considered superior. Although most models have been developed in association with a particular inference procedure, other inference procedures should be considered if prediction is poor. The quality of inference can be examined by generating simulated failure intervals based on the model with assumed parameter values and using them in the prediction, scheme (combination of model and inference procedure). This method removes any effects of the model; any consistent differences between the represent the effect of inference alone. Alternatively, the distributions of the parameter estimates may be compared to the actual values to evaluate inference quality.

2.2. CAPABILITY

Capability refers to the ability of the model to estimate with satisfactory accuracy quantities needed by software managers, engineers, and users in planning and managing software development projects or controlling change in operational software systems.. The degree of capability must be gauged by looking at the relative importance as well as number of quantities estimated. The quantities, in approximate order of importance, as denoted by the numbers, are

1) Present reliability, MTTF, or failure rate;

2) Expected date of reaching a specified reliability, MTTF, or failure rate goal (It is assumed that the goal is variable and that dates can be computed for a number of goals, if desired. If a date cannot be computed and the goal achievement can be described only in terms of additional execution time or failures experienced, this limited facility is preferable to no facility although it is very definitely inferior.);

3) Human and computer resource and cost requirements related to achievement of the foregoing goal(s).

Any capability of a model for prediction of software reliability in the system design and early development phases would be extremely valuable because of the resultant value for system engineering and planning purposes. It appears that these predictions must be made through measurable characteristics of the software (size, complexity, structure, etc.), the software development environment, and the operational environment.

2.3. QUALITY OF ASSUMPTIONS

The following considerations of quality should be applied to each assumption in turn. If it is possible to test an assumption, the degree to which it is supported by actual data is an important consideration. This is especially true of assumptions that may be common to an entire class of models. If it is not possible to test the assumption, its plausibility from the view-point of logical consistency and software engineering experience should be evaluated. For example, does it relate rationally to other information about software and software development? Finally, the clarity and explicitness of an assumption should be judged; these characteristics are often necessary to determine whether a model applies to particular circumstances.

2.4. APPLICABILITY

Another important characteristic of a model is its applicability. A model should be judged on its degree of applicability across different software products (size, structure, function, etc.), different development environments, different operational environments, and different life cycle phases. However, if a particular model gives outstanding results for just a narrow range of products or development environments, it should not necessarily be eliminated.

There are at least five situations that are encountered commonly enough in practice that a model should either be capable of dealing with them directly or should be compatible with which the model may diverge from reality in an application. Parameters should have readily understood interpretations; this property makes it more feasible for software engineers to estimate the values of the parameter where data is not available. Finally, a model must be readily implementable as a program that is a practical management and engineering tool. This means that the program must run rapidly and in expensively with no manual intervention required (does not rule out possibility of intervention) other than the initial input.

3. CONCLUSIONS

The systematization of comparison criteria presented above has been planned to encourage comparison of software reliability models on a common basis. Much better data than here and there are available can now be employed. Thus the ground work has been laid for evaluation efforts leading to a narrowing down of the number of models. The organized framework of comparison criteria and the information gathered for each model in regard to them should provide a basis for selection among the better models with respect to the needs of a particular situation. The question arises, whether we should be concerned so much with failures and the simple reliability study. It is quite obvious that something most be done for the future point of view that one should make a new model to compare with and analyze the result which could be able to solve the problem in better way.

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