A Comparative Analysis between Different Parametric and Non-Parametric Reliability Models

Sugam Srivastava, Monika Sharma
University Institute of Engg. And Technology Panjab University, Chandigarh, India

***Abstract*—**Reliability is considered to be one of the most important quality attributes for any system. Reliability Engineering can be defined as the ability that a system or particular component has to carry out its required functions under given conditions for a specific period of time. This paper evaluates and compares different parametric and non-parametric software reliability growth models. Parametric such as Jelinski-Moranda, S-shaped models have been used and Non-Parametric such as Neural Network, Fuzzy Logic and Regression models have been used.

Keywords*—Software reliability models, SRGM, Parametric models, Non-parametric models.*

I. Introduction

Software Reliability is one of the most important quality attribute and is beginning to be significantly considered in every software development. Reliability is stated or defined as the probability that software will display no fault when tested for a particular period of time. Software reliability model is a method of displaying the process when software fails in mathematical terms. For instance properties such as number of faults introduced, number of faults removed etc can be expressed in the form of mathematical functions with the help of software reliability model. Designing software is quite an easy task but to develop reliable software is becoming a tedious one nowadays. Factors such as scarcity of resources, time constraint, and unrealistic requirements lead to unreliable software.

We cannot construct a single reliability model which can work with all the software's, because a model which work with certain parameters is not necessary will work with other parameters as well. In this paper we have compared different types of software reliability growth models. SRGM's further can be divided into two types:

A. *Parametric reliability models*

The Parametric Software Reliability models are based on the theory of design and analysis. These models are based on mathematical theory of statistics. Parametric reliability models are primarily based on certain assumptions and these assumptions are based upon the characteristics of the failure software. The Parametric reliability models are constructed on certain parameters and these parameters are clearly defined and discussed and also have a physical meaning. These parameters are then used in the end in a way that they are fitted to the failure data and the estimation and prediction of software reliability is obtained [1].

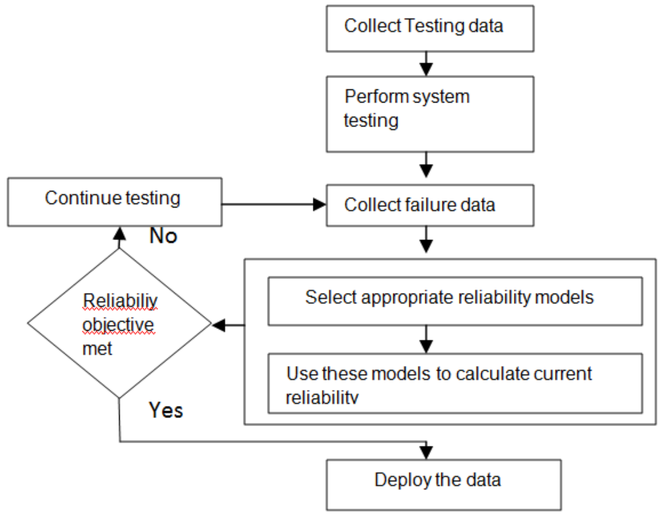

Fig.1: Software Reliability Process

B. *Non-Parametric reliability models*

One of the major problems of parametric reliability models are that the mathematical assumptions on which these models are based may not work in all the scenarios and under all circumstances. In software engineering this problem is known as model inconsistency problem in which due to these parameters the prediction result are always different for different models. Due to the model inconsistency problem encountered with Parametric Software Reliability Models (PSRMs) Non-Parametric Software Reliability Models (NPSRMs), which are based on machine learning techniques, are gaining popularity. In Non-Parametric models the effect of all the assumptions can be reduced completely. Non-Parametric models are able to evolve themselves based on the failure data which is collected during the initial stages. Although NPSRMs do have external parameters but these parameters have no physical interpretation. Non-Parametric models are based on machine learning techniques for the determination of reliability of any software. Therefore in non-parametric models no assumptions are made in early stages.

II. Types of Parametric Models

There are different types of parametric software reliability models which have been used in reliability engineering such as:-

A. Jelinski-Moranda Model

Jelinski-Moranda model is considered to be the first reliability model of the whole lot. It comes under the exponential order statistic model. Jelinski-Moranda assumes that the fault detection and fault correction starts when there are N number of faults and all the faults have the same rate. Every time a fault is corrected it is assumed that no new faults are introduced into the system [2]. In Jelinski-Moranda model each and every time a fault occurs, at that interval fault-detection rate remains constant [3].

B. Goel-Okumoto Model

The Goel-Okumoto Model is a simple Non Homogenous Poison Process (NHPP) model with the mean value function $m(t) = a(1- e^{-bt})$.

Where the parameter 'a' is the number of initial faults in the software and the parameter 'b' is the fault detection rate[4]. The corresponding failure intensity function is given by

$\lambda(t) = abe^{-bt}$.

The probability density function of Goel-Okumoto model has the form:

$f(t) = be^{-bt}$

C. Yamada Delayed S-Shaped Model

The delayed 'S' shaped model was originally proposed by Yamada and it is different than other Non Homogenous Poisson Process Models. In delayed 'S' Shaped model the errors are not only detected but are isolated too. This model describes S shaped curve for the cumulative number of faults detected such that the failure rate initially increases but then decreases in the later stages [5]. This process becomes a little more complex in later stages because the faults discovered are more difficult to uncover. The S-Shaped Model can be considered as a learning process for the testers because the skills of the testers will improve gradually as time progresses because with time the nature of the problem becomes more and more complex.

D. Power Model

The Power Model is the most basic type of Parametric Software Reliability Models. The power model is the worst predictor and has the highest value of normalized root mean square error (NRMSE). NRMSE is an evaluation criteria used by many researchers to evaluate the performance of the model. Higher the value of NRMSE lower is the performance of the model. The power model uses the original NHPP power law. This model will correct the errors introduced when multiple units are tested or observed [6]. When testing the reliability growth of a single unit the errors are not shown as such but when multiple units are observed. Several rules of the power law model are applied to remove the errors encountered during the testing.

E. Exponential Model

The exponential Model's behavior is somewhat similar to that of S-shaped model and it also has the best predictability compared to the Power model and S-shaped model. The exponential model uses the concept of exponential distribution which describes the time between the errors in a given Poisson process,in other words, it is a process under which an error occurs continuously and independently at a certain constant average rate. Exponential distribution is also related to a very important and common term in software reliability i.e. Mean Time between Failure (MTBF). Under exponential distribution, the mean value completely defines the distribution and is hence a sufficient metric. The exponential distribution can be effectively used into reliability analysis provided an assumption of constant failure rate be justified.

F. Bayesian Reliability Growth Model

A Bayesian Reliability Growth Model treats the situation where the program is sufficiently complete to work for continuous time periods between failures, and provides a repair rule for the action during such failures [8]. Analysis is based entirely upon the length of the periods of working between repairs and failures, and does not attempt to take account of the internal structure of the program.

III. TYPES OF NON-PARAMETRIC MODELS

Since there is a lot of scope left and lot of future work to be done in non parametric models therefore the number of non parametric models is very less as compared to the parametric models. Some of the most popular types of non parametric models used today in software engineering are:-

A. Neural-Network Model

Neural Networks are similar to brain and nervous system in biological organisms. They consist of many simple Processing units, called neurons, which perform all the computation. These neurons are connected to each other in some manner. Every connection has certain amount of weight associated with them which are adjusted at the starting of the model. Usually a neural network model consist of input layer a hidden layer and an output layer. Each layer has nodes or neurons [9]. The number of hidden layers to be used in the network and also the number of neurons to be used depends upon the problem to be solved.

B. Fuzzy Logic Model

Fuzzy Logic systems are those types of systems in which the variables can have either of the two values i.e. either true or false. In fuzzy logic we can never predict the outcome, there is always a sense of uncertainty in it. A fuzzy model gives us an explanation on how linguistic variables are related to their corresponding variables [10]. This is the reason why the output obtained from the fuzzy model and also the input provided to the model can be both numerical as well as linguistic in nature. A fuzzy model structure can be represented by a set of If-Then rules. A fuzzy rule can be divided into two parts the antecedent and the consequence [11]. The antecedent variables are related to the conditions where a process is operated. The consequent is usually a linear regression model which works around these operating conditions.

C. Regression Model

Regression Models are the types of non-parametric reliability models which are gaining fast popularity in the software engineering field. One of the most famous regression models is the Auto-Regressive models [12]. This model has been used in many applications. It can be described as following:

$$y(k) = a_0 + \sum_{i=1}^{n} a_i\, y(k-\tau)$$

y (k- τ) is the observed cumulative failure n days before the current day, is the tuning parameter for the auto-regression model and n is referred to as the 'order' of the model.

Brief comparison of different parametric and non-parametric models is given in table I and table II

TABLE I. LIST OF DIFFERENT PARAMETRIC MODELS

Parametric Models/Criteria	MSE
Goel-Okumoto	1.4522375
Jelinski-Moranda	3.9326750
Delayed S-shape	5.7948583
Power model	4.4730
Exponential model	2.3925
Bayesian model	5.982365

TABLE II. LIST OF DIFFERENT NON-PARAMETRIC MODELS

Non Parametric Models/Criteria	MSE
Neural-Network	0.7714
Fuzzy-Logic	1.2901
Auto-Regression	1.0659

IV. CONCLUSION

Developing reliable software requires the best knowledge of software reliability techniques. Since till now there is no single model which can predict accurate reliability of any software based on different data sets whether open or closed, therefore comparison between different parametric and non-parametric models have been made.

In this paper, we presented a comparison between various software reliability models. They include parametric models like the power, exponential, Delayed S-Shape, Goel-Okumoto, Jelinski-Moranda, Bayesian models and non-parametric models like regression, neural network and fuzzy logic models.

We have used Mean Squared Error (MSE) as the estimation parameter for the comparison of different reliability models. From the paper we can see that all the non parametric models are superior to the parametric models when estimating the reliability of the software's since for each non-parametric models the value of MSE is very less as compared to the parametric models.

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