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Introducing Burr Type XII Testing-Effort with Change Point based Software Reliability Growth Model.

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Abstract

Software reliability is the probability that software functions correctly under a given environment and during a specified period of time. The software reliability is highly related to the amount of testing-effort. Also, the reliability of software needs to be carefully assessed and analyzed during the software development process. Furthermore, the prediction of software reliability is also very important for failure free operation by software. To asses, analyze and predict a software reliability we need to develop a software reliability growth model (SRGM). In the earlier research, it is found that the probability of fault detection is not constant. It can be changed at some point of time which is called a change point. The change can take place due to some important factors like the skill of test teams, program size and software testability. This concept motivated to propose a software reliability growth model with testing effort function along with change point. In this paper, we introduced non-homogenous Poisson process software reliability growth model with Burr Type XII testing-effort function and change point.

1. Introduction

Software is considered to have performed a successful operation, when it functions completely as expected, without any failure. However, computer software is created by human being and a high degree of certainty in reliability cannot be guaranteed (Musa et al., 1987). Software reliability is defined as the probability of failure free operation of a computer program for a specified time in a specified environment (Musa et al., 1987; Lyu, 1996) and is a key factor in software development process. Therefore, accurately modeling of software reliability and predicting its possible trends are essential for determining the software's reliability overall. Numerous software reliability growth models (SRGMs) have been proposed during the last three decades and they have been applied successfully in practice to software reliability.

In software testing, the key factors are the testing-effort and change point. During the last three decades several authors have been proposed SRGMs. Some of the SRGMs are based only on testing-effort functions, but a very few are incorporated testing-effort functions and change point. In this paper we proposed a SRGM based on non-homogeneous Poisson process. The main idea is to incorporate the testing-effort function and change point. We used Burr Type XII testing-effort function and change point.

Many testing-efforts are consumed, such as the CPU time, the human power and the executed test cases in software testing process (Ahmad et al., 2009). The consumed testing-effort indicates how the errors are detected effectively in the software and can be modeled by different distributions (Putnam, 1978; Pillai et al., 1997; Musa et al., 1987, 1999; Yamada et al., 1986, 1993; Yamada et al., 1990; Kapur et al., 1999; Huang et al., 2002; Khan et al., 2008; Bokhari et al., 2006, 2007). Actually, the software reliability is highly related to the amount of testing-effort expenditures spent on detecting and correcting software errors.

On the other hand, in practice, if we want to detect more potential faults for a short period of time, we may introduce new techniques or tools that are not yet used, or bring in consultants to make a radical software risk analysis. In addition, there are newly proposed automated test tools for increasing test coverage and can be used to replace traditional manual software testing regularly. The benefits to software developers/testers include increased software quality, reduced testing costs, improve release time to market, repeatable test steps, and improved testing productivity. These technologies can make software testing and correction easier, detect more bugs, save more time, and reduce much expense. Altogether, we wish that the consultants, new automated test tools or techniques could greatly help us in detecting additional faults that are difficult to find during regular testing and usage, in identifying and in assisting clients to improve their software development processes. Thus, the fault detection rate may not smooth and can be changed at some time moment called change point (Zhao, 1993; Chang, 2001; Chen et al., 2001; Enachescu, 2002; Shyur, 2003; Zou, 2003). In other words, the proportionality is not just a constant or in some case may be changed at some point of time which is called change point.

Accordingly, we introduce Burr Type XII testing-effort function and change point parameter into software reliability growth modeling for better result.

In the remaining of this paper, we have four more segments. In Segment 2, we have the description of Burr type XII testing-effort function. We present the description of proposed SRGM in the Segment 3. The conclusions describe in Section 4 and finally the references are given in Section 5.

2. Burr Type XII Testing-Effort Function

Burr (1942) introduced twelve different forms of cumulative distribution functions for modeling actual data. The curve of Burr Type XII testing-effort function is very flexible and having a wide variety of possible expenditure patterns in real software projects (Bokhari et al., 2007). Also, Burr Type XII testing-effort function along with change point reveals significant prediction of software reliability. There are several advantages of Burr Type XII models over other SRGMs, these are:

- It covers the curve shape characteristics of normal, log-normal, gamma, logistic and Pearson type X distributions.
- It has simple algebraic forms for reliability and hazard rate functions.
- It provides a wide variety of density shapes along with functional simplicity.
- The special cases for this model include exponential, Weibull and Log-logistic.

We observed from the earlier studies (Huang et al., 2002) that actual testing-effort consumption pattern, sometimes the testing-effort consumption are difficult to describe only by Exponential, Rayleigh, Weibull or Logistic curve. But it is easy to describe with the help of Burr Type XII testing-effort function. Therefore, we tried to include a Burr Type XII test-effort function (Huang et al., 1997).

The current testing effort consumption curve at testing time t is given as

$$w(t) = \frac{\alpha\, \beta\, m\delta(\beta.t)^{\delta-1}}{[1+(\beta.t)^{\delta}]^{m+1}} \qquad (1)$$

$\alpha > 0, \beta > 0, m > 0, \delta > 0, t > 0$

where α, β, m and δ are constant parameters, α is the total amount of testing-effort expenditure required by software testing, β is the scale parameters, and m, δ are shape parameters.

The integral form of equation (3.1) is called the cumulative testing-effort consumption of Burr type XII in time [0, t] and is given by

$$W(t) = \int_0^1 w(x)dx = \alpha[(1-(1+(\beta.t)^{\delta})^{-m}] \qquad (2)$$

$\alpha, \beta, m, \delta > 0$, $t \geq 0$

3. SRGM with Burr Type XII Testing- Effort and Change Point

The basic assumptions for a SRGM with Burr Type XII testing-effort and change point are:

- The fault removal process is modeled by an NHPP.
- The software application is subject to failures at random times caused by the remaining faults in the system.
- The mean number of faults detected in the time interval (t, $t + \Delta t$) by the current testing-effort is proportional to the mean number of remaining faults in the system at time t, and the proportionality in a constant over time.
- Testing effort expenditures are described by Burr Type XII testing-effort function.
- Each time a failure occurs, the corresponding fault is immediately removed and no new faults are introduced.

- The hazard rate for software occurring initially after the testing is proportional to the elapsed time *r* and the remaining faults (Bokhari et al., 2007a).

An implemented software system is tested in the software development process. During the testing phase software errors remaining in the system cause software failures and the errors are detected and corrected by test personnel. A software failure is defined as an unacceptable departure of program operation. Following the usual assumptions in the area of software reliability growth modeling, we assume that the number of detected errors to the current testing effort expenditures is proportional to the current error (Huang, 2004).

Here, we formulated a software reliability growth model as a Poisson process for the expected value number of faults *N(t),* whose mean value function is *m(t)*:

$$P_r[N(t) = n] = \frac{[m(t)]^n \, exp[-m(t)]}{n!} \quad n = 0, 1, 2, 3, \ldots\ldots \tag{3}$$

where $P_r\,[A]$ means the probability event *A*.

In addition, if the number of faults detected by the current testing-effort expenditures is proportional to the number of remaining faults, then we obtain the following equation:

$$\frac{dm(t)}{dt} \times \frac{1}{w(t)} = r \times \big(a - \ m(t)\big) \tag{4}$$

where *m(t)* is the expected mean number of faults detected in time *(0, t]*, *w(t)* is current testing effort consumption at time *t*, a is the expected number of initial faults, and *r* is fault detection rate per unit testing effort at testing time *t* that satisfies $r > 0$ (Huang, 2004).

The marginal conditions for equation (4) are $m(t) = \ 0 \ and \ W(0) = 0$.

Solving equation (4), we have

$$m(t) = \ a \times (1 - \exp[-r\big(W(t) - \ W(0)\big)]$$

$$= a \ \times (1 - \exp[-rW(t)] \tag{5}$$

W(t) defined as

$$W(t) = \int_0^1 w(\tau) \, d\tau \tag{6}$$

Equation (6) is an NHPP model with mean value function considering the testing-effort consumption. The consumed testing effort indicates how effective the faults are detected in the software and can be modeled by different distributions. Actually, during the testing phase, software reliability is highly related to the amount of testing effort expenditures spent on detecting and correcting software faults. The testing effort can be measured by the human power, the number of test case runs, or the number of CPU hours.

If the number of faults detected by the current testing-effort expenditures is proportional to the number of remaining faults, then we obtain the following differential equation:

$$\frac{m(t)}{w(t)} = r(t) \times \big(a - m(t)\big) \qquad (7)$$

$$or, \qquad \frac{m(t)}{a - m(t)} = r(t)w(t) \qquad (8)$$

We can describe a software reliability growth model based on change point as follows:

$$r(t) = \begin{cases} r_1, & 0 \le t \le \tau \\ r_2, & t > \tau \end{cases}$$

Solving equation (8) under the boundary conditions *m(0) = 0* and *W(0) = 0* and *r(t) = r_1* where *0* $\le t \le \tau$,

$$\int_0^t \frac{m(t)}{a - m(t)} dt = \int_0^t r_1 w(t)\, dt$$

$$or, \qquad a - m(t) = a \times e^{-r_1 W(t)}$$

Therefore,

$$m(t) = a\big(1 - e^{-r_1 W(t)}\big) \qquad (9)$$

Plug in the value of *W(t)* from equation (2), we get

$$m(t) = a\left(1 - e^{-r_1 \alpha[(1-(1+(\beta.t)^{\delta})^{-m}]}\right)$$

Again, solving equation (8) under the boundary condition *m(0) = 0* and *W(0) = 0* and *r(t) = r_2* where $t < \tau$,

$$\int_0^t \frac{m(t)}{a - m(t)} dt = \int_0^{\tau} r_1 w(t)\, dt + \int_0^t r_2 w(t)\, dt$$

$$or, \qquad \frac{a - m(t)}{a} = e^{-(r_1 W(\tau) - r_2 W(\tau) + r_2 W(t))}$$

Therefore,

$$m(t) = a \times \left[1 - e^{-(r_1 W(\tau) - r_2 W(\tau) + r_2 W(t))}\right] \qquad (10)$$

Plug in the value of *W(t)* from equation (2), we get

$$m(t) = a \times \left[1 - e^{-(r_1 W(\tau) - r_2 W(\tau) + r_2 \alpha[(1-(1+(\beta.t)^{\delta})^{-m}])}\right] \qquad (11)$$

This is a SRGM by considering Burr Type XII testing-effort and change point.

4. Conclusions

In this paper we introduced a SRGM based on NHPP, which incorporates Burr Type XII testing-effort function and change point. We have discussed the advantages of Burr Type XII testing-effort function over other testing-effort functions.

We believe that Burr Type XII testing-effort along with change point gives a good predictive capability and better performance. In addition, the proposed model is more realistic, practical and more suitable for describing the software reliability. We also, conclude that the proposed SRGM has better performance in some aspects as compare to the other SRGMs.

We will discuss the data analysis in the subsequent paper.

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