Software Reliability Model when multiple errors occur at a time including a fault correction process

K. Harishchandra[1], K. M. Manjunatha[2] and Balakrishna[3]

1. Department of Statistics, Bangalore University, Bengaluru
2. Bio-Statistician, Data Control Cenduit India Services (P) Ltd. Bengaluru
3. Department of Statistics, Vijaya College, Bengaluru

* Correspondence to: Dr. K. Harishchandra, Department of Statistics, Bangalore University, Bangalore – 560 056, India. E-mail id: harish.jbc@gmail.com

Abstract

Most of the software reliability models are based on reliability growth models which deal with only failure detection process. In these models it is assumed that software faults occur randomly at different time points and fault correction times are either ignored or considered insignificant. It is also assumed that only one fault is detected at any given time point. In this paper we propose a software reliability model in which a random number of faults are detected whenever a failure occurs. The model also takes into account the correction times for the faults detected. The software failure times and the correction times are assumed to follow exponential distributions. The number of software faults detected at any time point is assumed to follow a geometric distribution. The distribution of the total correction time is derived and the model is formulated as an alternating renewal process. The properties of the reliability model are studied through the renewal process. We obtain the maximum likelihood estimators and also asymptotic interval estimators of the system parameters and their properties are discussed. We also propose some large sample tests for the system parameters. Some numerical studies have been made to evaluate the power of the tests.

Keywords: Software reliability; Failure detection process; Fault correction process; Maximum likelihood estimation; Renewal process; Large sample test; Power of test statistic.

1. INTRODUCTION

Computer systems have become more and more important in modern society. The problem of estimating reliability of the software and predicting the future behavior of computer software failures has received a great deal of attention over the last three decades. Software reliability is defined as *the probability of failure free software operation for a specified period of time in a specified environment*. During the last 30 years, numerous software reliability models have been developed by the researchers to provide useful information about how to improve software reliability. For a detailed review of software reliability models see [7, 9].

In most of the software reliability models discussed in the literature it is assumed that whenever a software failures are detected, these faults are immediately removed or corrected in the sense that detected

faults are corrected before continuing the software testing process. Goel and Okumoto [2] and Pham [9] have discussed some software reliability models with only fault detection processes with the assumption of perfect and immediate fault correction. Huang et. al. [4], Huang and Lin [5] and Yamada et. al. [14] have discussed some extensions of these models.

Ignoring fault correction may not be realistic in practice, because finding a software fault is one thing and fixing it is another and between these two there is a considerable time delay, we call this as correction time and this correction time depends on the availability of man power, skill of a programmer and experience of debugging team. Few models are developed taking into account the fault correction processes $(FCPs)$ for some work on these lines see [3, 10, 11, 12, 13].

Schneidewind [7] was the first one to incorporate a constant fault correction time in a model having non-homogeneous Poisson process for fault detection process and Xie et. al. [10] have assumed random time delay for the fault correction processes for modeling fault detection and correction processes, with the emphasis on $FCPs$ described by a delayed detection process with random or deterministic delay. The software failure times as well as correction times are assumed to be exponential. Further, in 2010 see [3] we proposed a software reliability model taking into account the fault correction time. The software failure times as well as correction times are assumed as exponential. The model is formulated as an alternating renewal process. The properties of the reliability model are studied through the renewal process. The system parameters are estimated by means of the maximum likelihood estimator.

In almost all software reliability models discussed in the literature it is assumed that only one fault is detected at a time. In this paper, we propose a software reliability model in which a random number of faults are detected whenever a failure occurs. The model also takes into account the correction times for the faults detected. The software failure times and the correction times are assumed to follow exponential distributions. The number of software faults detected at any time point is assumed to follow a geometric distribution. The distribution of the total correction time is derived and the model is formulated as an alternating renewal process. The properties of the reliability model are studied through the renewal process. We obtain the maximum likelihood estimators and also asymptotic interval estimators of the system parameters and their properties are discussed. We also propose some large sample tests for the system parameters. Some numerical studies have been made to evaluate the power of the tests.

2. MODELING OF FAULT DETECTION AND CORRECTION PROCESSES

In this section we develop a software reliability model in which the time between successive software failures are assumed to a have common exponential distribution and the correction time have a geometric compounding of exponential distribution.

2.1.   Model assumptions

The software reliability model is defined on following assumptions:

    i.   All the faults in a program are mutually independent from the failure detection point of view.

    ii.   The time between successive failures is assumed to have an exponential distribution with mean $1/\lambda$.

    iii.   Whenever a failure occurs, a random number of software faults are detected and this size is assumed to follow a geometric distribution with parameter p.

    iv.   The correction time for each software fault is assumed to have an exponential distribution with mean $1/\mu$.

    v.   The failure times and correction times are mutually independent.

2.2.   Development of the model

Suppose that particular software undergoes a testing process and the software failure times are observed. Let t_i denote the time at which the ith software failure occurs $(i = 1, 2, \ldots n)$. Let $X_i = t_i - t_{i-1}$, $i = 1, 2, \ldots n$ denote the software failure times and $\{X_n\}$ forms a sequence of identically and independently distributed $(i.i.d.)$ random variable having common exponential distribution with mean $1/\lambda$. Assume that whenever a failure occurs, the failure caused by faults occur in random size. Let M_i denote the number of software faults detected at the ith time point $(i = 1, 2, \ldots n)$. Let $Y_i = \sum_{j=1}^{M_i} Y_{ij}$ denote the total correction time for the M_i faults detected at the ith time point $i = 1, 2, \ldots n$. And where Y_{ij} denote the correction time for the jth fault detected at the ith time point, $j = 1, 2 \ldots, M_i$ and $i = 1, 2, \ldots n$.

Theorem 2.1 Let $Y_{ij}'s$ be $i.i.d.$ random variables having common exponential distribution with mean $1/\mu$ for $j = 1, 2, \ldots M_i$ *and* $i = 1, 2, \ldots n$.

Let $Y_i = \sum_{j=1}^{M_i} Y_{ij}$, where M_i is a random variable independent of $Y_{ij}'s$. Let the distribution of M_i be geometric with parameter p with p.m.f.

$$P(M_i = m) = g(m) = pq^{m-1}, m = 1, 2, \ldots \text{ and } 0 < p < 1 \qquad (1)$$

Then $\{Y_n\}$ forms a sequence of i.i.d. random variables having an exponential distribution with mean $1/\mu p$.

Proof: Define $Y_i = \sum_{j=1}^{M_i} Y_{ij}$. Since Y_{ij}'s are i.i.d. random variables and M_i's are independent of Y_{ij}'s, Y_i's are

also i.i.d. random variables and its density function is given by

$$dF(y) = P\{y \leq Y < y + dy\}$$

$$= \sum_{m=1}^{\infty} P\{M = m \text{ and } y \leq Y < y + dy\}$$

$$= \sum_{m=1}^{\infty} g(m) P\{y \leq Y < y + dy\} \tag{2}$$

Each Y_{ij}'s be i.i.d. random variables having common exponential distribution with mean $1/\mu$ then

$Y_i = \sum_{j=1}^{M_i} Y_{ij}$ has a gamma distribution with parameters m and μ and M has geometric distribution with

parameter p then density function of Y_i is given by

$$dF(y) = \sum_{m=1}^{\infty} pq^{m-1} \frac{\mu^m}{\Gamma(m)} y^{m-1} e^{-\mu y} dy \tag{3}$$

On simplification the expression (3) reduces to

$$f(y) = \mu p e^{-\mu p y}, y > 0 \text{ and } 0 < p < 1, \mu > 0 \tag{4}$$

Equation (4) is the density function of random geometric sum of exponential r.v's or common exponential

distribution with mean $1/\mu p$. This proves the theorem♦

2.3. Renewal process model

Let $\{X_n\}$ denote the sequence of failure times and $\{Y_n\}$ denote the sequence of correction times. The

sequence $\{X_n\}$ and $\{Y_n\}$ constitutes an alternating renewal process. If we denote by $Z_i = X_i + Y_i$, $i = 1, 2, \ldots n$

, then $\{Z_n\}$ is also a renewal process. Sequence $\{Z_n\}$ is a sequence of i.i.d. random variables with density,

$$f_Z(z) = \int_0^z f_X(x) f_y(z - x) dx$$

Then density function of Z reduces to

$$f_Z(z) = \frac{\lambda \mu p}{\lambda - \mu p} \left(e^{-\mu p z} - e^{-\lambda z} \right), \ z > 0, 0 < p < 1 \text{ and } \lambda, \mu > 0 \tag{5}$$

This is the Hypo-exponential distribution. The mean and variance of this distribution are given by

$$\text{mean} = m = \frac{\lambda + \mu p}{\lambda \mu p} \text{ and } \text{variance} = \sigma^2 = \frac{\lambda^2 + \mu^2 p^2}{\lambda^2 \mu^2 p^2} \tag{6}$$

Let $S_n = \sum_{i=1}^{n} Z_i$ and $N(t) = \underset{n}{Sup}\{n : S_n \le t\}$, then $\{N(t), t \ge 0\}$ is a renewal process induced by sequence $\{Z_n\}$ and $N(t)$ denote the total number of renewals in time interval $(0,t]$. Let $M(t)$ denote the renewal function which is equal to expected number of renewals in $(0,t]$. The Laplace transform of the renewal function is defined as

$$M^*(s) = L[M(t)] = \frac{f^*(s)}{s[1 - f^*(s)]}$$

i.e. $$M^*(s) = \frac{\lambda\mu p}{s(\lambda + \mu p)} - \frac{\lambda\mu p}{[s + (\lambda + \mu p)](\lambda + \mu p)} \qquad (7)$$

Where $f^*(s) = \dfrac{\lambda\mu p}{(s + \lambda)(s + \mu p)}$ is the Laplace transform of distribution function Z.

The renewal function of the fault detection and correction processes is defined as inverse of the above Laplace transform given in (7), that is

$$M(t) = \frac{\lambda\mu p}{(\lambda + \mu p)}\left(1 - e^{-(\lambda + \mu p)t}\right) \qquad (8)$$

The corresponding renewal density function is derivative of the renewal function given in (8), that is

$$\lambda(t) = \lambda\mu p e^{-(\lambda + \mu p)t} \qquad (9)$$

Renewal function $M(t)$ is also called as mean value function (MVF) is defined as expected number of faults detected and corrected up to time $(0,t]$ and renewal density function $\lambda(t)$ is also called as intensity function.

For this model the failure rate is constant and is equal to λ and is independent of time since the last failure. That is,

$$r(t|S_n) = \lambda$$

and the reliability function is

$$R(t|S_n) = P(X_{n+1} > t|S_n) = \exp(-\lambda t) \qquad (10)$$

Let $M(t)$ be the renewal function of $\{Z_i\}$, then $\lambda(x)\,dx$ is the probability of one or more corrections in $(x, x+dx)$. If $x(0) = 1$, that is, if the software is in operating condition at the initial time point, then the availability function $A(t)$ is given by

$$A(t) = \Pr\{T > t\} + \int_{0}^{t} \lambda(x)\Pr\{T > t - x\}\,dx$$

On simplification we get, $\quad A(t) = \dfrac{\mu p}{\lambda + \mu p} + \dfrac{\lambda}{\lambda + \mu p} e^{-(\lambda + \mu p)t}$ (11)

3. MAXIMUM LIKELIHOOD ESTIMATION OF THE PARAMETERS

Suppose that the software program has been put for testing and assume that the data are given for time between successive renewals, i.e. the realizations of the random variables Z_i for $i = 1, 2 ..... n$. Given the data on n successive renewals z_i the likelihood function for the random variable Z denoted by $L(\lambda, \mu; z)$ is obtained using the density function given in (5) as follows

$$L(\lambda, \mu; z) = \prod_{i=1}^{n} \left\{ \left(\frac{\lambda \mu p}{\lambda - \mu p} \right) \left(e^{-\mu p z_i} - e^{-\lambda z_i} \right) \right\}$$ (12)

Maximum likelihood estimation of λ and μ:

Taking log on both sides of (12), we get log-likelihood function that is defined as $\ln L(\lambda, \mu; z)$. That is,

$$\ln L(\lambda, \mu; z) = \ln l = n \ln \lambda \mu p - n \ln (\lambda - \mu p) + \sum_{i=1}^{n} \ln \left(e^{-\mu p z_i} - e^{-\lambda z_i} \right)$$ (13)

Take partial derivative on (13) w.r.t. unknown model parameters λ and μ, and equating to zero we get likelihood equations, those are

$$\frac{n}{\lambda} - \frac{n}{\lambda - \mu p} + \sum_{i=1}^{n} \left\{ \frac{z_i e^{-\lambda z_i}}{e^{-\mu p z_i} - e^{-\lambda z_i}} \right\} = 0$$

$$\frac{n}{\mu} + \frac{np}{\lambda - \mu p} - \sum_{i=1}^{n} \left\{ \frac{p z_i e^{-\mu p z_i}}{e^{-\mu p z_i} - e^{-\lambda z_i}} \right\} = 0$$ (14)

We do not get closed form expressions for the maximum likelihood estimates $(m.l.e.'s)$ of λ and μ. However, the m.l.e.'s can be obtained by iterative procedure. Let $\hat{\lambda}$ and $\hat{\mu}$ be the m.l.e.'s of parameters λ and μ, respectively. We can then obtain the m.l.e.'s of the renewal function, renewal density, reliability function and availability functions by replacing λ and μ by its m.l.e.'s $\hat{\lambda}$ and $\hat{\mu}$ in expressions $(8), (9), (10)$ and (11) respectively.

Asymptotic confidence intervals:

If we denote the m.l.e. of $\theta = (\lambda, \mu)$ by $\hat{\theta} = \left(\hat{\lambda}, \hat{\mu} \right)$, the observed information matrix is then given by

$$I(\theta) = \begin{pmatrix} -E\left[\dfrac{\partial^2 \ln l}{\partial \lambda^2}\right] & -E\left[\dfrac{\partial^2 \ln l}{\partial \lambda \partial \mu}\right] \\[3mm] -E\left[\dfrac{\partial^2 \ln l}{\partial \mu \partial \lambda}\right] & -E\left[\dfrac{\partial^2 \ln l}{\partial \mu^2}\right] \end{pmatrix}_{\lambda=\hat{\lambda},\,\mu=\hat{\mu}} \tag{15}$$

And hence the variance covariance matrix would be $I^{-1}(\theta)$. The approximate $(1-\delta)100\%$ confidence intervals for the parameters λ and μ are $\hat{\lambda} \pm \xi_{\delta/2} V(\hat{\lambda})$ and $\hat{\mu} \pm \xi_{\delta/2} V(\hat{\mu})$ respectively, where $V(\hat{\lambda})$ and $V(\hat{\mu})$ are the variances of $\hat{\lambda}$ and $\hat{\mu}$, which are given by the first and the second, diagonal element of $I^{-1}(\theta)$, and $\xi_{\delta/2}$ is the upper $(\delta/2)$ percentile of standard normal distribution.

4. HYPOTHESIS TESTING FOR λ and μ

Here we consider a hypothesis testing problem for the model parameters λ and μ. These hypotheses testing problems are basically of interest to compare two alternative software failure detection or correction processes. Consider the problem of testing the hypothesis

$H_0 : \lambda = \lambda_0, \mu = \mu_0$ against the alternative that the equality does not hold for at least for one parameter.   (16)

Here we propose three large sample test procedures for (16). We state below three basic central limit theorems related to renewal processes without proof.

Lemma 1: Let $\{N(t), t \geq 0\}$ be the renewal process generated by F and $\{Z_n, n=1,2,...\}$ be renewal times with distribution function F, with mean $m = E(Z_i)$ and variance $\sigma^2 = E(Z_i - m)^2$ exist and are finite. Let $\{Z_n, n=1,2,...\}$ be renewal times with distribution function F. Then from the central limit theorem on renewal process, we have

$$\lim_{t \to \infty} P\left\{ \frac{N(t) - t/m}{\sqrt{\sigma^2 t / m^3}} < s \right\} = \Phi(s) \tag{17}$$

where $\Phi(s)$ is the d.f. of standard normal variate.

Based on (17) we propose the test statistic be $Z_1 = \dfrac{N(t) - t/m_0}{\sqrt{\sigma_0^2 t / m_0^3}}$ (18)

For testing the hypothesis stated in (16) the rule is to reject H_0 if $|Z_1| > Z_{\alpha/2}$.

Power function of the above test is denoted by $\beta_1(\lambda, \mu)$ given by

$$\beta_1(\lambda, \mu) = 1 - P_{H_1}\left[Z_1 \leq \frac{tB_1}{\sqrt{tA_1}} + z_{\alpha/2}\sqrt{C_1}\right] + P_{H_1}\left[Z_1 \leq \frac{tB_1}{\sqrt{tA_1}} - z_{\alpha/2}\sqrt{C_1}\right] \qquad (19)$$

Where $A_1 = \dfrac{\lambda\mu p(\lambda^2 + \mu^2 p^2)}{(\lambda + \mu p)}$, $\quad B_1 = \dfrac{\lambda_0\mu_0 p_0(\lambda + \mu p)}{(\lambda_0 + \mu_0 p_0)} - \lambda\mu p$

and $\quad C_1 = \dfrac{\lambda_0\mu_0 p_0(\lambda_0^2 + \mu_0^2 p_0^2)(\lambda + \mu p)^3}{\lambda\mu p(\lambda^2 + \mu^2 p^2)(\lambda_0 + \mu_0 p_0)^3}$

Lemma 2: Let $\{Z_n, n = 1, 2, ...\}$ be renewals with distribution function F, for which the mean $m = E(Z_i)$ and variance $\sigma^2 = E(Z_i - m)^2$ exist and are finite. Let $\{N(t), t \geq 0\}$ be the renewal process generated by F. Then from the central limit theorem on renewal process, we have

$$\lim_{t \to \infty} P\left\{\frac{S_{N(t)} - t}{\sqrt{\sigma^2 t/m}} < s\right\} = \Phi(s) \qquad (20)$$

Where, $S_{N(t)} = \displaystyle\sum_{i=1}^{N(t)} Z_i$ that is time of the last event at time t.

Based on (20) we propose the test statistic $Z_2 = \dfrac{S_{N(t)} - t}{\sqrt{\dfrac{(\lambda_0^2 + \mu_0^2 p_0^2)t}{\lambda_0\mu_0 p_0(\lambda_0 + \mu_0 p_0)}}}$ \qquad (21)

For the hypothesis in stated in (16) based on (21) the rule is to reject H_0 if $|Z_2| > Z_{\alpha/2}$.

Power function of the above test is denoted by $\beta_2(\lambda, \mu)$, that is

$$\beta_2(\lambda, \mu) = 1 - P_{H_1}\left[Z_2 \leq z_{\alpha/2}\sqrt{A_2}\right] + P_{H_1}\left[Z_2 < -z_{\alpha/2}\sqrt{A_2}\right] \qquad (22)$$

Where, $A_2 = \dfrac{\lambda\mu p(\lambda_0^2 + \mu_0^2 p_0^2)(\lambda + \mu p)}{\lambda_0\mu_0 p_0(\lambda^2 + \mu^2 p^2)(\lambda_0 + \mu_0 p_0)}$

Lemma 3: Let distribution of the length of time the software system will be in correction process has been given by Barlow and Hunter see [1]. That is $D(t) = \displaystyle\sum_{i=1}^{N(t)} Y_i$ be the length of time t that the software under correction process. Then for large values of t, the asymptotic distribution of $D(t)$ will be

$$\lim_{t\to\infty} P\left\{ \frac{D(t) - \dfrac{\lambda t}{(\lambda + \mu p)}}{\sqrt{\dfrac{2\lambda\mu pt}{(\lambda + \mu p)^3}}} < s \right\} = \Phi(s) \qquad (23)$$

Based on (23) we define the statistic $Z_3 = \dfrac{D(t) - \dfrac{\lambda_0 t}{(\lambda_0 + \mu_0 p_0)}}{\sqrt{\dfrac{2\lambda_0\mu_0 p_0 t}{(\lambda_0 + \mu_0 p_0)^3}}}$ \qquad (24)

In this case for the hypothesis in (16) the rule is to reject H_0 if $|Z_3| > Z_{\alpha/2}$.

Power function of the above test is denoted by $\beta_3(\lambda, \mu)$ and is given by,

$$\beta_3(\lambda, \mu) = 1 - P_{H_1}\left[Z_3 > \frac{tB_3}{\sqrt{tA_3}} + z_{\alpha/2}\sqrt{C_3} \right] + P_{H_1}\left[Z_3 < \frac{tB_3}{\sqrt{tA_3}} - z_{\alpha/2}\sqrt{C_3} \right] \qquad (25)$$

Where, $A_3 = \dfrac{2\lambda\mu p}{(\lambda + \mu p)}$, $B_3 = \dfrac{\lambda_0(\lambda\mu p)}{(\lambda_0 + \mu_0 p_0)} - \lambda$ and $C_3 = \dfrac{\lambda_0\mu_0 p_0(\lambda + \mu p)^3}{\lambda\mu p(\lambda_0 + \mu_0 p_0)^3}$

5. NUMERICAL COMPUTATION

To illustrate the estimation procedure and application of the Software reliability model (existing as well as proposed), we have carried out the data analysis of a real software data set. The data set had been collected during 19 weeks of testing a real time command and control system, and 328 faults were detected during testing. These data are cited from Ohba *et al.* [8].

We make use of Akaike's information criteria (AIC) for comparing the performances of different models. AIC defined as

$$AIC = -2log\left(likelihood\ function\ at\ its\ maximumm\ value\right) + 2N \qquad (26)$$

Where, N represents the number of parameters in the model.

Analyzing data set, we obtain the estimation results and AIC value for existing models (Here we call Goel and Okumoto [2] model as SRM-1, Delayed S-shaped NHPP [14] model as SRM-2 and Harishchandra and Manjunatha [3] model as SRM-3) is shown in Table 5.1 and for different values of p proposed model summarized in Tables 5.2.

6. SIMULATION STUDY

In Section 3, we have discussed the maximum likelihood method of estimation of the parameters of the failure time and fault correction time distributions. It was observed that no closed form solutions are

available for the m.l.e's. In this section we provide the maximum likelihood estimates of the parameters for some choice of the parameters and sample sizes through a simulation study.

A sequence of n observations $\{x_i, i = 1, 2, ... n\}$ is generated from an exponential distributions with parameter λ with sample size n and another sequence of n observations $\{y_i, i = 1, 2, ... n\}$ generated from exponential distributions with parameter of μp with sample size n. For the values of $\lambda = 8, 12, 16$ and $\mu = 2, 4, 8$ and $p = 0.5, 0.8$ and m.l.e's of model parameters λ and μ are estimated using expression (14) for sample sizes $n = 50, 100$. These results are shown in Table 6.1.

From Table 6.1, it may be observed that the estimated values are fairly close to assumed values for sample size $n = 50$ and the performance of these estimates are further better for large sample size $n = 100$. It may be noted that for small sample size such as $n = 50$ the technique provides estimates of the parameters very close to assumed value. It is also observed that the standard error reduces to zero as sample size increases.

7. POWER OF THE TEST PROCEDURES

In this section, we evaluate the power of the three test statistics proposed in section 4.

Consider the hypothesis $H_0 : \lambda = \lambda_0, \mu = \mu_0$ against the alternative hypothesis $H_0 : \lambda \neq \lambda_0, \mu = \mu_0$. Let $\lambda_0 = 4$, $\mu_0 = 4$ and $p = 0.9, t = 35$ (t is in time units) and $\alpha = 0.05$ (level of significance). The power curves for three test statistics proposed in section 4 are shown in Fig. 7.1. In this case it may be observed that the test based on the statistic Z_2 does not perform well for values of $\lambda > 4$ and Z_2 also does not perform satisfactorily for $\lambda > 6$.

The power curves for testing power curves for testing $H_0 : \lambda = 4, \mu = 4$ against the alternative hypothesis $H_0 : \lambda = 4, \mu \neq 4$. Let $\lambda_0 = 4$, $\mu_0 = 4$ and $p = 0.9, t = 35$ (t is in time units) and $\alpha = 0.05$. The three proposed tests are shown in Fig. 7.2. In this case we can see that both statistics Z_1 and Z_3 performance are good and also it may be observed that the test based on the statistic Z_2 does not perform well for values of $\mu > 4$.

8. CONCLUSIONS AND REMARKS

In this paper we have developed a software reliability model which takes into account besides the failure occurrence times also the fault correction times. The model is developed assuming exponential distribution for failure times and whenever failure occurs a random number of software faults are detected. Assuming fault correction times to be exponential distribution the compound distribution of fault correction time is derived. The model is formulated as a renewal process and the properties of the software reliability model

are studied through the properties of the renewal process. The maximum likelihood estimates and asymptotic interval estimates of the model parameters have been obtained. Three different large sample tests have been proposed for the model parameters and their power functions are evaluated from numerical studies. It is observed that one test perform well for two sided alternatives for both detection and correction alternative hypothesis and one test performs well for only one two sided alternatives of correction type and the other one test perform only for one sided alternatives for both type of detection and correction alternatives. These tests are basically of importance from the point of view of comparing the performances of different fault correction processes. The model can be extended to the cases of other forms of failure times and fault correction times whose range of distribution taking continuous non-negative random variables.

References

[1]. Barlow R E, Hunter L C. Reliability analysis of a one unit system. *Operation Research 1961*; **9**(2); 200-208.

[2]. Goel AL, Okumoto K. Time-dependent error-detection rate model for software and other performance measures. *IEEE Transactions on Reliability 1979;* **28**; 206-211.

[3]. Harishchandra K, Manjunatha K M. Statistical inference on software reliability assuming exponential fault correction time. *Economic Quality Control 2010*; **25**; 269-279.

[4]. Huang C Y, Lyu M R, Kuo S Y. A unified scheme of some non-homogeneous Poisson process models for software reliability estimation. *IEEE Transactions on Software Engineering 2003;* **29**(3); 261-269.

[5]. Huang C Y, Lin C T. Software reliability analysis by considering fault dependency and debugging time lag. *IEEE Transactions on Reliability 2006*; **55**(3); 436-450.

[6]. Lo J H, Huang C Y. An integration of software failure detection and fault correction processes in software reliability analysis. *Journal of Systems and Software 2006*; **76**(2); 181-194.

[7]. Lyu M R. *Handbook of Software Reliability Engineering*. McGraw-Hill, New York 1996.

[8]. Obha M. Software reliability analysis models. *IBM Journal of Research and Development 1984;* **28**; 428-443.

[9]. Pham H. *System Software Reliability*. Springer-Verlag, 2006.

[10]. Schneidewind N F. Analysis of error processes in computer software. *In: Proc. of the Int. Conf. on Reliable Software. IEEE computer Society Press, Loss Alamitos, CA 1975;* 337-346.

[11]. Schneidewind N F. Modeling the fault correction. *In: Proc. of the 12th Int. Symp. On Software Reliability Engineering. IEEE computer Society Press, Loss Alamitos, CA 2001*; 185-190.

[12]. Wu Y P, Hu Q P, Xie M, Ng S H. Modeling and analysis of software fault detection and correction process by considering time dependency. *IEEE Transactions on Reliability 2007*; **56**(4); 629-642.

[13].   Xie M, Hu Q P, Wu Y P, Ng S H. A study of the modeling and analysis of software fault- detection and fault-correction process. *Quality and Reliability Engineering International 2007*; **23**(4); 459-470.

[14].   Yamada S, Obha M, Osaki S. S-shaped software reliability growth models and their applications. *IEEE Transactions on Reliability 1984;* **33**; 289-292.