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A New Reliability Model for Optimal Software Release Time

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Abstract: *As software applications infuse our day today life, reliability becomes a very important factor of the software. In this paper, a new model is proposed to find the expected software release time using Poisson count process. The testing cost, fault removal cost and risk cost due to uncovered fault codes after the release time are incorporated to obtain an analytical expression for expected total cost. Numerical illustrations are given for the better understanding of the model.*

Keywords: *Software reliability, Poisson Process, Geometric Process, Exponential distribution, Weibull distribution, Expected software release time, optimal software release time.*

1. Introduction

ANSI defines software reliability as the probability of failure-free software operation for a specified period of time in a specified environment. Testing the reliability of any software is essential to fix the errors and to rectify before its launch. Also this helps to upgrade the software according to the requirements of its users.

The main application of software reliability models is the determination of software release time. If the software is released quickly, the customer experience many failures and if the software is released late the software agencies spent more money on delay.

Various models for software reliability are available and these are mostly based on the non – homogeneous Poisson process with a mean value function [1,2,3,4,5]. Software reliability growth models using non-homogeneous Poisson processes (NHPP's) are studied by Shigeru Yamuda and Shurji Osaki(1985).

In 1997, Hoang Pham and Xuemei Zhang established a new reliability model based on total error content and error detection rate and applied to two widely used data sets.

A new model based on two criteria, cost minimization and reliability requirement, the optimal release time and the interval estimation of the release time prediction are derived by Xie and Hong in 1999.

Again Hoang Pham and Xuemei Zhang in 2003 established a new reliability model addressing the testing coverage time and cost. A software cost model has been developed incorporating the testing cost, fault removal cost and risk cost due to potential problems remaining in the uncovered code.

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Akilandeswari, Poornima and Saavithri studied reliability growth models [5,6] for early detection of software failure based on time between failure observations using LLD type-I distribution and LLD type-II distribution. It was showed that these models are better fit for the software failure data and also for the early deduction of failure points.

In this paper, four new models to find expected software release time and expected total cost using shock model approach are proposed.

This paper is laid out as follows. In section 2, the expected release time of software for all the four models are obtained. Analytical expressions for expected total cost are derived in section 3 . Conclusion is given in Section 4.

Notation

X_i - Test phase time after the i^{th} fault removal and before $(i+1)^{th}$ fault detection.

Y_i - Wrong code removal time after i^{th} fault detection.

$N(t)$ - Number of fault detections.

W - Software release time.

2. Expected Release time of Software

2.1 Model Formulation

Consider the testing phase of software development, the faults are removed whenever they are detected. This removal reduces the total number of faults in the software. The length of time intervals between fault detection should increase and fault removal time should decrease. When the fault detection rate reaches an acceptably low level, (i.e.,) the fault detection time becomes very minimum i.e., it tends to zero, the software can be considered suitable for the customer.

ASSUMPTIONS

(i) The software testing consisting of two states, the testing state and fault code removal state and the two sequences of states are alternate.

(ii) Assume $\{X_i, i = 1, 2, \ldots, n\}$ be a stochastically increasing geometric process. If $F(t) = Pr(X_1 \leq t)$ is the distribution function of X_1 with mean μ_1 then the distribution function of X_n is $F(a^{n-1} t) = Pr(X_n \leq t)$, $a \leq 1$ with mean $\frac{\mu_1}{a^{n-1}}$.

(iii) Assume that $\{Y_i, i = 1, 2, \ldots, n\}$ form a monotonically decreasing geometric process. If $G(t) = Pr(Y_1 \leq t)$ then the distribution function of Y_n is

$Pr(Y_n \leq t) = G(b^{n-1} t)$, $b > 1$ with mean $\frac{\mu_2}{b^{n-1}}$.

(iv) Also assume that X_i and Y_i are independent.

Then the release time of the software is

$$W = X_0 + \sum_{i=1}^{N(T)} (X_i + Y_i)$$

where X_0 is test phase time before the detection of 1st fault.
The expected release time of the software is

$$E(W) = E(X_0)P(N(t)=0) + \sum_{i=1}^{k} E(X_i + Y_i)\, P(N(t)=k)$$

$$= E(X_0)P(N(t)=0) + \sum_{i=1}^{k} [E(X_i) + E(Y_i)]\, P(N(t)=k)$$

Let $E(X_i) = \mu_1$ & $E(Y_i) = \mu_2$ Then

$$E(W) = \mu_1 p_0 + \left[\sum_{i=1}^{k} \frac{\mu_1}{a^{i-1}} + \frac{\mu_2}{b^{i-1}}\right] p_k$$

Where $p_0 = P(N(t)=0)$ and $p_k = P(N(t)=k)$.

The random variable $N(t)$ (number of fault detection) follows Poisson Process with parameter λ

$$P(N(t)=k) = \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} \qquad k = 1,2,3\,...$$

with $$P(N(t)=0) = p_0 = e^{-\lambda t}$$

2.1.1. Model 1

Let X_i follows exponential distribution with parameter A. Then $E(X_1) = \frac{1}{A}, A > 0$

Let Y_i follows exponential distribution with parameter B then $E(Y_1) = \frac{1}{B}, B > 0$

Then the expected software release time is,

$$E(W) = \frac{e^{-\lambda t}}{A} + \left[\sum_{i=1}^{k}\left(\frac{1}{Aa^{i-1}} + \frac{1}{Bb^{i-1}}\right)\right]\frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

2.1.2 Model 2

Let X_i follows exponential distribution with parameter A. Then $E(X_1) = \frac{1}{A}, A > 0$

Let Y_i follows Weibull distribution with parameters B, β then $E(Y_1) = B\,\Gamma\left(\frac{1}{\beta} + 1\right)$

Then the expected software release time is,

$$E(W) = \frac{e^{-\lambda t}}{A} + \left[\sum_{i=1}^{k}\left(\frac{1}{Aa^{i-1}} + \frac{B\,\Gamma\left(\frac{1}{\beta}+1\right)}{b^{i-1}}\right)\right]\frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

2.1.3 Model 3

Let X_i follows Weibull distribution with parameters A, α then $E(X_1) = A\,\Gamma(\frac{1}{\alpha} + 1)$

Let Y_i follows exponential distribution with parameter B then $E(Y_1) = \frac{1}{B}, B > 0$

Then the expected software release time is,

$$E(W) = A\,\Gamma\left(\frac{1}{\alpha} + 1\right)e^{-\lambda t} + \left[\sum_{i=1}^{k}\left(\frac{A\,\Gamma(\frac{1}{\alpha}+1)}{a^{i-1}} + \frac{1}{Bb^{i-1}}\right)\right]\frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

2.1.4 Model 4

Let X_1 follows Weibull distribution with parameters A, ⊠ then $E(X_1) = A\,\Gamma(\frac{1}{\alpha} + 1)$

Let Y_1 follows Weibull distribution with parameters B, ⊠ then $E(Y_1) = B\,\Gamma\left(\frac{1}{\beta} + 1\right)$

Then the expected software release time is,

$$E(W) = A\,\Gamma\left(\frac{1}{\alpha} + 1\right) e^{-\lambda t} + \left[\sum_{i=1}^{k} \left(\frac{A\,\Gamma(\frac{1}{\alpha} + 1)}{a^{i-1}} + \frac{B\,\Gamma\left(\frac{1}{\beta} + 1\right)}{b^{i-1}} \right)\right] \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

2.2. Numerical illustration

Let us assume that a=0.5, b=1.5, A=0.2, al=0.25, be=2, B=0.1 and t=10.

Using the above values, the parameter of Poisson process λ *is* estimated for different values of k to obtain expected release time.

No of faults (k)	Parameter (λ)	Expected Software Release Time			
		Model 1	Model 2	Model 3	Model 4
1	0.084	13.9445	5.4279	13.7499	5.2130
2	0.189	14.0216	5.6088	13.8026	5.3873
3	0.295	16.7467	8.7340	16.4004	8.3875
4	0.398	22.8670	15.3013	22.2577	14.6919
5	0.4999	34.8727	27.7337	33.7659	26.6269
6	0.5999	57.8152	51.0706	55.7748	49.0301
7	0.7	101.4373	95.0509	97.6376	91.2512
8	0.8	184.4415	178.3777	177.3085	171.2447
9	0.9	342.7918	337.0173	329.3132	373.5387
10	1	645.8157	640.3001	620.2056	614.6901

3 . Expected Total Cost

It is essential to determine when the software testing should be stopped so that the expected cost is minimized and the reliability of the software product satisfies customer's requirements as well.

ASSUMPTIONS

(i) The cost to perform testing is proportional to the testing time.

(ii) Expected testing cost is $E_1(TC)$.

(iii) The cost of removing faults is proportional to the wrong code removal time.

(iv) Expected fault removal cost is $E_2(TC)$.

(v) There is a risk cost. A software provider has to pay each customer a certain amount of money for potential faults in uncovered code. Assume that there are M customers in this system.

(vi) Expected risk cost due to fault remaining in the uncovered code $E_3(TC)$.

(vii) The risk cost is of the form

$$E_3(TC) \;=\; C_3(1{+}\mathrm{ct})e^{-ct}\, M$$

The expected total cost $E(TC)$ is

$$E(TC) = E_1(TC) + \; E_2(TC) + \; E_3(TC)$$

3.1. Cost Model 1

Let X_1 follows exponential distribution with parameter A. Then $E(X_1) \;=\; \frac{1}{A}\,, A > 0$

$$E_1(TC) \;=\; C_1 \sum_{i=1}^{k} \frac{1}{Aa^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Let Y_1 follows exponential distribution with parameter B then $E(Y_1) \;=\; \frac{1}{B}\,, B > 0$

$$E_2(TC) \;=\; C_2 \sum_{i=1}^{k} \frac{1}{Bb^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Then the expected total cost is,

$$E(TC) = \; C_1 \sum_{i=1}^{k} \frac{1}{Aa^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} \;+\; C_2 \sum_{i=1}^{k} \frac{1}{Bb^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$
$$+\, C_3(1{+}\mathrm{ct})e^{-ct}\, M$$

3.2 Cost Model 2

Let X_1 follows exponential distribution with parameter A. Then $E(X_1) \;=\; \frac{1}{A}\,, A > 0$

$$E_1(TC) \;=\; C_1 \sum_{i=1}^{k} \frac{1}{Aa^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Let Y_1 follows Weibull distribution with parameters B, β then $E(Y_1) \;=\; B\,\Gamma\left(\frac{1}{\beta} + \,1\right)$

$$E_2(TC) \;=\; C_2 \sum_{i=1}^{k} \frac{B\,\Gamma\left(\frac{1}{\beta} + \,1\right)}{b^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Then the expected total cost is,

$$E(TC) = \; C_1 \sum_{i=1}^{k} \frac{1}{Aa^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} \;+\; C_2 \sum_{i=1}^{k} \frac{B\,\Gamma\left(\frac{1}{\beta} + 1\right)}{b^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} \;+$$
$$C_3(1{+}\mathrm{ct})e^{-ct}\, M$$

3.3 Cost Model 3

Let X_1 follows Weibull distribution with parameters A, α then $E(X_1) \;=\; A\,\Gamma(\frac{1}{\alpha} + \,1)$

$$E_1(TC) = C_1 \sum_{i=1}^{k} \frac{A\,\Gamma(\frac{1}{\alpha}+1)}{a^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Let Y_1 follows exponential distribution with parameter B then $E(Y_1) = \frac{1}{B}$, $B > 0$

$$E_2(TC) = C_2 \sum_{i=1}^{k} \frac{1}{Bb^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Then the expected total cost is,

$$E(TC) = C_1 \sum_{i=1}^{k} \frac{A\,\Gamma(\frac{1}{\alpha}+1)}{a^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} + C_2 \sum_{i=1}^{k} \frac{1}{Bb^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} + C_3(1+\mathrm{ct})e^{-ct} M$$

3.4 Cost Model 4

Let X_1 follows Weibull distribution with parameters A, ⊠ then $E(X_1) = A\,\Gamma(\frac{1}{\alpha}+1)$

$$E_1(TC) = C_1 \sum_{i=1}^{k} \frac{A\,\Gamma(\frac{1}{\alpha}+1)}{a^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Let Y_1 follows Weibull distribution with parameters B, ⊠ then $E(Y_1) = B\,\Gamma\left(\frac{1}{\beta}+1\right)$

$$E_2(TC) = C_2 \sum_{i=1}^{k} \frac{B\,\Gamma\left(\frac{1}{\beta}+1\right)}{b^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!}$$

Then the expected total cost is,

$$E(TC) = C_1 \sum_{i=1}^{k} \frac{A\,\Gamma(\frac{1}{\alpha}+1)}{a^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} + C_2 \sum_{i=1}^{k} \frac{B\,\Gamma\left(\frac{1}{\beta}+1\right)}{b^{i-1}} \frac{e^{-\lambda t}\,(\lambda t)^k}{k!} + C_3(1+\mathrm{ct})e^{-ct} M$$

4. Conclusion:

In this paper four mathematical models are constructed to find the expected release time and the expected total cost of the software.

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