SRMS Journal of Mathematical Sciences, Vol-5, 2019, pp. 11-13
ISSN: 2394-725X

Software Reliability Growth Modeling Involving Burr Type XII distribution and Fault Removal Efficiency

Suneet Saxena*

Department of Mathematics, SRMS College of Engineering & Technology, Bareilly, India.
**Corresponding author Email: sunarn2012@gmail.com*

Received: *20 July, 2020;* ***Revised:*** *16 March, 2021;* ***Accepted:*** *02 May, 2021;* ***Published:*** *28 August, 2021*

DOI: 10.29218/srmsmaths.v5i1.2

Keywords:
Burr type XII TEF,
FRE, NHPP,
SRGM.

Abstract

In software reliability analysis various authors have used Burr type XII distribution to model the failure pattern of the system due to its wide variety of flexible shapes. In particular cases it can be reduced to Exponential, Normal, Weibull, Log-logistic, Gamma distributions etc. In proposed paper software reliability growth model has been developed incorporating fault removal efficiency (FRE) and Burr type XII based testing effort function. FRE represents fraction of detected faults which are removed completely. Parameters of model are predicted by LSE whereas MSE is used to perform comparison analysis. Results validate better fitting of data set.

1. INTRODUCTION

Reliability of software system is measured in terms of probability that software performs desired operations without failure for specific time duration known as testing time. Reliability depends on number of faults detected and corrected during testing time phase. Various mathematical models have been developed to formulate expression for mean number of faults $m(t)$ detected in time interval $(0, t)$. Such models are known as Software Reliability Growth Model's (SRGM). Software Reliability is the conditional probability that no faults detected in time interval $(t, t + \Delta t)$ and formulated as

$$R(t) = P\left(\frac{\Delta t}{t}\right) = \exp\{-\,[m(t+\Delta t) - m(t)]\}.$$

Broadly there are two types of SRGM, Markovian model and Fault counting model. Markovian process is used to represents faults in Markovian model. In Fault counting model failure distribution is described by Homogenous Poisson Process (HPP), Non-Homogenous Poisson Process (NHPP) etc.

Test Effort Function (TEF) is one of the various factors which influence reliability of software. It measures expenditure incurred on man power used, CPU working hour, number of test cases used, etc. Several SRGM's have been formulated involving different types of TEF [1-3], [5], [7-14]. Aggarwal *et al*.[12] incorporated various TEF into the model developed using modular approach. They classified faults as simple, hard and complex. An optimization problem has been formulated of maximizing faults removed subject to budgetary and reliability constrains. Genetic algorithm has been used to solve the problem. Many authors have used Burr type distributions to measure testing efforts. Ahmad *et al*.[15] proposed model involving Burr Type X TEF and determined optimum release time. Bokhari and Ahmad[16] used Burr Type XII TEF into SRGM and analyzed real data collected by Rome Air Development Centre. They also proposed optimum release policy of software system depending on reliability and cost criterion.

Fault removal efficiency (FRE) is another factor which affects the reliability of software. Fault removal process is very complex and time-consuming process. It involves detection and correction of faults. Many SRGM's assumes faults detected are removed completely during debugging process. It is possible some faults are left in software system. Fault removal efficiency is the fraction of removed faults in first repair attempt. Various authors [17-18] have developed SRGM involving FRE.

In this paper SRGM has been developed involving Burr type XII TEF and FRE. After introduction there are four sections. In Section 2 Burr type XII distribution and its properties are discussed. Section 3 presents development of model and solution. Section 4 provides estimation of the parameter and comparison using statistical tools. Finally, conclusion has been highlighted in section 5.

2. BURR TYPE XII DISTRIBUTION

I. W. Burr [20] developed twelve probability distributions collectively known as Burr system. Burr type XII is the most important distribution which has two positive shape parameters. It is widely applied for modeling in reliability analysis, survival analysis, actuaries, economics, forestry, hydrology and meteorology due to its probability density function which exhibits either decreasing or unimodal nature. Let T be a random variable which denotes the failure time of an item and $F(t)$ is the probabilty that item fails before or at time t. Burr type XII distribution of $F(t)$ is defined as

$$F(t) = Probability(T \leq t) = 1 - (1 + t^{\alpha})^{-\beta} \quad , \qquad t > 0 \tag{1}$$

Where α, β are shape parameters.

If $f(t)$ represents density function then

$$f(t) = \frac{dF(t)}{dt} = \alpha\beta t^{\alpha-1}(1 + t^{\alpha})^{-\beta-1} \, , \qquad t > 0 \tag{2}$$

Under fixed β, $f(t)$ is decreasing for $0 < \alpha \leq 1$ and unimodal for $\alpha > 1$.

Hazard rate function $h(t)$ is given by

$$h(t) = \alpha\beta t^{\alpha-1}(1 + t^{\alpha})^{-1} \, , \qquad t > 0 \tag{3}$$

Mean and variance are given by

$$\mu = E(T) = \frac{\Gamma\left(\beta - \frac{1}{\alpha}\right)\Gamma\left(1 + \frac{1}{\alpha}\right)}{\Gamma(\beta)} \, , \qquad \alpha\beta > 1 \tag{4}$$

$$\sigma^2 = \frac{\Gamma\left(\beta - \frac{2}{\alpha}\right)\Gamma\left(1 + \frac{2}{\alpha}\right)}{\Gamma(\beta)} - \mu^2 \, , \qquad \alpha\beta > 2 \tag{5}$$

3. MODEL DEVELOPMENT

Let $NF(t)$ be the number of faults detected by the time t. Using Poisson distribution probability of detecting r faults by the time $t = t_1$ is given by

$$P(NF(t = t_1) = r) = \frac{(m(t))^r \exp(-m(t))}{r!}$$

m(t) is given by differential equation

$$\frac{dm(t)}{dt} = b\big(a - m(t)\big) \, , \quad 0 < b < 1, \quad a, t > 0 \tag{6}$$

Where b is fault detection rate and a is total number of faults.

Introducing fault removal factor p in equation (6), we get

$$\frac{dm(t)}{dt} = b(a - pm(t)) \tag{7}$$

Term $pm(t)$ is the fraction of removed faults at time t. p lies between 0 and 1, if it is 1 then complete removal of detected faults.

Let $T_F(t)$ be the Burr type XII TEF and it has been modified in software reliability analysis as

$$T_F(t) = E\big(1 - (1 + (st)^{\alpha})^{-\beta}\big) \, , \qquad E, s, t, \alpha, \beta > 0 \tag{8}$$

Where E is the total amount of test effort expenditure and s is the scale parameter. Density function $t_f(t)$ is given by

$$t_f(t) = E\alpha\beta s(st)^{\alpha-1}(1 + (st)^{\alpha})^{-\beta-1} \tag{9}$$

Incorporating $tf(t)$ in equation (7), we get

$$\frac{dm(t)}{dt} = b\big(a - pm(t)\big)(t_f(t)) \tag{10}$$

Using condition $m(0) = 0$ and $T_F(0) = 0$, solution of equation (10) is

$$m(t) = \frac{a}{p}(1 - \exp(-pbT_F(t))) \tag{11}$$

4. PARAMETER ESTIMATION AND COMPARISION

Least Squares Estimation method is used to predict the values of parameters using CSR3 data set compiled by M.R. Lyu [21]. Proposed model is compared with Bokhari and Ahmad [16] model using statistical tool mean square error (MSE).

$$MSE = \sum_{i=1}^{n} \frac{(\ddot{m}(t) - \dot{m}(t))^2}{n}$$

Where $\ddot{m}(t)$ and $\dot{m}(t)$ are predicted and actual cumulative faults at time t respectively. n is number of data points. Lower the value of MSE better is the fitting.

Table 1

Model	*MSE*
Proposed Model	42.17
Bokhari and Ahmad [16] model	53.12

5. CONCLUSION

In proposed model mean number of faults are forecasted in which test efforts expenditure represented by Burr type XII probability distribution. While developing model it is also assumed that only fraction of faults detected are removed completely. On comparing with Bokhari and Ahmad [16] model, it has been found that the proposed model fits data set better.

REFERENCES

1. S. Yamada, J. Hishitani, and S. Osaki, "Software Reliability Growth Model with Weibull Testing Effort: A Model And Application", IEEE Trans. Reliability,1993, 42, pp 100–105.
2. P. K. Kapur, M. Xie, R. B. Garg, and A. K. Jha. A Discrete Software Reliability Growth Model with Testing Effort. 1st International Conference on Software Testing, Reliability and Quality Assurance, 1994.
3. P.K. Kapur, and S. Younes, "Modeling an Imperfect Debugging Phenomenon with Testing Effort", In: Proceedings of 5th International Symposium on Software Reliability Engineering, 1994, pp 178-183.
4. M. Shepperd, and C. Schofield, "Estimating Software Project Effort using Analogies", IEEE Trans. Software Engineering,1997, 23, pp 736–743.
5. C.Y. Huang, S.Y. Kuo, and I.Y. Chen, "Analysis of a Software Reliability Growth Model with Logistic Testing-Effort Function", In Proceedings of 8th International Symposium on Software Reliability Engineering (ISSRE'1997),1997, pp 378–388.
6. P. K. Kapur, R. B. Garg, and S. Kumar. Contributions to Hardware and Software Reliability. World Scientific, Singapore, 1999.
7. C.Y. Huang, J.H. Lo, S.Y. Kuo, and M.R. Lyu, "Software Reliability Modeling and Cost Estimation Incorporating Testing-Effort And Efficiency", In Proceedings of 8th International Symposium on Software Reliability Engineering (ISSRE'1999), 1999, pp 62–72.
8. C.Y. Huang, and S.Y. Kuo, "Analysis of Incorporating Logistic Testing-Effort Function into Software Reliability Modeling", IEEE Transactions On Reliability,2002, 51, 3, pp 261-270.
9. C.H. Lee, Y.T. Kim and D.H.Park,"S-shaped Software Reliability Growth Models Derived from Stochastic Differential Equations," IIE Transactions, 2004, Vol. 36, No. 12, pp 1193-1199.
10. N. Ahmad, M.U. Bokhari, S.M.K. Quadri, and M.G.M. Khan, "The Exponentiated Weibull Software Reliability Growth Model with Various Testing-Efforts and Optimal Release Policy: A Performance Analysis", International Journal of Quality and Reliability Management, 2008, 25 (2), pp 211-235.
11. N. Ahmad, M.G.M Khan, and L.S. Rafi, "Analysis of an Inflection S-Shaped Software Reliability Model Considering Log-Logistic Testing-Effort and Imperfect Debugging", International Journal of Computer Science and Network Security,2011, 11, 1, pp 161-171.
12. A.G. Agarwal, P.K. Kapur, G. Kaur, and R. Kumar, "Genetic Algorithm Based Optimal Testing Effort Allocation Problem for Modular Software", BIJIT-BVICAM's International Journal of Information Technology, 2012, 4,1, pp 445-451.
13. K.V.S Reddy and B. Raveendrababu, "Software Reliability Growth Model with Testing-Effort by Failure Free Software", International Journal of Engineering and Innovative Technology, 2012, Vol 2, 6, pp 103-107.
14. S. Inoue and S. Yamada, "Lognormal Process Software Reliability Modeling with Testing Effort", Journal of Software Engineering and Applications, 2013, Vol 6, pp 8-14.
15. N. Ahmad, M.G.M. Khan, S.M.K. Quadri and M. Kumar, "Modeling and Analysis of Software Reliability with Burr Type X Testing -Effort and Release-Time Determination", Journal of Modelling in Management,2009, Vol. 4(1), pp 28-54.
16. M. U. Bokhari and N. Ahmad, "Incorporating Burr Type XII Testing Efforts into SRGM and Actual Data Analys is with Applications", Journal of Software, 2014, Vol 9, No. 6, pp 1389-1399.
17. B. Purnaiah, K. V. Rama, and V. K. G. Bala, "Fault removal efficiency in software reliability growth model", Advances in Computational Research, 2012, Vol. 4, Issue 1, pp . 74-77.
18. X. Yang, N. Sang, and H. Lei, "An improved NHPP model with time-varying fault removal delay", Journal of Electronic Science and Technology of China, 2008, Vol 6, No. 3
19. X .M. Zhang, X. L. Teng, and H. Pham, "Considering fault removal efficiency in software reliability assessment", IEEE Trans. Systems, Man and Cybernetics-Part A: System and Humans, 2003,Vol. 33, no. 1, pp. 114-120.
20. I. W. Burr, Cumulative Frequency Function, Annals of Mathematical Statistics, 1942, Vol.13, pp 215-232.
21. M.R. Lyu, Handbook of Software Reliability Engineering, 1996.