Journal of Safety Engineering 2017, 6(1): 1-7
DOI: 10.5923/j.safety.20170601.01

Truncated Software Reliability Growth Model Based on Linear Failure Rate Model - Release Time Policy

B. Vara Prasad Rao[1,*], K. Gangadhara Rao[2]

[1]Department of Computer Science & Engineering, R.V.R & J.C College of Engineering, Chowdavaram, Guntur, Andhra Pradesh, India
[2]Department of Computer Science & Engineering, Acharya Nagarjuna University, Guntur, Andhra Pradesh, India

Abstract A Non Homogenous Poisson Process (NHPP) with its mean value function generated by the cumulative distribution function of linear failure rate distribution is considered. We consider some truncated time values and use them in the mean value function of NHPP. The variation of the original mean value function and the mean value function at the truncated time is considered. A decision is taken to stop testing the software based on the difference between the mean value function and the mean value function at the truncated time. Truncated reliability aspects are discussed using four data sets.

Keywords SRGM, RELEASE TIME

1. Introduction

In the theory of probability, F(t) is called the cumulative distribution function (CDF) of a continuous non-negative valued random variable. Thus an NHPP designed to study the failure process of a software can be constructed as a Poisson process with mean value function based on the cumulative distribution function of a continuous positive valued random variable. If a software system when put to use fails with probability F(t) before time t, if 'a' stands for the unknown eventual number of failures that it is likely to experience, then the average number of failures expected to be experienced before time t is a.F(t). Hence a.F(t) can be taken as the mean value function of an NHPP. We know that the cumulative distribution function (cdf) of the linear failure rate distribution is given by

$$F(x) = 1 - e^{\left(ax + \frac{b}{2}x^2\right)}, x > 0, a > 0, b > 0 \quad (1.1)$$

The NHPP with F(θ,x) as the mean value function is prepared by us as the SRGM for our present study.

$$F(\theta, x) = \theta\left[1 - e^{\left(ax + \frac{b}{2}x^2\right)}\right], x > 0, a > 0, b > 0, \theta > 0 \quad (1.2)$$

Cumulative distribution functions of positive valued random variables play an important role in the development of software reliability growth models through non-homogenous Poisson process (NHPP) in Pham (2000) [2]. The notion of NHPP with cumulative distribution function of LFRD along with the concept of truncation is used in this work in an admissible way to decide the point of truncation on one hand and the optimal release time of the software product in a di erent sense. The suggested procedure is illustrated for four different data sets also. The rest of the paper is organized as follows. Evaluation of the mean value function by moment type method of estimation of statistical science given by Kantam et al. (2014) [1] is briefly presented in section 2. Our suggested procedure for the estimated mean value function to a hypothetical data set is described by section 3. The illustration of the results of our procedure for live data sets is presented in section 4. Summary and conclusions are given in section 5.

2. Moment Type Method of Estimation

The parameters of the mean value function generated by NHPP using LFRD model requires estimation because they are generally unknown. The most frequently used classical method of estimation is the well known Maximum likelihood method. However for LFRD model this method does not yield analytical solutions. As an alternative Kantam et al. (2014) [1] suggested a simpler, efficient ready to use method called moment type method of estimation and provided auxiliary tables for immediate use overcoming numerical iterative procedures. For the sake of theoretical justication the moment type method of estimation is briefly in this section. This method applied to any data gives the estimation of parameters the mean value function which is essential for a suggested procedure described in section 3.

In the present paper we consider the CDF of LFRD as the genesis of mean value function of our SRGM. All these models are either constant failure rate (CFR) or of absolutely instantatenous failure rate (IFR). In the theory of

* Corresponding author:
boyapativaraprasad@gmail.com (B. Vara Prasad Rao)
Published online at http://journal.sapub.org/safety

distributions a com-bination of exponential distribution which is CFR model and Rayleigh which is IFR model is used through hazard function to get a model called LFRD whose hazard function is a perfectly increasing straight line of the form y=a+bx. Such a distribution is proved to be having a number of important applications in survival analysis, a proxy concept to reliability theory with a view to model software failure data with LFRD. We consider the pdf.

The probability density function (pdf) of Linear Failure Rate Distribution is given by

$$f(x) = (a+bx)\, e^{\left(ax+\frac{b}{2}x^2\right)}, x>0, a>0, b>0 \quad (2.1)$$

Its cumulative distribution function (cdf) is

$$F(x) = 1 - e^{\left(ax+\frac{b}{2}x^2\right)}, x>0, a>0, b>0 \quad (2.2)$$

The NHPP with F(θ,x) as the mean value function is prepared by us as the SRGM for our present study.

$$F(\theta,x) = \theta\left[1 - e^{\left(ax+\frac{b}{2}x^2\right)}\right], x>0, a>0, b>0, \theta>0 \quad (2.3)$$

Thus our proposed SRGM contains 3 parameters namely θ, a, b where θ stands for the unknown number of faults latent in the software. It is also the limiting value of the mean value function as $t\rightarrow\infty$. For any general NHPP representing as SRGM the software reliability is given by

$$R\left({}^{x}/_{t}\right) = P\{N(t+x) - N(t) = 0\} = e^{-[m(t+x)-m(t)]} \quad (2.4)$$

which is the probability of zero failures between the time t to t+x where t is the execution time of the software during which testing was done and x is additional time period upto which the user wants the software to function failure free. The quality of the software is based on the magnitude of the software reliability. We can know it only if the parameters of SRGM are known and t,x are specified. But generally, the parameters remain unknown and need to be estimated with the help of software failure data. Usually, the parameters will be estimated using the classical M.L. method. The loglikelihood equations to get the MLEs of the parameter after simplification for LFRD generated SRGM are:

Table 1. Auxiliary Table of CV for a given θ

	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.00	0.522723	0.523139	0.523556	0.523971	0.524387	0.524801	0.525215	0.525629	0.526042	0.526454
0.01	0.526866	0.527277	0.527688	0.528098	0.528508	0.528917	0.529326	0.529734	0.530142	0.530549
0.02	0.530955	0.531361	0.531767	0.532172	0.532576	0.532980	0.533384	0.533787	0.534189	0.534591
0.03	0.534992	0.535393	0.535793	0.536193	0.536592	0.536991	0.537389	0.537788	0.538184	0.538581
0.04	0.538977	0.539373	0.539768	0.540163	0.540557	0.540951	0.541344	0.541737	0.542129	0.542521
0.05	0.542912	0.543303	0.543693	0.544083	0.544472	0.544861	0.545249	0.545637	0.546024	0.546411
0.06	0.546797	0.547183	0.547569	0.547953	0.548338	0.548722	0.549105	0.549488	0.549871	0.550253
0.07	0.550634	0.551016	0.551396	0.551776	0.552156	0.552535	0.552914	0.553292	0.553670	0.554047
0.08	0.554424	0.554801	0.555177	0.555552	0.555927	0.556302	0.556676	0.557050	0.557423	0.557796
0.09	0.558168	0.558540	0.558911	0.559282	0.559653	0.560023	0.560392	0.560762	0.561130	0.561498
0.10	0.561866	0.562234	0.562601	0.562967	0.563333	0.563699	0.564064	0.564429	0.564793	0.565157
0.11	0.565520	0.565883	0.566246	0.566608	0.566969	0.567331	0.567692	0.568052	0.568412	0.568771
0.12	0.569130	0.569489	0.569847	0.570205	0.570563	0.570920	0.571276	0.571632	0.571988	0.572343
0.13	0.572698	0.573053	0.573407	0.573760	0.574113	0.574466	0.574818	0.575170	0.575522	0.575873
0.14	0.576224	0.576574	0.576924	0.577273	0.577623	0.577971	0.578319	0.578667	0.579015	0.579362
0.15	0.579708	0.580055	0.580400	0.580746	0.581091	0.581436	0.581780	0.582124	0.582467	0.582810
0.16	0.583153	0.583495	0.583837	0.584178	0.584519	0.584860	0.585200	0.585540	0.585879	0.586219
0.17	0.586557	0.586896	0.587234	0.587571	0.587908	0.588245	0.588581	0.588917	0.589253	0.589588
0.18	0.589923	0.590258	0.590592	0.590925	0.591259	0.591592	0.591924	0.592256	0.592588	0.592920
0.19	0.593251	0.593581	0.593912	0.594242	0.594571	0.594900	0.595229	0.595558	0.595886	0.596218
0.20	0.596541	0.596868	0.597194	0.597520	0.597846	0.598172	0.598497	0.598822	0.599146	0.599470
0.21	0.599794	0.600117	0.600440	0.600763	0.601085	0.601407	0.601728	0.602049	0.602370	0.602691
0.22	0.603011	0.603330	0.603650	0.603969	0.604287	0.604606	0.604924	0.605241	0.605558	0.605875
0.23	0.606192	0.606508	0.606824	0.607139	0.607455	0.607769	0.608084	0.608398	0.608712	0.609025
0.24	0.609338	0.609651	0.609963	0.610275	0.610587	0.610898	0.611209	0.611520	0.611830	0.612140
0.25	0.612450	0.612759	0.613068	0.613377	0.613685	0.613993	0.614301	0.614608	0.614915	0.615222
0.26	0.615528	0.615834	0.616139	0.616445	0.616750	0.617054	0.617359	0.617662	0.617966	0.618269
0.27	0.618572	0.618875	0.619177	0.619479	0.619781	0.620082	0.620383	0.620684	0.620984	0.621284
0.28	0.621584	0.621884	0.622183	0.622481	0.622780	0.623078	0.623376	0.623673	0.623970	0.624267
0.29	0.624564	0.624860	0.625156	0.625451	0.625746	0.626041	0.626336	0.626630	0.626924	0.627218
0.30	0.627511	0.627804	0.628097	0.628389	0.628682	0.628973	0.629265	0.629556	0.629847	0.630137

	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.31	0.630428	0.630718	0.631007	0.631297	0.631586	0.631874	0.632163	0.632451	0.632739	0.633026
0.32	0.633313	0.633600	0.633887	0.634173	0.634459	0.634745	0.635030	0.635315	0.635600	0.635884
0.33	0.636168	0.636452	0.636736	0.637019	0.637302	0.637585	0.637867	0.638149	0.638431	0.638713
0.34	0.638994	0.639275	0.639555	0.639836	0.640116	0.640395	0.640675	0.640954	0.641233	0.641511
0.35	0.641790	0.642068	0.642345	0.642623	0.642900	0.643177	0.643453	0.643730	0.644006	0.644281
0.36	0.644557	0.644832	0.645107	0.64538	0.645655	0.645929	0.646203	0.646476	0.646750	0.647022
0.37	0.647295	0.647567	0.647839	0.64811	0.648382	0.648654	0.648924	0.649195	0.649465	0.649735
0.38	0.650005	0.650275	0.650544	0.65081	0.651081	0.651350	0.651618	0.651886	0.652153	0.652421
0.39	0.652688	0.652954	0.653221	0.65348	0.653753	0.654018	0.654284	0.654549	0.654814	0.655078
0.40	0.655343	0.655607	0.655870	0.65613	0.656397	0.656660	0.656923	0.657185	0.657447	0.657709
0.41	0.657971	0.658232	0.658493	0.65875	0.659014	0.659275	0.659535	0.659794	0.660054	0.660313
0.42	0.660572	0.660831	0.661089	0.66134	0.661605	0.661863	0.662120	0.662378	0.662634	0.662891
0.43	0.663147	0.663403	0.663659	0.66391	0.664170	0.664425	0.664680	0.664935	0.665189	0.665443
0.44	0.665697	0.665950	0.666204	0.66645	0.666709	0.666962	0.667214	0.667466	0.667718	0.667969
0.45	0.668221	0.668472	0.668722	0.66897	0.669223	0.669473	0.669723	0.669972	0.670222	0.670471
0.46	0.670719	0.670968	0.671216	0.67146	0.671712	0.671959	0.672207	0.672454	0.672700	0.672947
0.47	0.673193	0.673439	0.673685	0.67393	0.674176	0.674421	0.674666	0.674910	0.675155	0.675399
0.48	0.675643	0.675886	0.676130	0.67637	0.676616	0.676858	0.677101	0.677343	0.677585	0.677826
0.49	0.678068	0.678309	0.678550	0.67879	0.679031	0.679272	0.679512	0.679751	0.679991	0.680230
0.50	0.680469	0.680708	0.680947	0.68118	0.681423	0.681661	0.681899	0.682136	0.682373	0.682610

$$\sum \frac{t_i e^{-at_i-\frac{b}{2}t_i^2} - t_{i-1}e^{-at_{i-1}-\frac{b}{2}t_{i-1}^2}}{e^{-at_{i-1}-\frac{b}{2}t_{i-1}^2} - e^{-at_i-\frac{b}{2}t_i^2}}(y_i - y_{i-1})$$

$$-\theta t_n \mathrm{e}^{-at_n+\frac{b}{2}t_n^2} = 0 \quad (2.5)$$

$$\sum \frac{t_i^2 e^{-at_i-\frac{b}{2}t_i^2} - t_{i-1}^2 e^{-at_{i-1}-\frac{b}{2}t_{i-1}^2}}{e^{-at_{i-1}-\frac{b}{2}t_{i-1}^2} - e^{-at_i-\frac{b}{2}t_i^2}}(y_i - y_{i-1})$$

$$-\theta t_n^2 \mathrm{e}^{-at_n+\frac{b}{2}t_n^2} = 0 \quad (2.6)$$

$$\theta = \frac{\mathrm{y_n}}{1-\mathrm{e}^{-at_n+\frac{b}{2}t_n^2}} \quad (2.7)$$

In view of the complicated nature to get the solutions of loglikelihood equations, we resort to moment type of estimation of the parameters as provided in kantam et al (2014) [1]. For a ready reference this method is presented below briefly:

The Mean, Variance and coefficient of variation (CV) of a reparameterised LFRD are respectively

$$\mu = \sqrt{\frac{2\pi}{b}}\; e^{\left(\frac{a^2}{2b}\right)}\left\{1-\phi\left(\frac{a}{\sqrt{b}}\right)\right\} \quad (2.8)$$

$$\sigma^2 = \frac{2}{b}(1 - a\mu) - \mu^2 \quad (2.9)$$

$$CV = \left(\frac{\frac{2}{b}\left[1-\sqrt{2\pi\theta}\,\mathrm{e}^{\frac{\theta^2}{2}}(1-\phi(\theta))-\pi\left(e^{\frac{\theta^2}{2}}\right)^2(1-\phi(\theta))^2\right]}{\frac{2\pi}{b}\left(e^{\frac{\theta^2}{2}}\right)^2(1-\phi(\theta))^2}\right)^2 \quad (2.10)$$

where $\phi(\theta)$ is cumulative distribution function of standard normal distribution. It can be seen that from equation (2.10) that there is a one-one correspondence between the population CV and θ of reparameterised LFRD. This motivates us to develop an auxiliary table between various hypothetical values of and CV expressed by equation (2.10). In fact the RHS of equation (2.10) is evaluated for various values of =0(0.001)0.5, so that for any live value of coefficient of variation (CV) one can get back the corresponding θ, with interpolation if necessary. A part of the values corresponding to =0(0.001)0.5 is listed in the table 1. The remaining values are available with the authors.

3. Procedure to Determine Truncated Point

It is well known that a typical software failure data set shall be of the form (t_i, y_i), i=1,2,..,k. where t_i is the time and y_i is the number of failures experienced by a software up to time t_i, also $t_1 < t_2 < ::: < t_k$. In our procedure we take the first two time incidents initially say (t_1, t_2) and define a hypothetical truncated time for this subset as something more than t_2 say T_1. Using the time point (t_1, t_2) the parameters of the mean value function are estimated by the method described in section 2. These estimates would give the estimated values of the mean value function at $(t_1; t_2; T_1)$.The absolute difference of $|m(t_2) - m(T_1)|$ is noted down say A_1.

The data is now supplemented by the next two time points namely $(t_3; t_4)$ thus having a data set of four time points $t_1 < t_2 < t_3 < t_4$ in a moving manner. For this supplemented data set another hypothetical truncation time say T_2 typically more than t_4 is taken. As described above the parameters are estimated using t_1 to t_4 and the absolute difference between $|m(t_4) - m(T_2)|$ say A_2 is noted down.

This procedure is repeated each time supplementing the data by the successive pairs of time incidents t_i, t_{i+1} and estimating the corresponding absolute difference A_l at the i^{th} time till all the time points up to t_k are exhausted. For a given data set the graph of A_l against l (l=1,2,...) shows a trend of falling down and raising at a particular l where the direction is changed is identi ed and the maximum t_i of the time points used at that stage is recommended as the suitable point of truncation. That point may be taken as the optimum release time of the software product and also the termination time at the software testing. This procedure is applied to four data sets as illustration and is given in section 4.

4. Illustration

Four different data sets published in Wood (1996) [3] and Pham (2005) [4] are considered for illustration of the above procedure to determine the truncation point. The last row presented in the table of each data set indicates A_l values. The place at l where the trend of A_l changes its direction is shown in bold type. At that place in the column of t_is the largest t_i is recommended as truncation time also marked in bold type which in our proposal as the optimal release time / stoppage rule of the software testing.

Table 2. *Data Sets*

	Data Set 1 Wood(1996)		Data Set 2 Wood(1996)		Data Set 3 Pham(2005)		Data Set 4 Pham(2005)	
Test Week	CPU hours	defects found	CPU hours	defects found	CPU hours	defects found	CPU hours	defects found
1	519	16	254	1	384	13	416	3
2	968	24	788	3	1186	18	832	4
3	1430	27	1054	8	1471	26	1248	4
4	1893	33	1393	9	2236	34	1664	7
5	2490	41	2216	11	2772	40	2080	9
6	3058	49	2880	16	2967	48	2496	9
7	3625	54	3593	19	3812	61	2912	10
8	4422	58	4281	25	4880	75	3328	13
9	5218	69	5180	27	6104	84	3744	17
10	5823	75	6003	29	6634	89	4160	19
11	6539	80	7621	32	7229	95	4576	23
12	7083	86	8783	32	8072	100	4992	25
13	7487	90	9604	36	8484	104	5408	30
14	7846	93	10064	38	8847	110	5824	32
15	8205	96	10560	39	9253	112	6240	36
16	8564	98	11008	39	9712	114	6656	37
17	8923	99	11237	41	10083	117	7072	39
18	9282	100	11243	42	10174	118	7488	39
19	9641	100	11305	42	10272	120	7904	39
20	10000	100	--	--	--	--	8320	42
21	--	--	--	--	--	--	8736	43

Table 3. Difference table of m(t)-m(T) for Data Set 1

	519	*519*	*519*	*519*	*519*	*519*	*519*	*519*	*519*	*519*
	968	*968*	*968*	*968*	*968*	*968*	*968*	*968*	*968*	*968*
		1430	*1430*	*1430*	*1430*	*1430*	*1430*	*1430*	*1430*	*1430*
		1893	*1893*	*1893*	*1893*	*1893*	*1893*	*1893*	*1893*	*1893*
			2490	*2490*	*2490*	*2490*	*2490*	*2490*	*2490*	*2490*
			3058	*3058*	*3058*	*3058*	*3058*	*3058*	*3058*	*3058*
				3625	*3625*	*3625*	*3625*	*3625*	*3625*	*3625*
				4422	*4422*	*4422*	*4422*	*4422*	*4422*	*4422*
					5218	*5218*	*5218*	*5218*	*5218*	*5218*
					5823	*5823*	*5823*	*5823*	*5823*	*5823*
						6539	*6539*	*6539*	*6539*	*6539*
						7083	*7083*	*7083*	*7083*	*7083*
							7487	*7487*	*7487*	*7487*
							7846	*7846*	*7846*	*7846*
								8205	*8205*	*8205*
								8564	*8564*	*8564*
									8923	*8923*
									9282	*9282*
										9641
										10000
$\hat{\theta}$	0	0	0.068	0.169	0.258	0.277	0.23	0.173	0.123	0.084
$\hat{a}$	0	0	0.4712 x10^{-4}	0.8152 x10^{-4}	0.9113 x10^{-4}	0.7913 x10^{-4}	0.5805 x10^{-4}	0.2699 x10^{-4}	0.2708 x10^{-4}	0.1089 x10^{-4}
$\hat{b}$	0.2842 x10^{-5}	0.1086 x10^{-5}	0.4803 x10^{-6}	0.2327 x10^{-6}	0.1248 x10^{-6}	0.8816 x10^{-5}	0.6870 x10^{-7}	0.2440 x10^{-7}	0.4850 x10^{-7}	0.1680 x10^{-7}
Truncated at T	1000	1900	3100	4500	5900	7100	7900	8600	9300	10000
m(t)-m(T)	0.0000	0.0000	**0.3868 x10^{-3}**	0.6358 x10^{-4}	0.1122 x10^{-2}	0.000	0.6110 x10^{-3}	0.4754 x10^{-3}	0.1013 x10^{-3}	0.0000

Table 4. Difference table of m(t)-m(T) for Data Set 2

	254	*254*	*254*	*254*	*254*	*254*	*254*	*254*	*254*
	788	*788*	*788*	*788*	*788*	*788*	*788*	*788*	*788*
	1054	*1054*	*1054*	*1054*	*1054*	*1054*	*1054*	*1054*	*1054*
		1393	*1393*	*1393*	*1393*	*1393*	*1393*	*1393*	*1393*
		2216	*2216*	*2216*	*2216*	*2216*	*2216*	*2216*	*2216*
			2880	*2280*	*2280*	*2280*	*2280*	*2280*	*2280*
			3593	*3593*	*3593*	*3593*	*3593*	*3593*	*3593*
				4281	*4281*	*4281*	*4281*	*4281*	*4281*
				5180	*5180*	*5180*	*5180*	*5180*	*5180*
					6003	*6003*	*6003*	*6003*	*6003*
					7621	*7621*	*7621*	*7621*	*7621*
						8783	*8783*	*8783*	*8783*
						9604	*9604*	*9604*	*9604*
							10064	*10064*	*10064*
							10560	*10560*	*10560*
								11008	*11008*
								11237	*11237*
									11243
									11305
$\hat{\theta}$	0.160	0.346	0.544	0.608	0.778	0.882	0.737	0.573	0.413
$\hat{a}$	0.2537x10^{-3}	0.2961x10^{-3}	0.2677x10^{-3}	0.2092x10^{-3}	0.1816x10^{-3}	0.1497x10^{-3}	0.1139x10^{-3}	0.8476x10^{-4}	0.6200x10^{-4}
$\hat{b}$	0.2515x10^{-4}	0.7326x10^{-6}	0.2423x10^{-6}	0.1184x10^{-6}	0.5450x10^{-7}	0.2880x10^{-7}	0.2390x10^{-7}	0.2190x10^{-7}	0.2250x10^{-7}
Truncated at T	1100	2300	3600	5200	7700	9700	10600	11300	11400
m(t)-m(T)	0.3857 x10^{-2}	**0.4489x10^{-2}**	0.3454x10^{-3}	0.6864x10^{-3}	0.1850x10^{-2}	0.2231x10^{-2}	0.4303x10^{-3}	0.1146x10^{-2}	0.1445x10^{-2}

Table 5. Difference table of m(t)-m(T) for Data Set 3

	384	*384*	*384*	*384*	*384*	*384*	*384*	*384*	*384*
	1186	*1186*	*1186*	*1186*	*1186*	*1186*	*1186*	*1186*	*1186*
	1471	*1471*	*1471*	*1471*	*1471*	*1471*	*1471*	*1471*	*1471*
		2236	*2236*	*22363*	*2236*	*2236*	*2236*	*2236*	*2236*
		2216	*2216*	*2216*	*2216*	*2216*	*2216*	*2216*	*2216*
			2772	*2772*	*2772*	*2772*	*2772*	*2772*	*2772*
			2967	*2967*	*2967*	*2967*	*2967*	*2967*	*2967*
				3812	*3812*	*3812*	*3812*	*3812*	*3812*
				4880	*4880*	*4880*	*4880*	*4880*	*4880*
					6104	*6104*	*6104*	*6104*	*6104*
					6634	*6634*	*6634*	*6634*	*6634*
						7229	*7229*	*7229*	*7229*
						8484	*8484*	*8484*	*8484*
							8847	*8847*	*8847*
							9253	*9253*	*9253*
								9712	*9712*
								10083	*10083*
									10174
									10272
$\hat{\theta}$	0.084	0.141	0.085	0.336	0.359	0.332	0.256	0.192	0.121
$\hat{a}$	0.9759x10^{-4}	0.9853x10^{-4}	0.4726x10^{-4}	0.1152x10^{-3}	0.9666x10^{-4}	0.7537x10^{-3}	0.5370x10^{-4}	0.3761x10^{-4}	0.2291x10^{-4}
$\hat{b}$	0.1349x10^{-5}	0.4884x10^{-6}	0.3090x10^{-6}	0.1176x10^{-5}	0.7250x10^{-7}	0.5150x10^{-7}	0.4401x10^{-7}	0.3840x10^{-7}	0.3590x10^{-7}
Truncated at T	1500	2800	3900	6200	7300	8500	9300	10100	10300
m(t)-m(T)	0.9992x10^{-3}	0.6578x10^{-3}	0.7765x10^{-3}	**0.1438x10^{-2}**	0.1162x10^{-2}	0.2242x10^{-3}	0.5085x10^{-3}	0.1343x10^{-3}	0.1571x10^{-3}

Table 6. Difference table of m(t)-m(T) for Data Set 4

	416	*416*	*416*	*416*	*416*	*416*	*416*	*416*	*416*	*416*
	832	*832*	*832*	*832*	*832*	*832*	*832*	*832*	*832*	*832*
	1248	*1248*	*1248*	*1248*	*1248*	*1248*	*1248*	*1248*	*1248*	*1248*
		1664	*1664*	*1664*	*1664*	*1664*	*1664*	*1664*	*1664*	*1664*
		2080	*2080*	*2080*	*2080*	*2080*	*2080*	*2080*	*2080*	*2080*
			2496	*2496*	*2496*	*2496*	*2496*	*2496*	*2496*	*2496*
			2912	*2912*	*2912*	*2912*	*2912*	*2912*	*2912*	*2912*
				3328	*3328*	*3328*	*3328*	*3328*	*3328*	*3328*
				3744	*3744*	*3744*	*3744*	*3744*	*3744*	*3744*
					4160	*4160*	*4160*	*4160*	*4160*	*4160*
					4576	*4576*	*4576*	*4576*	*4576*	*4576*
						4992	*4992*	*4992*	*4992*	*4992*
						5408	*5408*	*5408*	*5408*	*5408*
							5824	*5824*	*5824*	*5824*
							6240	*6240*	*6240*	*6240*
								6656	*6656*	*6656*
								7072	*7072*	*7072*
									7488	*7488*
									7904	*7904*
										8320
										8736
$\hat{\theta}$	0	0.011	0.043	0.062	0.075	0.085	0.092	0.098	0.102	0.106
$\hat{a}$	0	1.10 x10^{-5}	3.14x10^{-5}	3.56x10^{-5}	3.57x10^{-5}	3.44x10^{-5}	3.23 x10^{-5}	2.95 x10^{-5}	2.84x10^{-5}	2.66x10^{-5}
$\hat{b}$	2.27x10^{-6}	9.93x10^{-8}	5.33x10^{-7}	3.31x10^{-7}	2.26$10^{-7}$	1.64x10^{-7}	1.23x10^{-7}	9.59x10^{-8}	7.77x10^{-8}	6.32x10^{-8}
Truncated at T	1250	2100	3000	3800	4600	5500	6300	7100	8000	8800
m(t)-m(T)	0	0.3782 x10^{-3}	**0.5403 x10^{-3}**	0.3706 x10^{-3}	0.1720 x10^{-3}	0.5272 x10^{-3}	0.3216 x10^{-3}	0.1414 x10^{-3}	0.4327 x10^{-3}	0.2747 x10^{-3}

Graphs indicating release time based on the mean value function

Figure 1

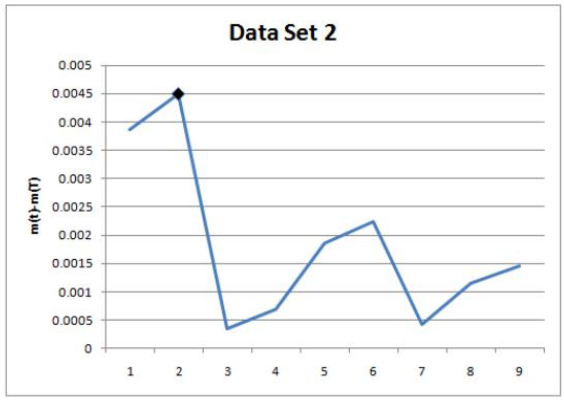

Figure 2

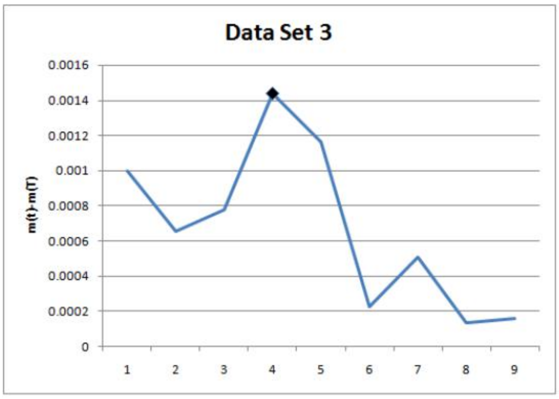

Figure 3

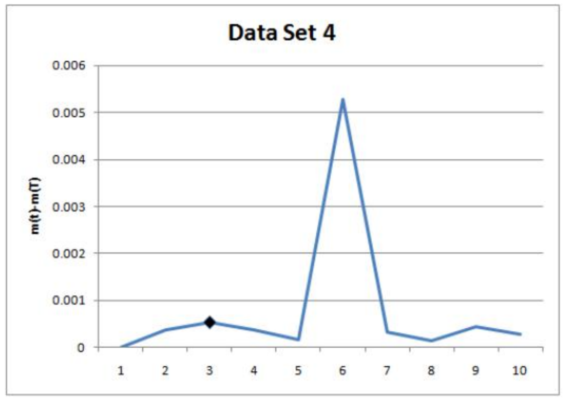

Figure 4

5. Summary & Conclusions

In software testing processes testing time is a key aspect. It is desirable to suggest a time point where testing is to be terminated and the product is to be released. In such situations a admissible stoppage rule is necessary to save the time aspect. The notion of truncation is used in this work to suggest optimal stoppage rule for a software product assuming that the failure phenomenon of the product is described by our NHPP with LFRD cdf as its mean value function. The method we suggested is simpler in mathematics without sacri cing its precision and can be readily used by practitioners to arrive at the stopping rule of the experiment.

REFERENCES

[1] Kantam. R. R. L., Priya. M. Ch., and Ravikumar. M. S Moment type estimation in linear failure rate distribution. IAPQR Transactions, 39(1):87-97, 2014.

[2] Pham. H. Software Reliability. Springer-Verlag, 2000.

[3] Wood. A. P. Predicting software reliability. IEEE Computer, 11:69-77, 1996.

[4] Hoang Pham. A generalized logistic software reliability growth model. Operational Research Society of India (OPSEARCH), 42(4): 322-331, Dec 2005.