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Testing Domain based Software Reliability Growth Models using Stochastic Differential Equation

Manohar Singh, Harminder Pal Singh Dhami, Dr. Vaibhav Bansal

Department of Computer Science, OPJS University, Churu, Rajasthan, India

ABSTRACT

Software testing is a process to detect the errors in a totality and worth of developed software. Software reliability models provide quantitative measures of the software development processes. In this paper, an attempt has been made to discuss some testing domain based software reliability models and testing software and testing domain software reliability models based on ItO types Stochastic Differential Equation(SDE) with basic testing domain functions and testing domain with skill factor functions.

Keywords: SDE, SRGM, MSE, Testing-Domain, Ranking, Accuracy Estimation (AE)

I. INTRODUCTION

In the software engineering, reliability of software system is considered as the key characteristics of quality of software. In the testing phase of software development, there is a set of paths and functions that are influenced by executed test cases and this set is called a testing-domain. This set of paths and functions is isolated from the software and is called an isolated testing-domain. The faults lying in the isolated testing-domain are basically the detectable faults. Now an effort is made by the testing team to actually detect/remove the faults from these detectable faults. This process of detection/removal includes finding of faults in the code of paths or functions that are influenced. The growth of isolated testing-domain in the software system is closely related to the number of executed test-cases and their quality. The number of detectable faults is determined by the growth of isolated testing-domain. Some of the work has been done in this area by Yamada et al. [1], Yamada and Fujiwana [2][3]. Before the software system is released in the market, a number of faults are detected and removed during the long testing phase of software development life cycle. However, the software companies release an updated version of the system and the users find some faults still lying in it. Thus in this particular case, faults that are left in the system can be considered to be a stochastic process with continuous state space [4].

Yamada, Nishigai and Kimura [5] proposed a simple model for the growth of software reliability for describing the process of fault detection during the phase of testing by application of ItO type Stochastic Differential Equation (SDE) and also obtained several measures of software reliability on the basis of probability distribution of the stochastic process. Later on a flexible equation model on Stochastic Differential Equation was proposed by them that described a process of fault detection during the phase of system-testing of the distributed development environment Yamada and Tamura[6] and Lee, Kim and Park[7] used SDEs for representation of a per-fault detection rate that includes an inconsistent fluctuation instead of an NHPP and consider a per-fault detection rate which is dependent on testing time *t*. Recently, Kapur, Anand, Yadavalli and Beichelt [8] developed a generalized software growth model using SDE. In all these models the fault removal process (debugging) is assumed to be perfect, i.e., every detected fault is removed with certainty. In other words, it implies that there is a one-to-one correspondence between the initial fault-content and the total number of failures caused by these faults. This assumption, however, seems to be a bit unrealistic. Due to the analytical nature of testing phase, man power is mainly involved and hence there is a possibility that a fault removal effort does not succeed. Therefore, a fault which is imperfectly debugged may cause a failure again.

In this paper we have discussed some existing testing-domain based software skilled growth models and proposed testing-domain software reliability models based on ItO type stochastic differential equation, using basic testing-domain functions and testing-domain with skill factor functions. Organization of this paper consist of five sections. Section II describe the stochastic differential equations and testing-domain function used in modeling. This section also contains various notation used in the paper. In section III, we have discussed Kapur et. at. [9] Testing-Domain based SRGMs and modeling of Testing-Domain SRGMs using SDE, corresponding to Kapur models.

The parameter estimation using a real time software failure date set cited in Pham [10] of proposed and existing SRGMs is given in section IV. The evaluation of comparison and predictive criterion for goodness of fit of models and ranking of models based on weighted criteria values are also given in section IV. Finding & conclusion is discussed in section V.

II. METHODS AND MATERIAL

2. Testing domain functions and SDE

In this section we have discussed about the basic testing domain functions, testing domain functions with skill factor and the basics of Stochastic Differential Equation(SDE), which are required in the existing and proposed software reliability growth models. We have also included here the various notations used in this paper.

2.1 Notation:

SRGMs are mathematical functions that describe the fault detection the removal process. The following notation will be used throughout in this paper for modeling:

a : a constant representing the initial number of errors in software at the starting of test.

$a(t)$: total fault content of software at time t.

b : constant, rate of fault detection/correcting/ isolation.

v : growth rate of testing domain.

$u(t)$: no. of detectable faults existing in the isolated testing domain at time t.

$u_a(t)$, $u_b(t)$: no. of detectable error in this isolated basic testing domain at time t.

$u_c(t)$, $u_b(t)$: no. of detectable error in this isolated testing domain with skill factor at time t.

$m(t)$: excepted faults detected at time t, called mean value function.

$m_a(t)$, $m_b(t)$: mean value functions of basic testing domain.

$m_c(t)$, $m_d(t)$: mean value functions of testing domain with skill factor.

p : uniformity factor in error distribution.

$b(t)$: time dependent fault detection rate per remaining fault.

$m_{as}(t)$, $m_{bs}(t)$: expected faults exposed in time (0,t] in testing with basic testing domain

$m_{cs}(t)$, $m_{ds}(t)$: expected faults exposed in time (0,t] in testing with testing domain with skill factor.

$R(t)$: a random variable, representing no. of faults detected at testing time t.

σ : a positive constant, signifies the value of irregular fluctuation of faults.

$\gamma(t)$: standardized Gaussian white noise for some stochastic process.

$W(t)$: Weiner process.

2.2 Testing-Domain Functions:

Testing domain functions are used to identify the number of detectable faults existing in the isolated testing domain at given time t. The following for testing domain functions are used in the paper.

- **Basic Testing-Domain function:**

Basic testing domain function without skill factor, $u_a(t)$ is given as:

$$u_a(t) = a[1 - e^{-vt}] \qquad (1)$$

- **Basic Testing-Domain function with uniformity factor**

Basic testing domain function without skill factor and with uniformity factor, $u_b(t)$is given as:

$$u_b(t) = a[1 - pe^{-vt}],\ (1 > p > 0) \qquad (2)$$

- **Testing-Domain function with skill factor**

Testing-domain function with skill factor, $u_c(t)$ is given as:

$$u_c(t) = a[1 - (1 + vt)e^{-vt}] \qquad (3)$$

This function shows that testing-domain does not exist at the starting point of testing phase since skill of test-case designer is very low. It also shows that testing-domain growth curve is S-shaped.

- **Basic Testing-Domain function with skill and uniformity factors:**

Basic testing-domain function with skill and uniformity factors $u_d(t)$, is given as:

$$u_d(t) = a[1 - p(1 + vt)e^{-vt}],\ (1 > p > 0) \quad (4)$$

The factor $p = 0$ indicates that test-case designers are expert and experienced leading to high potential of detecting the faults in initial stages of testing. On the other hand, when $p = 1$ signifies that designers have low level of skill.

2.2 Basics of Stochastic Differential Equation

This paper is focus on the study of Stochastic Differential Equation (SDE) based models. A stochastic process is a set of random variables defined on a probability space and is given as[11]:

$$\{ R(t),\ t \in T \} \tag{5}$$

Where, T is the index set of process and for each $t \in T$, R(t) is a random variable. A stochastic process W(t) is Wiener process, if P[W(0)=0] =1, E(W(t) = 0 and E [W(t), W(t′)] = Min[t, t′], Where W(t) follows normal distribution with mean σ and variance t.

Let us take a single population growth model

$$\frac{d}{dt}P(t) = a(t)P(t) \tag{6}$$

Where, a(t) and P(t) denote relative rate of growth and population size at time t respectively.

$$\text{Let } a = r(t) + \text{"noise"} \tag{7}$$

Here we, consider r(t) as a non-random. To find mathematical interpretation of the "noise", we have

$$\frac{d}{dt}P(t) = P(t)[r(t) + \text{"noise"}] \tag{8}$$

The general form of equation is

$$\frac{d}{dt}\ P(t) = \ b\ (t,\ P(t) + \ \sigma\ (t,\ P(t) *\ \text{noise} \tag{9}$$

Where b and σ denotes some functions. Let γ (t) represents "noise" for some stochastic Process, we have

$$\frac{d}{dt}\ P\ (t) = b(t, P(t)\ ) + \sigma\ (t, P(t)\ \gamma(t) \tag{10}$$

The derivative Winner process with respect to time is white noise and given as

$$\frac{d}{dt}\ W\ (t) = \gamma(t) \tag{11}$$

From equation (9), we have

$$dP(t) = b\big(t, P(t)\big)dt + \sigma\ (t, P))dW(t) \tag{12}$$

This is called a stochastic differential of ItO type. Solving equation (6) with a(t) = b(t) + σγ(t), we have

$$P(t) = \ P_0\ e^{\left(b - \frac{1}{2}\right)\ t + \ \sigma W(t)} \tag{13}$$

Where $\sigma, \gamma(t)$ and b denote magnitude of irregular fluctuations constant, standardized Gaussion while noise and b(t) = b (constant) respectively.

For modeling SDE based software reliability growth models, we take the linear differential equation to describe the fault detection process as:

$$\frac{d}{dt}\ P(t) = \ b(t)[a - P(t)] \tag{14}$$

$$\frac{d}{dt}\ P(t) = \ \lfloor b(t) + \sigma\gamma\ (t)]\ [a - P(t)] \tag{15}$$

Where, b(t) is not-negative function describe error detection rate per remaining error. Assuming irregular fluctuation in b(t), equation (13) can be written stochastic different equation as :

Extending equation (14) to ItO type SDE and solving, we have

$$P(t) = \ a\ \left[1 - e^{-\int_{0}^{t} b(t)dt - \ \sigma\ W(t)}\right] \tag{16}$$

This equation is the general solve of SRGM based as SDE of equation (15) under condition P(t =0) = 0

3. Testing-Domain based SRGMs using SDE

In this part, we have given, a brief description about the existing testing domain based model for basic testing domain functions and testing-domain functions with skill factor given by Kapur et. at. [9] have been used. The failure intensity differential equation of Kapur flexible testing domain based software reliability models is given as:

$$\frac{d}{dt}\ m(t) = \ b(t)[\ u(t) - \ m(t)] \tag{17}$$

Where , fault detection rate per fault remaining in testing domain b(t) as logistic function is given as

$$b\ (t) = \ \frac{b}{1 + \beta e^{-bt}}$$

using testing domain functions $u_a(t)$, $u_b(t)$ $u_c(t)$ and $u_d(t)$ from equation (1), (2), (3) and (4) in equation (17), we get four flexible testing domain based SRGMs suggested by Kapur et [9] as under:

SRGM -1: Model using Basic Testing Domain functions

$$m_a(t) = \left[\frac{a}{1+\beta e^{-bt}}\right]\left[1 + \frac{be^{-vt} - \ ve^{-bt}}{v - b}\right],\ v \neq b \tag{18}$$

SRGM-2: Model using Basic Testing Domain function and uniformity factor.

$$m_b(t) = \ \left[\frac{a}{1+\beta e^{-bt}}\right]\ \left[1 - \ \frac{(v-b+bp)e^{-bt}\ -bpe^{-vt}}{v-b}\right],\quad v \neq b, 1 > p > 0 \tag{19}$$

SRGM-3: Model using Testing-Domain function with skill factor.

$$m_c(t) = \ \left[\frac{a}{1+\beta e^{-bt}}\right]\left[1 + \frac{b}{v-b}\left[vt + \ \frac{2v-b}{v-b}\right]e^{-vt} - \left[\frac{v}{v-b}\right]^2\ e^{-bt}\right] \tag{20}$$

SRGM-4: Model using Testing-Domain function with skill and uniformity factors.

$$m_d(t) = \ \left[\frac{a}{1+\beta e^{-bt}}\right]\left[\ 1 + \frac{bp}{v-b}\ \left[vt + \ \frac{2v-b}{v-b}\right]\ e^{-vt} - \left[1 + \frac{bp\ (2v-b)}{(v-b)^2}\right]\ e^{-bt}\right] \tag{21}$$

Corresponding to these four testing domain based SRGMs introduced by Kapur et at [9], we have proposed four testing domain SRGMs using SDE. The following assumptions are taken into consideration for proposed testing domain models using SDE:

(i) A stochastic process with a continuous state space is used for software fault detection.

(ii) The number of faults left in the software gently decreases as the testing procedure continues.

(iii) Software is subject to failures during execution caused by faults remaining in the software.

(iv) During the errors isolation/removal, no new error is introduced into the system and the errors are debugged perfectly.

The deviation of the mean value function corresponding to Kapur et at SRGM in equation (18), we have

$$\frac{d}{dt} m_a(t) = b[u_a(t) - m_a(t)] \quad (22)$$

Equation (18) can be obtained in one stage process using the fault detection rate per remaining fault b = b(t) as

$$b(t) = \frac{b}{1+\beta e^{-bt}}\left[\frac{b(e^{-b1} - e^{-vt})}{ve^{-bt} - be^{-vt}}\right] \quad (23)$$

Thus from equations (22), (23) and equation (15) we get transition probability of basic testing domain using SDE model

$$P_a(t) = \frac{a}{1+\beta e^{-bt}}\left[1 - \frac{(ve^{-bt} - be^{-vt})e^{-\sigma W(t)}}{v-b}\right] \quad (24)$$

The expected detected faults at testing time t for basic testing domain model using SDE is given as

$$m_{as}(t) = \frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\left[1 + \frac{be^{-vt+\frac{\sigma^2 t}{2}} - ve^{-bt+\frac{\sigma^2 t}{2}}}{v-b}\right] \quad (25)$$

The equation (25) is mean value functions of basic testing domain based Proposed SRGM-1 using SDE.

In the same way, we can drive the equation of mean value function for basic testing domain model with uniformity factor p and using SDE, corresponding to Kapur SRGM-2, the Proposed SRGM-2 given as in equation (26)

$$m_{bs}(t) = \left[\frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\right]\left[1 - \frac{(v-b+bp)e^{-bt+\frac{\sigma^2 t}{2}}}{v-b}\right] \quad (26)$$

For derivation of mean value function corresponding to Kapur et at SRGM-3 in equation (20), we have

$$\frac{d}{dt} m_c(t) = b\,[u_c(t) - m_c(t)] \quad (27)$$

Equation (20) can be obtain in one stage process using b = b(t) as

$$b(t) = \left[\frac{b}{1+\beta e^{-bt}}\right]\left[\frac{v^2\,(e^{-bt} - (1+(v-b)t)e^{-vt}}{v^2\,e^{-bt} - b(vt(v-b)+2v-b)e^{-vt}}\right] \quad (28)$$

From equation (27), (28) and equation (15), we get transition probability distribution of testing domain with skill factor using SDE model.

$$P_c(t) = \left[\frac{a}{1+\beta e^{-bt}}\right]\left[1 - \left(\frac{v}{v-b}\right)^2 e^{-bt}\,e^{-\sigma W(t)} + \frac{b}{v-b}\left[vt + \frac{2v-b}{v-b}\right]e^{-vt}\,e^{-\sigma W(t)}\right] \quad (29)$$

The mean value function of Proposed SRGM-3 based on testing domain with skill factor using SDE is given

$$m_{cs}(t) = \left[\frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\right]\left[1 - \left(\frac{v}{v-b}\right)^2 e^{-bt+\frac{\sigma^2 t}{2}} + \frac{b}{v-b}\left[vt + \frac{2v-b}{v-b}\right]e^{-bt+\frac{\sigma^2 t}{2}}\right] \quad (30)$$

For derivation mean value function corresponding to Kapur et at SRGN-4 in equation (21) we have

$$\frac{d}{dt} m_d(t) = b\,[u_d(t) - m_d(t)] \quad (31)$$

Equation (21) can be obtained in stage process using b = b(t) =

$$\frac{b}{1+\beta e^{-bt}}\left[\frac{[(v-b)^2 + bp\,(2v-b)]e^{-bt} - [1+(v-b)t]v^2 pe^{-vt}]}{[(v-b)^2 + bp(2v-b)]e^{-bt} - bp[vt(v-b)+2v-b]e^{-vt}}\right] \quad (32)$$

Thus from equation (31), (32) and equation (15), we get transition probability distribution of testing domain with skill and uniformity factors using SDE model.

$$P_{ds}(t) = \left[\frac{a}{1+\beta e^{-bt}}\right]\left[1 - \left[1 + \frac{bp(2v-b)}{(v-b)^2}\right]e^{-bt}\,e^{-\sigma W(t)} + \frac{bp}{v-b}\left[vt + \frac{2v-b}{v-b}\right]e^{-vt}\;e^{-\sigma W(t)}\right] \quad (33)$$

Thus mean value function of the Proposed SRGM-4 based on testing domain with skill and uniformity factors using SDE is given as

$$m_{ds}(t) = \left[\frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\right]\left[1 - \left[1 + \frac{bp(2v-b)}{(v-b)^2}\right]e^{-bt+\frac{\sigma^2 t}{2}} + \frac{bp}{v-b}\left[vt + \frac{2v-b}{v-b}\right]e^{-vt+\frac{\sigma^2 t}{2}}\right] \quad (34)$$

The mean value functions of Kapur et at [9] testing domain based SRGMs given in equations (18), (19), (20) and (21) and corresponding to these, the Proposed testing domain SRGMs using SDE, given in equations (25) (26), (30) and (34) are summarized in Table-1.

III. RESULTS AND DISCUSSION

4. Numerical Implementation of Models

This section includes parameters estimation of models, computation of comparison criteria, ranking of models and graphical illustration of goodness of fit curves of models.

4.1 Estimation of Parameters of Models

The functions of Software Reliability Growth Models given in Table 1 are Non- Linear, therefore we have used non linear regression technique using method of least square Parameter Estimation and Model Validation are important aspects of modeling. The parameters of models are estimated using a statistical package IBM SPSS. To check the validity of SRGMs, we have collected a Data Set from the paper by Pham[10]. In this data set the number of faults detected in asd each week of testing is found, and the cumulative number of faults since the start of testing is recorded for each week. It provides the cumulative number of faults by each week up to 21 weeks. It observes 416 hours per week of testing. Over the time interim of 21 weeks, there was a consumption of 8736 CPU hours and with the removal of 43 software faults. The results of the parameters estimation are given in Table-2.

Model	**Mean Value Function $m(t)$ of Testing Domain based SRGM using SDE**
SRGM-1	$\left[\frac{a}{1+\beta e^{-bt}}\right]\left[1+\frac{be^{-vt}-ve^{-bt}}{v-b}\right], \quad v \neq b$
SRGM-2	$\left[\frac{a}{1+\beta e^{-bt}}\right]\left[1-\frac{(v-b+bp)e^{-bt}-bpe^{-vt}}{v-b}\right], v \neq b, 1 > p > 0$
SRGM-3	$\left[\frac{a}{1+\beta e^{-bt}}\right]\left[1+\frac{b}{v-b}\left[vt+\frac{2v-b}{v-b}\right]e^{-vt}-\left[\frac{v}{v-b}\right]^2 e^{-bt}\right]$
SRGM-4	$\left[\frac{a}{1+\beta e^{-bt}}\right]\left[1+\frac{bp}{v-b}\left[vt+\frac{2v-b}{v-b}\right]e^{-vt}-\left[1+\frac{bp\,(2v-b)}{(v-b)^2}\right]e^{-bt}\right]$
Proposed SRGM -1	$\frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\left[1+\frac{be^{-vt+\frac{\sigma^2 t}{2}}-ve^{-bt+\frac{\sigma^2 t}{2}}}{v-b}\right]$
Proposed SRGM -2	$\left[\frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\right]\left[1-\frac{(v-b+bp)e^{-bt+\frac{\sigma^2 t}{2}}}{v-b}\right]$
Proposed SRGM -3	$\left[\frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\right]\left[1-\left(\frac{v}{v-b}\right)^2 e^{-bt+\frac{\sigma^2 t}{2}}+\frac{b}{v-b}\left[vt+\frac{2v-b}{v-b}\right]e^{-bt+\frac{\sigma^2 t}{2}}\right]$
Proposed SRGM-4	$\left[\frac{a}{1+\beta e^{-bt+\frac{\sigma^2 t}{2}}}\right]\left[1-\left[1+\frac{bp(2v-b)}{(v-b)^2}\right]e^{-bt+\frac{\sigma^2 t}{2}}+\frac{bp}{v-b}\left[vt+\frac{2v-b}{v-b}\right]e^{-vt+\frac{\sigma^2 t}{2}}\right]$

Table-1: Summary of mean value functions of Testing Domain based SRGMs

Model	**Estimated Parameters**					
	a	**b**	**v**	**β**	**σ**	**p**
SRGM-1	411.345	1.226	0.006	5.634		
SRGM-2	88.216	0.527	0.041	3.619		0.998
SRGM-3	54.238	0.467	0.164	2.178		
SRGM-4	55.447	0.420	0.159	1.238		0.972
Proposed SRGM-1	51.279	0.160	0.277	2.556	0.004	
Proposed SRGM-2	48.021	0.209	0.632	7.478	0.020	0 .963
Proposed SRGM-3	51.832	0.364	0.208	2.879	0.166	
Proposed SRGM-4	47.405	2.427	2.294	3.702	2.018	0.877

Table-2: Results of Estimated Parameters of SRGMs

4.2 Comparison and Predictive Validation Criteria

In this paper, the performance analysis of models given in Table-1 has been measured by using the eight comparison and predictive criteria of Goodness-of-Fit models. These Criteria includes: Coefficient of Multiple Determination (R^2), Mean Square Error(MSE), Root Mean Square Predictive Error (RMSPE), Mean Absolute Error (MAE), Mean Error Of Prediction (MEOP), Predictive-Ratio Risk(PRR), Sum of Square Error(SSE) and Accuracy Estimation(AE). The Criteria MSE, MAE, MEOP are used to measure the deviation whereas the criteria AE and SSE measures the errors[12][13]][14]. The results of Goodness-of-Fit comparison and predictive validity criteria are given in Table-3.

Model	R^2	MSE	SSE	RMPSE	MAE	MEOP	AE	PRR
SRGM-1	0.970	7.300	158.53	11.11	3.18	2.99	0.091	3.59
SRGM-2	0.985	3.770	61.94	7.00	2.14	2.01	0.048	0.59
SRGM-3	0 .989	2.761	46.97	5.77	1.65	1.56	0.019	1.39
SRGM-4	0.991	2.420	38.75	5.37	1.64	1.54	0.023	0.24
Proposed SRGM-1	0.987	3.447	55.11	6.35	1.94	1.82	0.010	1.69
Proposed SRGM-2	0.989	3.216	48.15	5.75	1.88	1.76	0.003	1.57
Proposed SRGM-3	0. 988	3.024	48.94	6.13	1.87	1.76	0.014	1.28
Proposed SRGM-4	0.995	1.294	19.74	3.58	1.17	1.09	0.002	0.20

Table-3: Results of Comparison and Predictive Criteria of SRGMs

4.3 Ranking of SRGMs using weighted criteria value

The comparison of Goodness of fit models, we have suggested ranking methodology based on weighted criteria for computation of permanent values of models[14][15]. Ranking of models are calculated on the basis of the permanent values of the models. Lesser the permanent value represents good rank of model as compare to larger permanent value of model. The results of Ranking of models are given in Table-4 and Table-5.

Model	Sum of Weights	Sum of Weighted Values	Permanent Value of Model	Rank of Model
SRGM-1	8.000	178.59	22.32	8
SRGM-2	3.169	25.12	7.93	7
SRGM-3	2.000	12.55	6.28	4
SRGM-4	1.441	8.34	5.79	2
Proposed SRGM-1	2.598	19.80	7.62	6
Proposed SRGM-2	2.214	14.73	6.65	5
Proposed SRGM-3	2.271	13.51	5.95	3
Proposed SRGM-4	0.001	0.000	0.00	1

Table-4: Permanent values and Ranks of SRGMs

Testing Domain	Existing		Proposed	
	Model	Rank	Model	Rank
Without Skill Factor	SRGM-1	8	Proposed SRGM-1	6
Without Skill Factor and with Uniformity Factor	SRGM-2	7	Proposed SRGM-2	5
With Skill Factor	SRGM-3	4	Proposed SRGM-3	3
With Skill Factor and with Uniformity Factor	SRGM-4	2	Proposed SRGM-4	1

Table-5: Comparison of ranks of proposed and corresponding SRGMs

4.4 Analysis of the models for Data Set

The results of the comparison and predictive criteria for data set of models given in Table-3 are clearly indicated that values R^2 of proposed models are better as compare to the corresponding values of existing models and are much closed to one. The values of Accuracy Estimation(AE) and SSE of most of the proposed models in data set are smaller than the existing model. The values of AE of models show that the errors are less than 10% in proposed models (except Proposed SRGM-3). The values of the various comparison and predictive criteria of the proposed models are almost better than the values of the corresponding existing models.

The goodness of fit curves of proposed and corresponding existing models for Data Set shown are in Figure 1, Figure 1, Figure 2 , Figure 3, Figure 4.The Figure 5 shows the goodness of fit of all the models with actual data. It is indicated that the proposed Software Reliability Growth Models fit data sets excellently well. It is observed from Tables-4 and Table-5 that the Ranks of Proposed SRGMs are good as compare to the corresponding existing SRGMs which clearly indicated that software Reliability Growth Models based on Testing-Domain Function using SDE gives better results.

4.4 Goodness of Fit Curves for Data Set

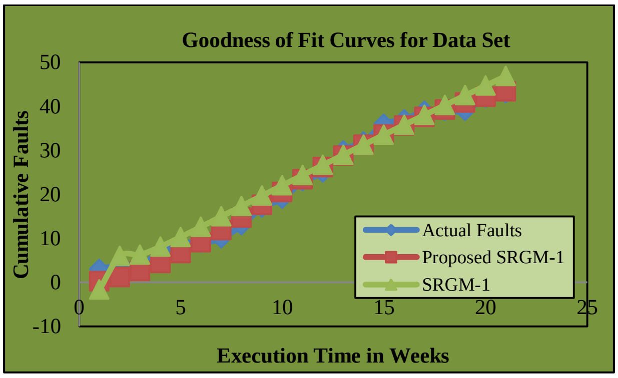

Figure 1: Goodness of Fit Curves of Proposed SRGM-1 and existing SRGM-1

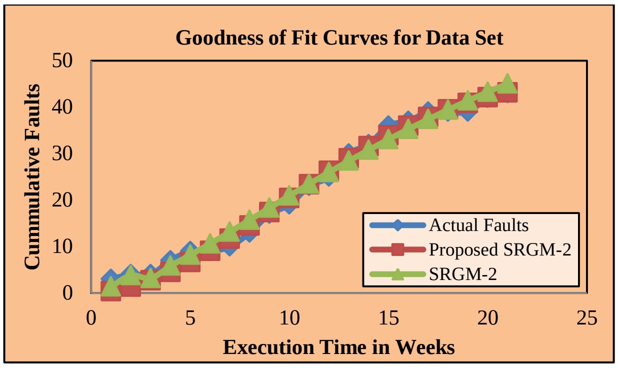

Figure 2: Goodness of Fit Curves of Proposed SRGM-2 and existing SRGM-2

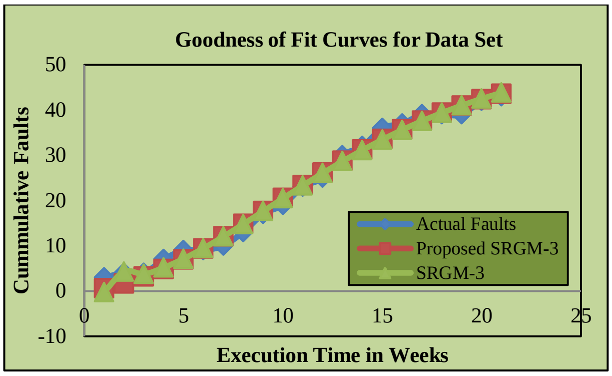

Figure 3: Goodness of Fit Curves of Proposed SRGM-3 and existing SRGM-3

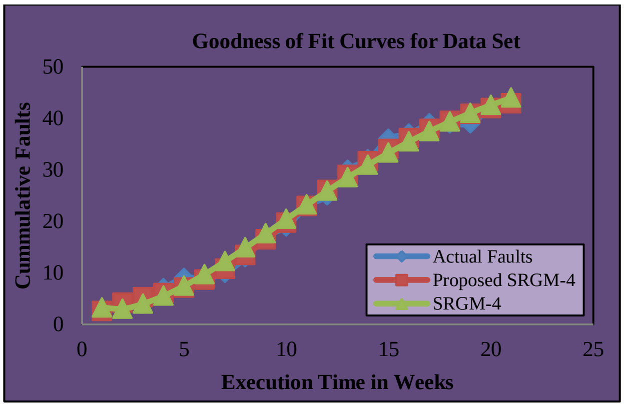

Figure 4: Goodness of Fit Curves of Proposed SRGM-4 and existing SRGM-4

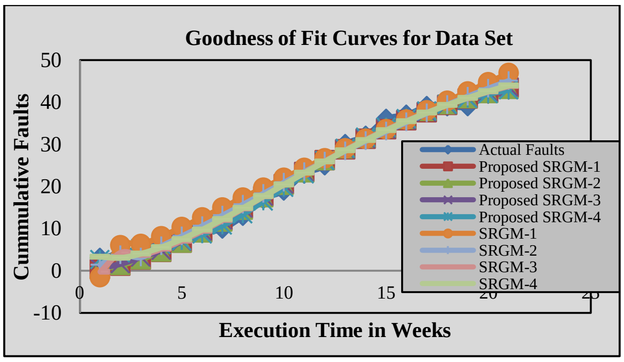

Figure 5: Goodness of Fit Curves of Proposed SRGMs and existing. SRGMs

IV. CONCLUSION

In this paper we have discussed the concept of the testing domain software reliability growth model using Stochastic Differential Equation (SDE) which includes basic testing domain function and testing domain with skill factor. As compare to previous software reliability growth models, proposed models give better performance analysis. The ranking methodology based on weighted criteria value used in this work helps to compare the models in better way. It was concluded form the experimental results of goodness of fit for data set of the proposed SRGMs and existing SRGMs that testing domain based SRGMs using SDE gives better performance.

V. REFERENCES

[1]. Yamada S, Tamura Y and Kimura M, "A Software Reliability Growth Model for a Distributed Development Environment, Electronics and Communication in Japan 2000, Part 3, Vol. 83, pp. 1446-1453. [110]

[2]. Yamada S, Ohba M and Osaki S, "S-shaped software reliability growth modeling for software error detection", IEEE Trans. On Reliability, R-32(5), pp. 475-484, 1983. [106]

[3]. Yamada S, Ohtera H and Ohba M, "Testing-Domain Dependent Software Reliability Model", Computers Mathematical Applications, 24, pp. 79-86, 1992. [107]

[4]. Pham H, Software Reliability, Springer-Verlag, 2000.[84]

[5]. Yamada S, Nishigaki A, Kimura M, "A Stochastic Differential Equation Model for Software Reliability Assessment and its Goodness of Fit", International Journal of Reliability and Applications, Vol. 4, No. 1, pp. 1-11, 2003. [112]

[6]. Yamada S and Tamura Y, "A Flexible Stochastic Differential Equation Model in Distributed Development Environment", European Journal of Operational Research Vol. 168, pp. 143-152, 2006. [113]

[7]. Lee CH, Kim YT and Park DH, "S-Shaped Software Reliability Growth Models derived from Stochastic Differential Equations", IIE Transactions (36), pp-1193-1199, 2004. [63]

[8]. Kapur PK, Anand S, Yadavalli VSS and Beichelt F, "A Generalised Software Growth Model using Stochastic Differential Equations", to appear in Communication in Dependability and Quality Management Belgrade, Serbia, 2007.[34]

[9]. Kapur PK, Khatri, Gupta A, Singh VB, Flexible Testing Domain dependent SRGMs. In Proceeding VARDE PV, Srividya Rao VVS, NARSA Publication Pvt. Ltd, New Delhi PP-170, 2006.

[10]. Pham H, “System Software Reliability”, Reliability Engineering series Springer Verlog, London, 2006.

[11]. P.K Kapur et al, “Software Reliability Assessment with OR Application”, Springer series in Reliability Engineering, Springer Verlog, London, 2011.

[12]. Kapur PK, Garg RB and Kumar S, Contribution to Hardware and Software Reliability, Word Scientific Singapore, 1999.

[13]. Pillai K and Nair VSS, “A Model for Software Development effort and Cost Estimation“, IEEE Transactions on Software Engineering Vol 23(8), PP. 485-497, 1997.

[14]. Singh M, Bansal V, “Testing Coverage based Software Reliability Models: Critical Analysis and Ranking based on Weighted Criteria.”, International Journal of Computer Science and Information Security (IJCSIS), 15 (2), PP -362-373, 2017.

[15]. Mohd. Anjum, Md. Asraful Haque, Nesar Ahmad, “Analysis and Ranking of software reliability models based on weighted criteria value”, I.J. Information Technology and Computer Science, PP-1-14, 2013.