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Estimation and Analysis of MYSQL Database Server Reliability using Beta and Generalized Gamma Distribution

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Abstract: Arrival failure times for different major sub versions of MySQL5 open source data base server are analyzed and compared. In this research 3-step approach consists of bug-gathering, bug-filtering, and bug-analysis is followed. After collecting failure data for this project, time to failures for each of these products is calculated. On this time to failure data entire analysis is performed.
Apart from reliability measurement, each of these sub versions are analyzed on the basis of bug frequency and hazard function and then compared. It is projected that the future release of this project under the same operational environment to follow similar reliability patterns. The results exhibit that Generalized Gamma and Beta distributions are powerful analytical tools to be used in reliability modeling of such open source products.

Keywords: Open source software (OSS) Mysql; Software reliability model; Software architecture; Reliability growth model; Generalized Gamma Distribution; Beta Distribution; Goodness of Fit Test.;

I. INTRODUCTION

The Mysql database [3] has become the world's most popular open source database because of its high performance, high reliability and ease of use. It is database of choice for a new generation of applications. The purpose of this study is to develop reliability models suitable for main sub versions of Mysql5 series. There are different editions of Mysql used for specific purposes. Commercial customers have the flexibility of

choosing from multiple editions to meet specific business and technical requirements:

- Mysql Standard Edition
- Mysql Enterprise Edition
- Mysql Cluster Carrier Grade Edition

In this research mainly 5.0, 5.1 and 5.5 sub versions of Mysql5 are considered. All the failure records are extracted from online bug repositories and after preprocessing it is stored in Mysql database. Initially it is analyzed on the basis of bug severity and bug frequency and is shown graphically. Later on it is analyzed by considering major sub versions of Mysql5 individually. Finally the entire result is compared from all possible dimensions and result is shown.

Due to worldwide usage of Mysql as an open source database its reliability becomes a major concern which is defined as the probability of failure free operation of a computer program in a specified environment for a specified period of time [4],[5]. Here in this research for software reliability concern growth modeling [6], [7] approach is used.

Software reliability growth models generally fall into two major classes: time between failures and fault count models. The main input parameter to the "time between failures" models is the intervals of successful operations. As the failures occur and fixed, it is expected that these intervals to increase. The pattern of these intervals is reflected by different statistical distributions. By using these distributions reliability models are constructed and then data is analyzed in detail.

In case of "fault count" the input parameter of study is the number of faults in a specified period of time rather than the times between failures. Normally the failure rate, defined as the number of failures per hour, is used as the parameter of a Probability Distribution Function (PDF). Like the first class, as the fault counts drop, the reliability is expected to increase [8], [9].

This study is concerned with Time to failure data of latest versions of three Mysql5 versions Mysql5.0, 5.1 and 5.5.Additionally, this product of open source software is widely used on all operating systems for web as well as windows application.

The following table reflects on the number of years that these products have been in operation.

TABLE: 1. RELEASE DATES OF THE Mysql5

Mysql Version	Release Date
Mysql5.0	04-10-2005
Mysql5.1	02-11-2008
Mysql5.5	01-12-2009

On the basis of goodness of fit test applied on Time to failure data of above products Generalized Gamma and Beta Distributions are identified as best distribution for reliability model construction. [11], [18].

These distributions are widely used in lifetime data analysis because of its flexibility in modeling different phases of bathtub reliability.

The rest of the paper is organized as follows. Section 2 provides some definitions and background information.

Section 3 concentrates on Research Methodology Used for reliability modeling process. Section 4 concludes the paper with a summary.

II. BACKGROUND

Normally White box and black-box models are used for predication of software reliability. The white-box models

are used to estimate reliability at design phase of software product .Thus for **White box models** Relationship of software components and their correlation are focus for software reliability measurement [19],[20].

In Black-Box approach, the entire software system is considered as a single entity. These models are used to measure and predict software quality in the later phases of software development, such as testing or operation phase.

Black Box models rely on the testing data collected over an observed time period. This study is concentrated on the black-box reliability approach to measure and compare the reliability of the selected products.

To represent failure behavior of a software product different life data distributions are used. On the basis of goodness fit test applied in selected samples best distribution is identified [21]. On the basis of PDF, which is relative concentration of data samples at different points of measurement scale, such that the area under the graph is unity reliability is estimated.

CDF is another function which is derived from PDF and is given by F(t)=P[T<=t]

$$\Rightarrow \quad F(t)= \int_{-\infty}^{t} f(t)dt$$

Mathematically reliability is defined as

R (t)= P[T>=t]

$$\Rightarrow \quad R(t)=1\text{-}CDF =1- \int_{-\infty}^{t} f(t)dt$$

Apart from this hazard function that is failure rate of a product is also used for reliability analysis which is defined as ratio of pdf and reliability.

Thus

$$\Rightarrow \quad H(t)= \frac{f(t)}{R(t)}$$

Problem Identification

After a detail study of research papers, articles and books related to reliability and other statistical analysis, it has been found that in maximum of researches either a single goodness of fit test is applied or a particular distribution is selected randomly. Apart from this only Reliability that is R (t) is used for reliability analysis. Very little importance is given to Goodness of fit test and other aspects of reliability due to which sometimes researchers got unexpected results.

The main problems in all these researches are:

- **Random selection of distributions without any test.[22]**
- **Complete analysis on the basis of R(t) by excluding H(t) and failure frequency?**

It is very difficult to analyze reliability by calculating only reliability estimate of a software product. Final conclusion is given on the basis of following calculations:

- Weekly Failure Count of Mysql 5 as well as its sub versions.
- Graphical view of Failure Count with respect to Severity.
- Probability density function i.e. probability of occurrence of failure.
- Weekly Reliability Estimates.
- Hazard function which is ratio of pdf and reliability.
- Average Estimates of probability of failure, reliability estimates and Hazard function.

III. RESEARCH METHODOLOGY USED

In this study for reliability analysis failure data of Mysql5 versions 5.0, 5.1 and 5.5 are extracted from online bug repository www.bugs.mysql.com.
Data is collected for Mysql5, which is latest available stable version of Mysql. This version of Mysql came into existence in year 2005. Failure data are collected from October 2005 to February 2011. Data are extracted directly from the web site. Bugs reported might be duplicates, provide incomplete information, or may not represent real defects. Therefore, during the bug preprocessing such noises are removed from the bugs gathered in the first step. Finally, in the third step, the preprocessed data is stored in Mysql database. Initially data was in csv (comma separated value) format. Total of 6399 records were extracted from repository and after preprocessing finally 2171 records were stored in Mysql Table. During preprocessing following records were deleted:

- ⇨ Versions other than Mysql5: Because here only Mysql5 with major subversions are considered, thus versions other than Mysql5 are not considered.
- ⇨ Some of the Sub Versions of Mysql5 have fewer records: Sample size less than 30, so difficult to fit distribution. All those records were deleted.
- ⇨ The records whose status was Need Info: These types of records may or may not be considered as failure records.
- ⇨ The records having severity other than S1 to S5 were deleted.
- ⇨ Some of the records were irrelevant means there open date were less than that of the release date. All those records were deleted.
- ⇨ Some of the records were without any versions, all those records were deleted.

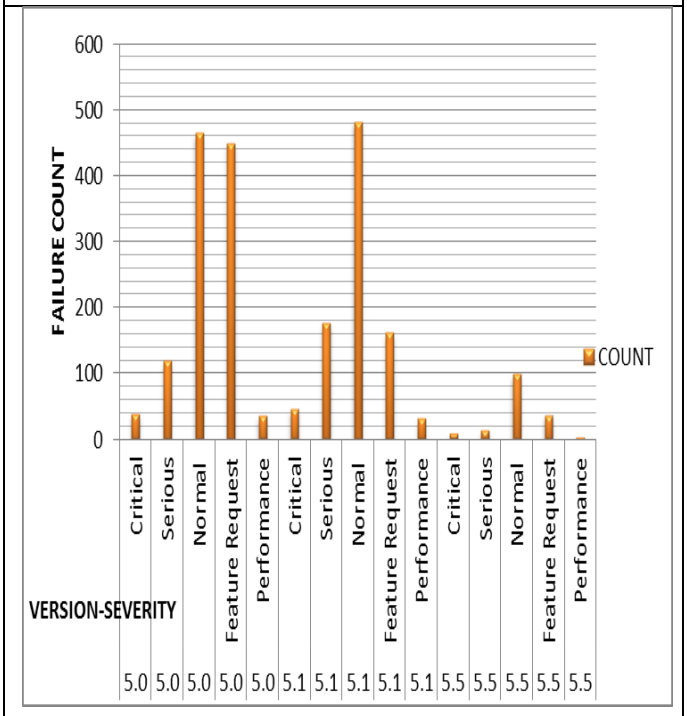
Main fields of the table are as given below:

Table2: TABLE STRUCTURE		
Field	**Data Type**	**Purpose**

Bug_Id	Int	Identification Number (Primary Key)
Opendate	Date	Date of submission of the bug
Bug_Severity	**Varchar and can be any of the following:** S5: Performance S4:Feature Request S3:Normal-Severity(Non Critical) S2: Serious S1:Critical	

Abstract of the Failure count of sample under study is graphically shown in Figure 1.

Figure 1:Version wise Abstract of Mysql

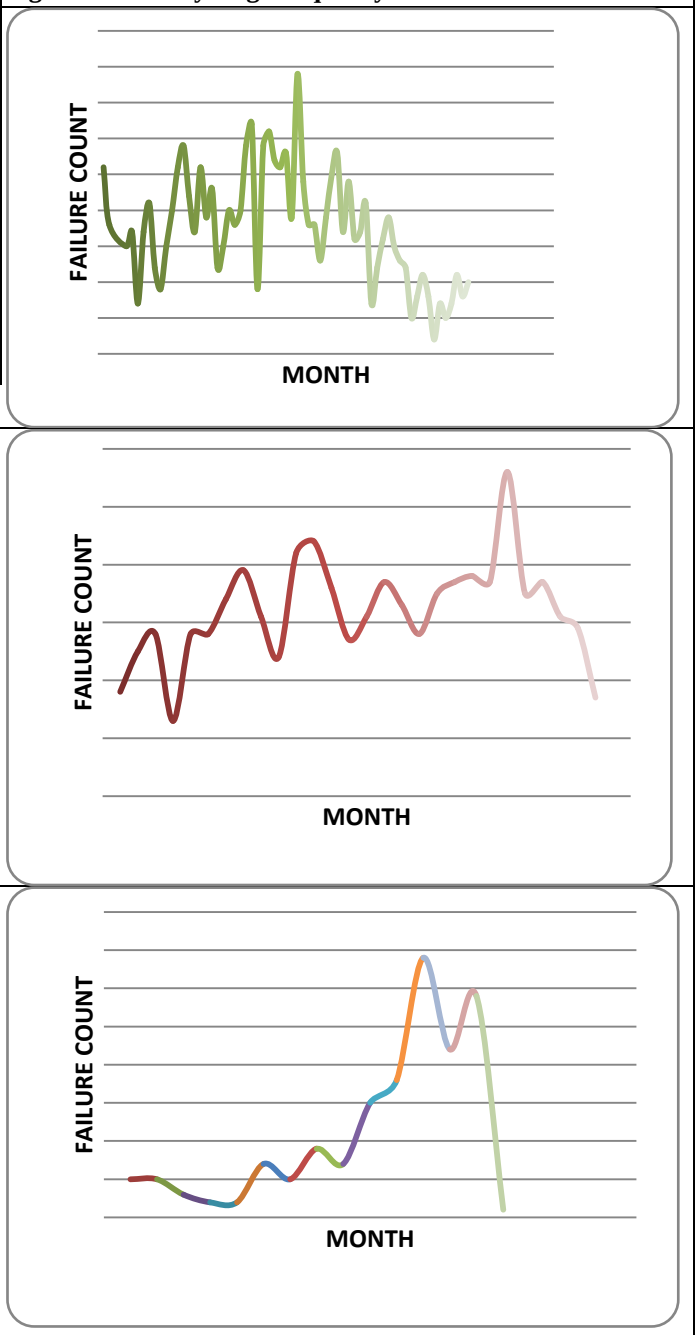


Before applying goodness of fit test on data collected for each of the major sub versions of Mysql5 series bug frequency corresponding to time to failure in month is plotted and shown in Figure 2. From Figure 1 it is clear that in all three cases maximum of the bugs has S3 and S4 bug severity. Further from Figure2 no idea regarding distribution to be fitted can be drawn, thus Goodness of fit Test is applied for all the samples and best distribution is identified. By using these distributions models are constructed and using these models different measures are estimated and analyzed in detail.

Mysql 5.0

From collected failure data, on the basis of version, records related to Mysql 5.0 version is extracted and stored in a separate table. By using appropriate Sql query Time to Failure in terms of week is calculated and stored. This data is used for further analysis.

Figure 2:Monthly Bug Frequency



Goodness of Fit Test [21]

Goodness of Fit Test is applied for extracted time to failure data for Mysql5.0.

For goodness of fit test all major life data distributions are tested by using

- Kolmogorov Smirnov Test
- Anderson Darling Test and
- Chi Square Test

All above tests are applied on 1%, 2%, 5%, 10% and 20% level of significance. On the basis of these tests best distribution which is accepted on the basis of these tests and at maximum number of level of significance is selected for reliability model construction.

On the basis of goodness fit test result following is the list of distributions which are suitable for time to failure data of Mysql 5.0 sample.

- Gen. Gamma Distribution(4 Parameters)
- Gen. Extreme Value Distribution.

Among these two distributions on the basis of their test statistic ranking and detail result of goodness of fit test Gen. Gamma distribution with 4 parameters is identified as best distribution to be fitted. Gen. Gamma distribution (4 Parameters) is accepted by Kolmogorov-Smirnov test at 1%, 2%, 5% and 10% level of significance. It is accepted by Anderson-Darling test at 1%, 2% and 5% level of significance and by Chi-Squared test it is accepted at 1% level of significance. On the basis of this distribution reliability model is constructed and all other measures are estimated and shown graphically.

Model Construction and Reliability Estimation (C3), (C4) using Gen. Gamma Distribution

Generalized Gamma distribution with 4 parameters is one of the life data distributions which are widely used in life data analysis. This distribution is used in many researches regarding reliability Analysis.

Its pdf is given by

$$f(t) = \frac{k(t-\gamma)^{k(\alpha-1)}}{\beta^{k\alpha}\Gamma(\alpha)} \exp(-((t-\gamma)/\beta)^{k}) \qquad (1)$$

Its CDF is given by

$$F(t) = \frac{\Gamma_{((t-\gamma)/\beta)^{k}}(\alpha)}{\Gamma(\alpha)} \qquad (2)$$

where k=continuous shape parameter, α=continuous shape parameter , β=continuous scale parameter and γ=continuous location parameter(k,α,β>0).

Here to construct reliability model parameters are estimated . Parameters are estimated by using method of Maximum Likelihood . These parameters are estimated with the help of Easy Fit 5.5 and is given by K=6.3702, α=0.1862, β=243.69 and γ=0.20005.

Thus we have

Reliability Model R (t) =1-F (t)

$$= 1- \frac{\Gamma_{((t-\gamma)/\beta)^{k}}(\alpha)}{\Gamma(\alpha)} \qquad (3)$$

and Hazard function which is defined as failure rate is given by

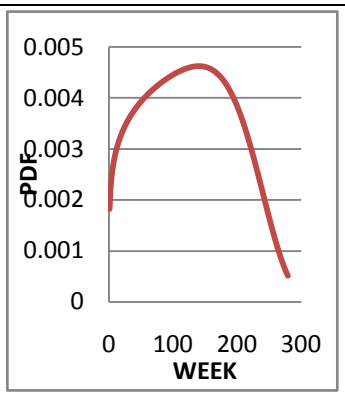
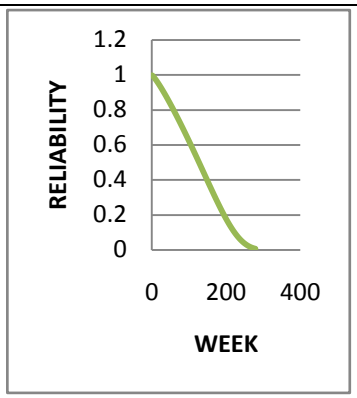
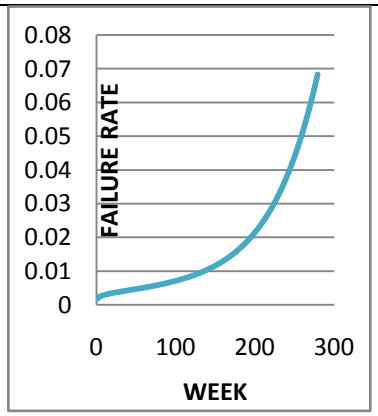
$$H(t) = \frac{f(t)}{R(t)} \qquad (4)$$

By using above equations value of pdf, cdf, reliability and hazard function (failure rate) is estimated. Weekly value of these estimates after every 4 weeks is shown in Table 3 and its graphical representation is shown in Figure 6.2.

Table3: Value of Pdf , Reliability, and Hazard Function: Mysql 5.0

TTFWEEK	PDF	RELIABILITY	HAZARD FUNCTION
4	0.00243353	0.99220381	0.002452654
8	0.00278207	0.9817052	0.00283392
12	0.00300492	0.97010626	0.003097516
16	0.00317271	0.95773774	0.003312708
20	0.00330881	0.94476638	0.003502254
24	0.0034241	0.93129481	0.003676706
28	0.00352455	0.91739328	0.003841919
32	0.00361385	0.90311322	0.004001546
36	0.00369442	0.88849409	0.004158071
40	0.00376796	0.87356721	0.004313304
44	0.0038357	0.85835813	0.004468644
48	0.00389855	0.84288814	0.004625226
52	0.00395722	0.82717531	0.004784016
56	0.00401226	0.81123522	0.004945868
60	0.00406411	0.79508147	0.005111566
64	0.00411311	0.77872612	0.00528185
24	0.0034241	0.93129481	0.003676706
28	0.00352455	0.91739328	0.003841919
32	0.00361385	0.90311322	0.004001546
36	0.00369442	0.88849409	0.004158071
40	0.00376796	0.87356721	0.004313304
44	0.0038357	0.85835813	0.004468644
48	0.00389855	0.84288814	0.004625226
52	0.00395722	0.82717531	0.004784016
56	0.00401226	0.81123522	0.004945868
60	0.00406411	0.79508147	0.005111566
64	0.00411311	0.77872612	0.00528185
68	0.00415955	0.76217998	0.005457434
72	0.00420363	0.74545287	0.005639028
76	0.00424553	0.72855384	0.005827344

Figure 3: Graphical Representation of Reliability Measures Mysql5.0[Weekly after every 4 Weeks]

Probability Density Function	
Reliability	
Hazard Function	

Mysql 5.1

This version of Mysql came into existence in November 2008.Total of 898 preprocessed failure records related to this version of Mysql is extracted. Goodness of fit test is applied on time to failure data of these records and on the basis of goodness of fit test best distribution is identified and model is constructed.

Goodness of Fit Test [36]

Goodness of Fit Test is applied for collected sample data. For goodness of fit test all major life data distributions are tested by using

- Kolmogorov Smirnov Test
- Anderson Darling Test and
- Chi Square Test

All above tests are applied on 1%, 2%, 5%, 10% and 20% level of significance. On the basis of these tests best distribution which is accepted on the basis of these tests and at maximum number of level of significance is selected for reliability model construction.

On the basis of goodness fit test result following is the list of distributions which are suitable for time to failure data of Mysql 5.1 sample.

- Beta Distribution
- Gen. Gamma Distribution(4 Parameters)

Among these two distributions on the basis of their test statistic ranking and detail result of goodness of fit test Beta distribution is identified as best distribution to be fitted. In probability theory and statistics, the beta distribution [67], [68] is a family of continuous probability distributions defined on the interval (a, b) parameterized by two positive shape parameters, typically denoted by α1 and α2. This distribution is widely used in life data analysis.

Pdf of this distribution is as given by

$$f(t) = \frac{1}{\beta(\alpha_1, \alpha_2)} \frac{(t-a)^{\alpha_1 - 1}(b-t)^{\alpha_2 - 1}}{(b-a)^{(\alpha_1+\alpha_2-1)}} \qquad (5)$$

Where α1 = continuous shape parameter α1 >0, α2 = continuous shape parameter, α2 >0 and a, b is continuous boundary parameter (a<=b). Domain of this distribution is given by a ≤t ≤b.

Here

$$\beta(\alpha_1, \alpha_2) = \int_0^1 t^{\alpha_1 - 1}(1-t)^{\alpha_2 - 1} dt \qquad \alpha_1, \alpha_2 > 0 \qquad (6)$$

Incomplete Beta function is given by

$$\beta_x(\alpha_1, \alpha_2) = \int_0^x t^{\alpha_1 - 1}(1-t)^{\alpha_2 - 1} dt \qquad \alpha_1, \alpha_2 > 0 \ , 0 \le x \le 1 \qquad (7)$$

CDF of this distribution is given by F (t) = $I_z(\alpha_1,\alpha_2)$ where $z=\frac{t-a}{b-a}$ (8)

Here Iz is regularized incomplete beta function.

β (α1,α2) is beta function given by

$I_Z(\alpha1,\alpha2)=\frac{\beta_z(\alpha_1,\alpha_2)}{\beta(\alpha_1,\alpha_2)}$ (9)

Likelihood function is given by

$L=\prod_{i=1}^{n} f(t;\alpha1,\alpha2,a,b).$

To estimate parameters following equations are used

$$\frac{\partial \ln(L)}{\partial \alpha1}=0;\frac{\partial \ln(L)}{\partial \alpha2}=0;\frac{\partial \ln(L)}{\partial a}=0;\frac{\partial \ln(L)}{\partial b}=0 \quad (10)$$

By using method of Maximum Likelihood [69] these parameters are estimated as α1=1.2095, α2=1.0743, a=0.81959 and b=119.02.

Thus we have

Reliability Model

$R(t)=1-F(t)=1-\frac{\beta_z(1.2095,1.0743)}{\beta(1.2095,1.0743)}$ (11)

Hazard function which is defined as failure rate is given by

$H(t)=\frac{f(t)}{R(t)}$ (12)

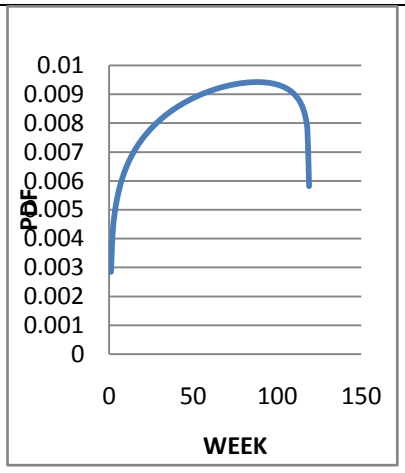
By using above equations value of pdf, reliability and hazard function (failure rate) is estimated. Weekly value of these estimates after every 4 weeks are shown in following Table 4 and its graphical representation is shown in Figure 4.

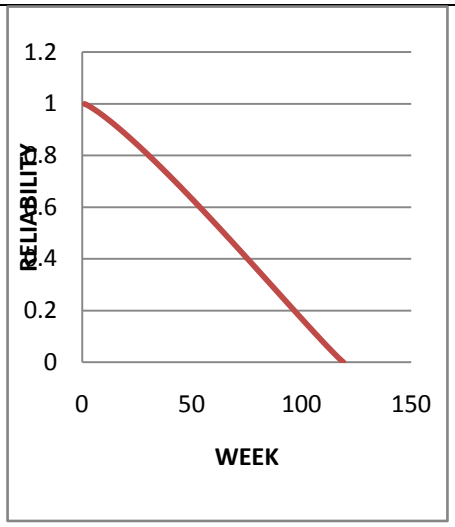
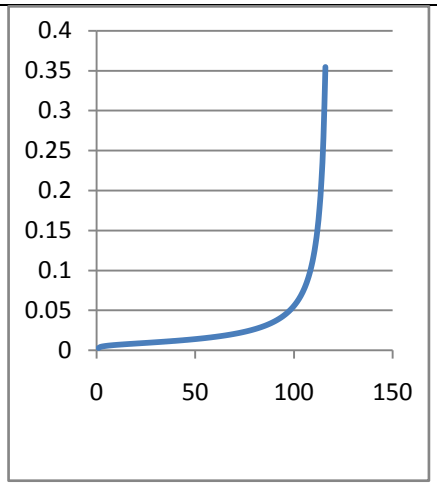
Table 4:Weekly Reliability Measures Mysql 5.1

TTFWEEK	PDF	RELIBILITY	HAZARD FUNCTION
4	0.005192	0.986336	0.005263475
8	0.006141	0.963464	0.00637401
12	0.00672	0.937672	0.007166416
16	0.007144	0.909907	0.007851518
20	0.007481	0.880634	0.008494879
24	0.00776	0.850137	0.009127831
28	0.007997	0.81861	0.009769565
32	0.008203	0.786199	0.010434251
36	0.008384	0.753016	0.011134038
40	0.008544	0.719154	0.01188064
44	0.008686	0.684688	0.012686371
48	0.008813	0.649685	0.013565001
52	0.008926	0.614202	0.01453264
56	0.009026	0.578294	0.015608769
60	0.009115	0.542006	0.016817597
64	0.009193	0.505386	0.018189928
68	0.00926	0.468477	0.019765864
72	0.009316	0.431322	0.021598845
76	0.009361	0.393963	0.023761927
80	0.009395	0.356446	0.02635789
84	0.009417	0.318818	0.029536268
88	0.009425	0.281131	0.033523532
92	0.009416	0.243443	0.038680077
96	0.009389	0.205825	0.04561662
100	0.009337	0.168364	0.055457443
104	0.009251	0.131174	0.070524275
108	0.009113	0.094425	0.096509563
Average	**0.005511**	**0.507482**	**0.266878032**

Figure 4 :Graphical representation of Pdf,Reliability and Hazard Function MYSQL 5.1

Pdf



Reliability	
Hazard Function	

Mysql 5.5

All data related to Mysql5.5 is extracted .By using appropriate sql query Time to Failure in terms of week is calculated and stored. For Mysql5.5 we have total of 164 preprocessed failure records.

Goodness of Fit Test (36)

As in previous case Goodness of Fit Test is performed on data related to this version of Mysql. On the basis of goodness fit test result attached following is the list of distributions which are suitable for time to failure data of Mysql 5.5:

- Gen. Gamma Distribution and
- Gen. Extreme Value Distribution.

Among these two distributions on the basis of their test statistic ranking and detail result of goodness of fit test Gen. Gamma Distribution is identified as best distribution to be fitted. This distribution is accepted at all level of significance by Kolmogorov-Smirnov and Anderson-Darling test and at 1% and 2% level of significance by Chi Squared Test.

Reliability Model Construction and Model Fitting

Same model as in case of Mysql 5.0 is used here. All parameters are estimated by using Method of Maximum Likelihood and is given by K=155.47,α=0.03372, β=107.51 and γ=-46.962.

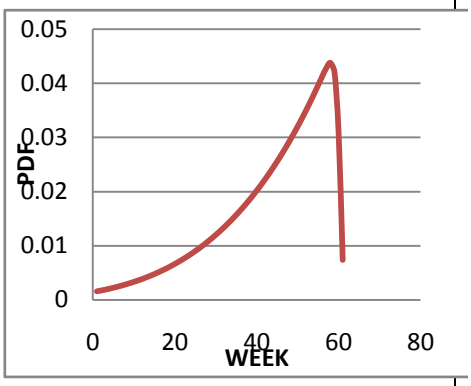
Thus using these parameters in Equation (1) to Equation (4) Reliability measures is estimated and its value after every 4 week is shown in Table 5 and graphically it is shown in Figure 5.

Table 5:Reliability Measures of Mysql 5.5 after every 4 Weeks

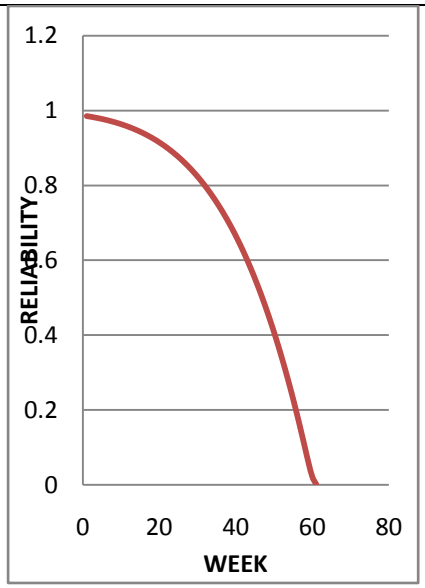
TTF	PDF	RELIABILITY	HAZARD FUNCTION
4	0.002092795	0.97965587	0.002136255
8	0.002883681	0.9697674	0.00297358
12	0.003884927	0.95630608	0.004062431
16	0.005132388	0.93835983	0.005469531
20	0.006665067	0.91486683	0.007285287
24	0.008525176	0.88460287	0.009637291
28	0.010758175	0.84616839	0.012713988
32	0.013412825	0.79797542	0.016808569
36	0.016541228	0.73823427	0.022406475
40	0.020198872	0.66494009	0.03037698
44	0.024444669	0.57585924	0.042449035
48	0.029340999	0.46851552	0.062625459
52	0.034953654	0.34017624	0.102751601
56	0.041302458	0.18786991	0.219846055
61	0.00741434	0.00193903	3.823728088
Average	0.016163601	0.69888002	0.139064222

FIGURE 5:GRAPHICAL REPRESENTATION OF RELIABILITY ESTIMATES OF MYSQL 5.5

PDF



RELIABILITY



HAZARD FUNCTION

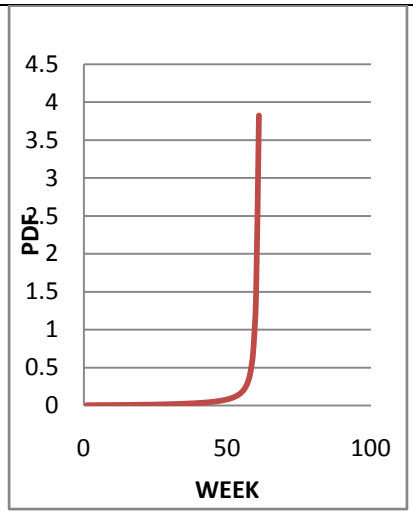
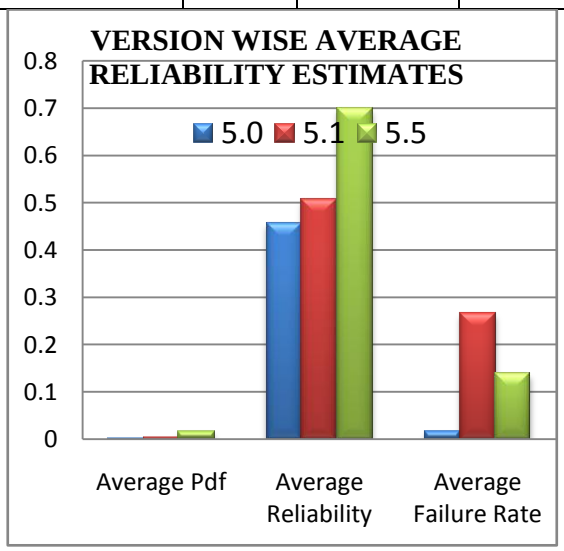


Table 6: Average Reliability Estimates for Mysql5 series.

MYSQL VERSION	Average Pdf	Average Reliability	Average Failure Rate
5.0	0.003557009	0.45704778	0.017660222
5.1	0.005510869	0.507482169	0.266878032
5.5	0.016163601	0.69888002	0.139064222
OVERALL AVERAGEMYSQL5	0.008410493	0.55446999	0.141200825



On the basis of above table it is clear that from all three prospects Mysql 5.1 is found to most reliable. The research of this type will be very useful for researchers in Open Source and Reliability.

Section IV: Conclusion

In above study a detail methodology to estimate reliability is discussed and it has been analyzed that mere calculating reliability one cannot judge whether the product is reliable or not. The average value of three estimates for each of these sub versions are calculated and is shown here:

References:

[1] Ying ZHOU, Joseph DAVIS "Open source software reliability model: an empirical approach"

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