Comparative Study on the Attributes Analysis of Software Development Cost Model Based on Exponential-type Lifetime Distribution

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Abstract— In this paper, the development cost attributes were newly analyzed by applying the Exponential-type lifetime distributions (Burr-Hatke-exponential, Exponential-Basic, Exponential-exponential, Inverse-exponential) widely utilized in the field of software lifetime testing and quality evaluation to the software development cost model. Also, to verify the attributes of the analyzed development cost, after analyzing the future reliability, the optimal cost model was presented.

For this study, an analysis algorithm using software failure time data was proposed to solve the research solution, the maximum likelihood estimation (MLE) was applied to solve the parameter values, and the nonlinear equation was calculated using the binary method. Simulations show that if the cost of removing one flaw found during the test phase increases, the development cost increases, but the release time does not change. However, if the cost of flaws correction discovered by operators increased, both development costs and release times increased. Therefore, we must remove all possible flaws at the testing stage to eliminate failures. In conclusion, First, the Exponential-exponential distribution model showed the best performance among the proposed models because it had the lowest software development cost and the highest future reliability. Second, the software development cost attributes of the Exponential-type lifetime distributions were newly analyzed. Third, through this data, it was able to help software developers to analyze the most economical development cost.

Keywords— Burr-Hatke-exponential, Exponential-exponential, Exponential-type distribution, Inverse-exponential, Future Reliability, Software Development Cost

I. INTRODUCTION

Unlike the era of the 3rd industrial revolution when only internet-based technologies such as internet home shopping and online banking were used, in the current 4th industrial revolution era based on digital convergence technology, the most important thing is to develop reliable software that can accurately process large amounts of data that can be applied in various industrial fields without failure.

In the process of developing such reliable software, the most important topic is research on development cost. Therefore, software developers and researchers have been doing a lot of research to find a way to develop reliable software at an economical cost [1]. In particular, Yang [2] presented a study on the property of the software reliability model using Type-2 Gumbel and Erlang lifetime distribution based on the non-homogeneous Poisson process (NHPP) model. Pham [3] presented a new type of distribution function using the failure rate function. Banga and Bansal, Singh [4] proposed a new analysis method using a hybrid approach to predict software fault detection. Also, Dohi and Suzuki, Osaki [5] performed the property analysis of software cost models with periodic/non-periodic examples. Also, Pham and Zhang [6] analyzed and presented the correlation of the NHPP software reliability model and cost model. Kim and Shin [7] performed the property study of software optimal release time using Gamma distribution and the Non-Exponential family distribution. Also, Kim [8] presented a study on the attributes of the software development cost model based on shape parameter of the NHPP Weibull distribution model.

Therefore, in this study, after applying the Exponential-type lifetime distributions which are widely utilized in the field of reliability tests to the finite failure NHPP software reliability model, we will newly analyze the cost attributes by using the proposed software development model.

II. RELATED WORKS

A. NHPP Model and NHPP Software Reliability Model

a) NHPP model

The NHPP model is a stochastic distribution model in which the number of occurrences $N(t)$ at time t follows a Poisson distribution with parameters.

Mainly, it is useful for modeling permutations in which the number of mutually independent events occurs steadily over time.

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In the NHPP model, $N(t)$ refers to the accumulated number of software flaws detected up to the test time t , and $m(t)$ refers to the expected value at which flaws can occur. Therefore, the NHPP model is as follows.

$$P\{N(t) = n\} = \frac{[m(t)]^n \cdot e^{-m(t)}}{n!} \quad (1)$$

Note. $n = 0, 1, 2, \dots, \infty$.

Thus, the NHPP model contains property about mean value $m(t)$ and intensity pattern $\lambda(t)$ as below.

$$m(t) = \int_0^t \lambda(s) ds \quad (2)$$

$$\frac{dm(t)}{dt} = \lambda(t) \quad (3)$$

b) NHPP Software Reliability model

We will use the NHPP software reliability model with software failure time based on the NHPP model to analyze the attributes of software development costs.

The time-domain NHPP model is divided into a finite failure which means that no more failures occur when repairing a failure, and an infinite failure in which failures can continue to occur even when repairing a failure.

In this study, we will analyze based on the finite failure cases.

In the finite failure NHPP model, if $f(t)$ is a probability density function and $F(t)$ is a cumulative distribution function, then the average value function $m(t)$ and the intensity function $\lambda(t)$ are as follows [9].

$$m(t|\theta, b) = \theta F \quad (4)$$

$$\lambda(t|\theta, b) = \theta F(t)' = \theta f(t) \quad (5)$$

Therefore, the likelihood function is as follows [9].

$$L_{NHPP}(\theta|\underline{x}) = \left(\prod_{i=1}^n \lambda(x_i) \right) \exp[-m(x_n)] \quad (6)$$

Note. $\underline{x} = (x_1, x_2, x_3 \dots x_n)$.

B. Exponential-Basic: Finite Failure NHPP Model

Among the models widely applied and utilized in reliability testing, the basic type is the Goel-Okumoto model whose lifetime distribution follows the exponential distribution.

When the Exponential-Basic distribution is applied to the NHPP reliability model as shown in Eq. 4 and Eq. 5, it is as follows [10].

$$m(t|\theta, b) = \theta F(t) = \theta(1 - e^{-bt}) \quad (7)$$

$$\lambda(t|\theta, b) = \theta f(t) = \theta b e^{-bt} \quad (8)$$

Note that $\theta > 0$, $b > 0$.

After substituting Eq. 7 and Eq. 8 into Eq. 6, if taking the logarithm of both sides, then the log-likelihood function can be solved as follows.

$$\ln L_{NHPP}(\theta|\underline{x}) = n \ln \theta + n \ln b - b \sum_{k=1}^n x_k - \theta(1 - e^{-bx_n}) \quad (9)$$

If the partial derivatives of the parameters θ and b are obtained, then parameters $\hat{\theta}_{MLE}$ and $\hat{b}_{MLE}$ can be solved by the binary method as below.

$$\frac{\partial \ln L_{NHPP}(\theta|\underline{x})}{\partial \theta} = \frac{n}{\theta} - 1 + e^{-bx_n} = 0 \quad (10)$$

$$\frac{\partial \ln L_{NHPP}(\theta|\underline{x})}{\partial b} = \frac{n}{b} - \sum_{i=1}^n x_i - \hat{\theta} \hat{b} x_n e^{-\hat{b} x_n} = 0 \quad (11)$$

C. Exponential-exponential lifetime distribution: Finite Failure NHPP Model

Among the software reliability models, a particular type of the Weibull exponential distribution is the exponential-exponential distribution.

When the Exponential-exponential lifetime distribution is applied to the NHPP reliability model as shown in Eq. 4 and Eq. 5, it is as follows.

$$m(t|\theta, a, b) = \theta F(t) = \theta[1 - \exp(-ae^{bt} + a)] \quad (12)$$

$$\lambda(t|\theta, a, b) = \theta f(t) = \theta[ab \exp(bt - ae^{bt} + a)] \quad (13)$$

Therefore, the log-likelihood function is as follows.

$$\ln L_{NHPP}(\theta|x) = -\hat{\theta} [1 - \exp(-a e^{\hat{\theta} x_n} + a)] + \sum_{i=1}^n \ln [\hat{\theta} (a b \exp(b x_i - a e^{\hat{\theta} x_i} + a))] \quad (14)$$

Note that $\theta = \{\theta, a, b\}$ is the parameter space.

If the partial derivatives of the parameters θ and b are obtained, then the parameters $\hat{\theta}_{MLE}$ and $\hat{b}_{MLE}$ can be solved by the binary method as below.

$$\frac{\partial \ln L_{NHPP}(\theta|x)}{\partial \theta} = \frac{n}{\theta} - [1 - \exp(-2 e^{\hat{\theta} x_n} + 2)] = 0 \quad (15)$$

$$\frac{\partial \ln L_{NHPP}(\theta|x)}{\partial b} = \frac{n}{b} + \sum_{i=1}^n x_i - 2 \sum_{i=1}^n x_i e^{b x_i} - 2 \hat{\theta} x_n \exp(b x_n - 2 x_n e^{\hat{\theta} x_n} + 2) = 0 \quad (16)$$

Note that $x = (x_1, x_2, \dots, x_n)$.

D. Inverse-exponential lifetime distribution: Finite Failure NHPP Model

The Inverse-Weibull distribution is widely utilized distribution in the reliability lifetime test. Here, the Inverse-exponential distribution is got when the shape parameter (γ) is 1. Thus, the cumulative distribution function $F(t)$ of the Inverse-Weibull distribution is as follows [11].

$$F(t) = e^{-(bt)^{-\gamma}} \quad (17)$$

Note that γ is a shape parameter.

Where, if the Inverse-exponential lifetime distribution is applied to the NHPP reliability model as shown in Eq. 4 and Eq. 5, it is as follows.

$$m(t|\theta, b) = \theta F(t) = \theta e^{-(bt)^{-\gamma}} \quad (18)$$

$$\lambda(t|\theta, b) = \theta f(t) = \theta b^{-1} t^{-2} e^{-(bt)^{-\gamma}} \quad (19)$$

Therefore, the log-likelihood function is as follows.

$$\ln L_{NHPP}(\theta|x) = n \ln \theta - n \ln b + 2 \sum_{i=1}^n x_i - \sum_{i=1}^n (b x_i)^{-1} - \hat{\theta} e^{-(b x_n)^{-1}} = 0 \quad (20)$$

Note that $x = (x_1 \leq x_2 \leq x_3 \leq \dots \leq x_n)$.

The partial derivatives of the parameter and are as follows.

$$\frac{\partial \ln L_{NHPP}(\theta|x)}{\partial \theta} = \frac{n}{\theta} - e^{-(b x_n)^{-1}} = 0 \quad (21)$$

$$\frac{\partial \ln L_{NHPP}(\theta|x)}{\partial b} = -\frac{n}{b} + \frac{1}{b^2} \sum_{i=1}^n \frac{1}{x_i} - \theta \frac{1}{b^2 x_n} e^{-(b x_n)^{-1}} = 0 \quad (22)$$

Note that $x = (x_1, x_2, \dots, x_n)$.

E. Burr-Hatke-exponential lifetime distribution: Finite Failure NHPP Model

The Burr-Hatke-exponential distribution is widely utilized in the field of software reliability testing because the pattern of the hazard function increases or decreases.

Where, the Burr-Hatke-exponential lifetime distribution is applied to the NHPP reliability model as shown in Eq. 4 and Eq. 5, it is as follows.

$$m(t|\theta, b) = \theta F(t) = \theta \left[1 - \frac{e^{-bt}}{1 + bt} \right] \quad (23)$$

$$\lambda(t|\theta, b) = \theta f(t) = \theta \left[b e^{-bt} \frac{2 + bt}{(1 + bt)^2} \right] \quad (24)$$

Note. $a, b > 0, t \in [0, \infty]$

After substituting Eq. 23 and Eq. 24 into Eq. 6, if taking the logarithm of both sides, then the log-likelihood function can be solved [12]. Therefore, the partial derivatives of the parameter θ and b are as follows.

$$\frac{\partial \ln L_{NHPP}(\theta | \underline{x})}{\partial \theta} = \frac{n}{\theta} - \left(1 - \frac{e^{-bx_n}}{1 + bx_n}\right) = 0 \quad (25)$$

$$\begin{aligned} \frac{\partial \ln L_{NHPP}(\theta | \underline{x})}{\partial b} &= \frac{n}{b} - \sum_{i=1}^n x_i - \sum_{i=1}^n \frac{x_i}{2 + bx_i} \\ -2 \sum_{i=1}^n \frac{x_i}{1 + bx_i} - \hat{\theta} x_n e^{-bx_n} \frac{2 + bx_i}{(1 + bx_i)^2} &= 0 \end{aligned} \quad (26)$$

Note. $\mathbf{x} = (x_1, x_2, x_3 \dots x_n)$.

F. Software Development Cost Model

The software development cost model using the mean function $m(t)$ is as follows [13].

$$\begin{aligned} E_t = E_1 + E_2 + E_3 + E_4 &= E_1 + C_2 \times t + C_3 \times m(t) \\ &+ C_4 \times [m(t + t') - m(t)] \end{aligned} \quad (27)$$

Note that E_t is the total cost of software development.

① E_1 is initial development costs.

② E_2 is the testing cost per unit time.

$$E_2 = C_2 \times t \quad (28)$$

Note that C_2 is the testing cost per unit time.

③ E_3 is the cost of removing one flaw.

$$E_3 = C_3 \times m(t) \quad (29)$$

Note that C_3 refers to the cost of removing one flaw found in the test stage before releasing the software, and $m(t)$ refers to the average value function.

④ E_4 is the cost of removing all remaining flaws in the operating stage.

$$E_4 = C_4 \times [m(t + t') - m(t)] \quad (30)$$

Note that C_4 is the flaw correction cost found in the software operation stage, and t' refers to the time during which the software system can operate normally after the software is released.

III. SOLUTIONS BY THE ANALYSIS ALGORITHM USING SOFTWARE FAILURE TIME DATA

In this study, the proposed algorithm for analyzing and predicting software development costs is as follows.

Development cost analysis algorithm:

Step 1: Verification of software failure data collected during desktop application operation.

Step 2: Calculating the reliability attributes parameters

$(\hat{\theta}_{MLE}, \hat{b}_{MLE})$ for the proposed models.

Step 3: Calculating the software development cost (E_t) using the mean value function.

Step 4: Analyzing the results of changing the cost attributes (C_2, C_3, C_4, t') that make up the software

development cost.

Step 5: Analyzing the future reliability attributes $\hat{R}(t)$ of the proposed models by using the mean value function.

Step 6: Determining the best performance model that meets both development cost and future reliability.

The software failure time data used in this paper is shown in Table 1 [14].

Table 1
Software Failure Time Data

Failure Number	Failure Time (hours)	Failure Time (hours) $\times 10^{-2}$	Failure Number	Failure Time (hours)	Failure Time (hours) $\times 10^{-2}$
1	30.02	0.30	16	151.78	1.51
2	31.46	0.31	17	177.50	1.77
3	53.93	0.53	18	180.29	1.80
4	55.29	0.55	19	182.21	1.82
5	58.72	0.58	20	186.34	1.86
6	71.92	0.71	21	256.81	2.56
7	77.07	0.77	22	273.88	2.73
8	80.90	0.80	23	277.87	2.77
9	101.90	1.01	24	453.93	4.53
10	114.87	1.14	25	535.00	5.35
11	115.34	1.15	26	537.27	5.37
12	121.57	1.21	27	552.90	5.52
13	124.97	1.24	28	673.68	6.73
14	134.07	1.34	29	704.49	7.04
15	136.25	1.36	30	738.68	7.38

A. Step 1: verification of software failure data collected during desktop application operation.

The failure time data used in this paper means random failures caused by software design and analysis errors and insufficient testing during the normal operation of desktop applications. Therefore, in this study, Laplace trend test was applied to determine the availability of the collected failure time data.

Figure 1. Estimation Results of Laplace Trend Test

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As shown in Figure 1, the estimated result of the Laplace trend test existed between 0 and 2 [15]. Therefore, this failure data can be applied because there are no extreme values.

B. Step 2: Calculating the reliability attributes

Parameters $(\hat{\theta}_{MLE}, \hat{b}_{MLE})$ for the proposed models.

Where, θ is the expected value of software flaw that can be found at the observing time (0, t), b is the shape parameter that means the shape of failure occurring.

The maximum likelihood estimation (MLE) was applied to calculate parameter estimation [16].

And to facilitate parameter estimation, numerical conversion data was used. Table 2 below shows the parameter estimation result of the proposed models.

C. Step 3: Calculating the software development cost (E_t) using the mean value function.

The calculating method of the mean value function that determines the software development cost is shown in Table 3 [17].

Also, the estimated result value of mean value function $m(t)$ is shown in Table 4.

D. Step 4: Analyzing the results of changing the cost attributes (C_2, C_3, C_4, t') that make up the software development cost.

In this study, to test the same development conditions, the software development cost is presented as [Assumption 1] ~ [Assumption 5].

Table 2
Parameter Estimation Result of the Proposed Models

Type	NHPP Model	MLE (Maximum Likelihood Estimation)	
Basic Model	Exponential-Basic	$\hat{\theta} = 33.409$	$\hat{b} = 0.309$
Exponential-type Lifetime Distribution	Burr-Hatke-exponential	$\hat{\theta} = 32.241$	$\hat{\tau} = 0.495$
	Exponential-exponential	$\hat{\theta} = 30.598$	$\hat{b} = 0.792$
	Inverse-exponential	$\hat{\theta} = 31.209$	$\hat{b} = 1.810$

a) [Assumption 1: basic conditions]

$$E_1 = 50\$, C_2 = 5\$, C_3 = 1.5\$, C_4 = 10\$, t' = 50H \quad (31)$$

Figure 2 shows the development cost simulation results using [Assumption 1].

Figure 2. The Development Cost Test Simulated by [Assumption 1]

Table 3
Software Development Cost Model and Mean Value Function

Type	NHPP Model	$m(t)$ of Exponential-type Lifetime Distribution	$m(t)$ of Software Development Cost Model
Basic Model	Exponential-Basic	$m(t) = \theta(1 - e^{-bt})$	$E_3 = C_3 \times m(t)$ $E_4 = C_4 \times [m(t + t') - m(t)]$
Exponential-type Lifetime Distribution	Burr-Hatke-exponential	$m(t) = \theta \left[1 - \frac{e^{-bt}}{1 + bt} \right]$	
	Exponential-exponential	$m(t) = \theta[1 - \exp(-ae^{bt} + a)]$	
	Inverse-exponential	$m(t) = \theta e^{-(bt)^{-1}}$	

Analyzing the simulation results in Figure 2, it can be seen that the shape of the development cost test curve gradually increases with time passing.

The reason is that the probability of finding the remaining flaws at the latter stage gradually decreases. In the end, it means that the development cost increases even more towards the latter stage [18].

As shown in Figure 2, the exponential-exponential model showed the best performance among the proposed models because of the lowest development cost and relatively fast release time.

Table 4
The Estimated Result Value of Mean Value Function m(t)

Failure Number	Release Time (hours)	Basic-type	Exponential-type Lifetime Distribution		
		Exponential - Basic	Burr-Hatke-exponential	Exponential-exponential	Inverse-exponential
1	0.3	3.90049458	4.687852552	3.357564084	4.269634291
2	0.6	7.276973275	8.480708436	6.510429638	11.39123187
3	0.9	10.19983553	11.58288572	9.450681527	15.79903994
4	1.2	12.7300229	14.143576	12.17267886	18.60632915
5	1.5	14.9202897	16.27401069	14.67320264	20.52478898
6	1.8	16.81630289	18.05861218	16.95154958	21.91243808
7	2.1	18.45759427	19.56245098	19.00956428	22.96069281
8	2.4	19.8783847	20.83636018	20.85160454	23.7796634
9	2.7	21.10829761	21.92052154	22.48443647	24.43678325
10	3.0	22.17297663	22.84702984	23.91705961	24.97552946
11	3.3	23.09462027	23.64175858	25.16046528	25.42514458
12	3.6	23.89244476	24.32573886	26.22733542	25.80600067
13	3.9	24.58308471	24.9161926	27.13169215	26.13271611
14	4.2	25.18093995	25.42731684	27.888512	26.41604814
15	4.5	25.69847572	25.87088576	28.51332087	26.6640862
16	4.8	26.14648262	26.25671765	29.02178767	26.88902926
17	5.1	26.53430158	26.59304073	29.42933481	27.0777068
18	5.4	26.87001861	26.88678205	29.75078318	27.25193671
19	5.7	27.1606334	27.14379754	30.00004685	27.40877669
20	6.0	27.41220525	27.36905663	30.18988965	27.55070428
21	6.3	27.62997943	27.56679132	30.33175132	27.67974812
22	6.6	27.81849651	27.7406173	30.4356462	27.79758513
23	6.9	27.98168708	27.89363302	30.51013246	27.9056135
24	7.2	28.12295365	28.02850109	30.56234527	28.00500828
25	7.5	28.24524161	28.1475155	30.59808338	28.09676412
26	7.8	28.35110068	28.25265741	30.62193636	28.18172863
27	8.1	28.442738	28.34564169	30.63743801	28.26062854
28	8.4	28.52206421	28.42795579	30.64723223	28.33409052
29	8.7	28.59073327	28.50089244	30.65323858	28.40265781
30	9.0	28.65017691	28.56557723	30.65680766	28.46680364

b) [Assumption 2: Supposed that the cost is twice increased in Assumption 1]

$$E_1 = 50\$, C_2 = 10\$, C_3 = 1.5\$, C_4 = 10\$, t' = 50H \quad (32)$$

[Assumption 2] is a case where the software testing cost (is twice increased in [Assumption 1].

The simulation results shown in Figure 3 show that development costs have increased but release time has not changed at all.

Figure 3 The Development Cost Test Simulated by [Assumption 2]

c) [Assumption 3: Supposed that the cost C_3 is twice increased in Assumption 1]

$$E_1 = 50\$, C_2 = 5\$, C_3 = 3\$, C_4 = 10\$, t' = 50H \quad (32)$$

[Assumption 3] is a case where the software cost (C_3) is twice increased in [Assumption 1].

Figure 4. The Development Cost Test Simulated by [Assumption 3]

Figure 4 shows that development costs have increased, but release times have not changed at all. Therefore, to remove the cause of the development cost increase, it is necessary to eliminate as many flaws as possible at once.

d) [Assumption 4: Supposed that the cost is twice increased in Assumption 1]

$$E_1 = 50\$, C_2 = 5\$, C_3 = 1.5\$, C_4 = 20\$, t' = 50H \quad (34)$$

[Assumption 4] is a case where the software cost (is twice increased in [Assumption 1].

As shown in Figure 5, it can be seen that both the development cost and the release time increased together.

Therefore, in this case, all possible defects should be eliminated during the testing process rather than the operating phase to remove all flaws before the software is released [19].

Figure 5. The Development Cost Test Simulated by [Assumption 4]

Also, the Exponential-exponential model showed the best performance because the development cost was low and the time was relatively fast.

e) [Assumption 5: Supposed that the time t' is twice increased in Assumption 1]

$$E_1 = 50\$, C_2 = 5\$, C_3 = 1.5\$, C_4 = 10\$, t' = 100H \quad (35)$$

[Assumption 5] is a case where the time (t') that the software system solution can be operated normally after releasing the software is twice increased in [Assumption 1].

As shown in Figure 6, it can be seen that the simulation result of assumption 5 is the same as the result of assumption 1 (basic condition).

That is, as the time of t' increases, the cost increases, but the cost is almost the same after the optimal release time.

Figure 6. The Development Cost Test Simulated by [Assumption 5]

E. Step 5: Analyzing the future reliability attributes of the proposed models by using the mean value function.

In this paper, to verify the property of the software development cost model, future reliability analysis was also performed using the average value function of the proposed distribution models.

Table 5 shows how to calculate future reliability using the mean value function.

Table 5
Future Reliability Calculation Using Mean Value Function

NHPP Model	$\hat{R}(t)$ using the mean value function $m(t)$
Exponential-Basic	$\exp[-\{m(t + \tau) - (t)\}]$ $= \exp[-\{m(x_n + \tau) - (x_n)\}]$
Exponential-exponential	
Inverse-exponential	
Burr-Hatke-exponential	

The calculating method of the mean value function that determines the future reliability of software development cost is shown in Table 5.

Where, the future reliability $\hat{R}(t)$ is the probability that a software error will occur and no software error will occur between the confidence intervals when testing at $t = x_n = 738.68 \times 10^{-2} = 7.38$ (where τ is the future mission time) [20].

$$\begin{aligned}
 \hat{R}(\tau|x_n) &= e^{-\int_{x_n}^{x_n+\tau} \lambda(\tau) d\tau} \\
 &= \exp[-\{m(x_n + \tau) - (x_n)\}] \\
 &= \exp[-\{m(7.3868 + \tau) - m(7.3868)\}] \quad (36)
 \end{aligned}$$

Here, the larger the reliability value, the better the reliability performance.

As shown in Fig 7, the Exponential-exponential distribution model showed higher predictive ability than the other models whose future reliability decreased with mission time passing.

That is, in terms of reliability, the Exponential-exponential distribution model is further reliable than the other models because of the highest reliability.

Figure 7. The Future Reliability Prediction

F. Step 6: Determining the best performance model that meets both software development cost and future reliability.

The Exponential-exponential distribution model showed the best performance because it had lower development costs and reliable reliability than other distribution models (Burr-Hatke-exponential, Exponential-Basic, Inverse-exponential).

In conclusion, if using this data, we can analyze the software development cost trends, and software operators are considered to be helpful to predict the economic development costs

IV. CONCLUSIONS

If the software development cost can be quantitatively modeled during the software testing process, it is possible to efficiently analyze and predict the attributes of the development cost. Therefore, in this study, development cost was analyzed and predicted based on the Exponential-type distribution using the software development cost model.

The results of this study are as follows.

First (in Assumption 1), the software development cost test pattern initially decreased and then showed a constant shape for a short time, but showed a shape that increased again in the latter. The reason is that in the process of removing the flaws, the number of remaining flaws gradually decreases so that the probability of finding the residual defects decreases. Therefore, the cost eventually increases.

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Second, when the cost of removing a single flaw found during the test process increases, the development cost increases but the release time does not change at all. However, when the cost of correcting the flaws found by the operator increases, both the development cost and the release time increase together.

Third, in terms of future reliability, the Exponential-exponential distribution model is further reliable than the other models because of the highest reliability.

Fourth, the Exponential-exponential distribution model showed the best performance among the proposed models because it had the lowest software development cost and relatively fast release time.

In conclusion, as a result of comprehensively analyzing these simulation results, the Exponential-exponential model showed the best performance among the proposed Exponential-type distributions.

In addition, after applying the software failure time data applied in this study to various distribution models, future research topics to find the optimal development cost model will be needed.

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