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A COMPARATIVE ANALYSIS ON THE PERFORMANCE ATTRIBUTES OF SOFTWARE DEVELOPMENT COST MODEL BASED ON WEIBULL LIFETIME DISTRIBUTION

TAI HEOUN PARK
Professor, College of General Education, Namseoul University, 91 Daehak-ro, Seonghwan-eup,
Seobuk-gu, Cheonan-si, Chungnam, Korea, 31020
E-mail: thpark@nsu.ac.kr

ABSTRACT

In this paper, we analyzed the efficiency and cost attributes of the software development cost model applying the Weibull lifetime distribution, which is known to be suitable for the field of reliability because it can express all kinds of various probability distributions. For this study, failure time data detected during normal operation of the software system were utilized, the maximum likelihood estimation was used for the parameter estimation. Conclusively, first, in the result of comparing reference values (MSE, R^2) for efficient model selection as well as reliability attributes analysis using m(t), the Rayleigh and Inverse-exponential models were evaluated as efficient. Second, as a result of analyzing the attributes of development cost, the Rayleigh model showed the best performance. Therefore, as a result of the comprehensive evaluation of the relevant analysis data, the Rayleigh cost model was found to be the best in terms of performance attributes. Through this study, the performance properties of the software development cost model applying the Weibull lifetime distribution were newly analyzed, and the results related to this are expected to be used as primary design data for developers to explore the cost properties in the initial testing process.

Keywords: *Exponential-basic, Inverse-exponential, NHPP, Performance Attributes, Rayleigh, Software Development Cost Model.*

1. INTRODUCTION

When compared with the 3rd industrial era, which brought the development of IT technology through the method of information sharing by internet technology, in the 4th industrial era like the present, due to the rapid increase in system solutions equipped with intelligent software, the size of software systems capable of processing large amounts of data is continuously expanding. Thus, the need for the development of reliable software capable of accurately processing big data without flaws is increasing. Therefore, the most important topic in the process of developing reliable software is probably the issue of cost [1]. So far, many studies have been presented on the cost model using the Non-homogeneous Poisson process (NHPP), in which a method suitable for reliability analysis using the occurring number of failures is applied as a reliability attributes data [2]. Thus, Xiao and Dohi [3] demonstrated the effectiveness of the proposed models using a goodness-of-fit test and predictive analysis on the reliability of the Weibull-type distribution. Tokuno and Fukuda, Yamada [4] explained a new reliability evaluation method considering real-time attributes analysis utilizing the properties relationship between system reliability and software performance. Kim [5] presented a control mechanism for NHPP software reliability with the time between failure observations using a statistical analysis method including process measurement and control improvement. Also, Kim [6] analyzed the cost model with the Burr-Hatke exponential-type distribution and suggested methods that can help software providers understand the properties of software development costs. Yang [7] newly presented the characteristics of cost based on a software development model with a Lindley-type distribution and analyzed cost attributes so that developers could understand economic costs. Also, Yang [8] evaluated the cost property of the NHPP exponential-type distribution model.

In this study, the Weibull lifetime distribution, which is known to be suitable for reliability analysis because it can represent all types of probability distributions, was applied to the NHPP software development cost model, and then the efficiency and cost performance was analyzed. Also, we intend to present research data on the optimal model to software developers.

2. RELATED RESEARCH

2.1 NHPP software reliability model

2.1.1 NHPP model

A software reliability model in which software failures depend on the NHPP is classified as a model having a time domain. In this stochastic process, the parameter λ(t) represents the intensity function related to the software execution time. If N(t) represents the cumulative number of failures at an arbitrary observation time t, then m(t) represents the mean value function, which is an expected failure occurrence value. Therefore, N(t) is known as a Poisson probability density function with m(t) as a parameter as shown in Equation (1). Therefore, the NHPP model is as follows.

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

Note that $n = 0,1,2,\cdots\infty$.

The m(t) applied to the NHPP model as in Equation (1) is as follows.

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

Therefore, the $\lambda(t)$ can be derived as follows.

$$\frac{dm(t)}{d(t)}=\lambda(t) \qquad (3)$$

2.1.2 NHPP software reliability model

The NHPP models assume that the expected value of a defect has a finite value given sufficient test time. When given sufficient testing time in the NHPP model, if the residual failure remaining in the system is θ, then m(t) and λ(t) can be respectively written as the following function expressions [9].

Therefore, if F(t) is a cumulative distribution function, the m(t) and λ(t) an be defined as Equation (4).

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

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

Note that θ is the residual failure.

If applying Equations (4) and (5), the likelihood function of the NHPP model is defined as follows.

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

2.2 NHPP Goel-Okumoto basic Model

The Goel-Okumoto model is well known as the basic type in software reliability. In particular, in the Goel-Okumoto basic model, the lifetime distribution following the distribution of failure occurrence time per software defect assumes an exponential distribution. Therefore, the attributes functions of the reliability performance are as follows [10].

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

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

If applying the values of m(t) and λ(t) to Equation (6) and rearranging it, the following log-equation can be written.

$$lnL_{NHPP}(\Theta|\underline{x})=nln\theta+nlnb-b\sum_{k=1}^{n}x_k-\theta(1-e^{-bx_n}) \qquad (9)$$

Thus, the parameter estimators $\hat{\theta}_{MLE}$ and $\hat{b}_{MLE}$ of this model can be estimated in the following way after partial differentiation of Equation (9) with the parameters θ and b, respectively.

$$\frac{\partial lnL_{NHPP}(\Theta|\underline{x})}{\partial\theta}=\frac{n}{\hat{\theta}}-1+e^{-\hat{b}x_n}=0 \qquad (10)$$

$$\frac{\partial lnL_{NHPP}(\Theta|\underline{x})}{\partial b}=\frac{n}{\hat{b}}-\sum_{i=1}^{n}x_n-\hat{\theta}x_n e^{-\hat{b}x_n}=0 \qquad (11)$$

2.3 NHPP Inverse-exponential Distribution Model

The Weibull distribution is a distribution designed to represent all kinds of probability distributions by generalizing the exponential distribution and is a life distribution frequently applied in reliability. Thus, since the Inverse-Weibull distribution has an exponential lifetime distribution, it is widely used for reliability applications and reliability analysis in medical-related fields.

$$F(\mathrm{t}) = e^{-(bt)^{-\gamma}} \tag{12}$$

Note that γ is a shape parameter.

Therefore, since the Inverse-exponential distribution to be proposed in this work is established when the shape parameter (γ) is 1 in Equation (12), the F(t) can be rearranged as in Equation (13).

$$\mathrm{F(t)} = e^{-(bt)^{-1}} \tag{13}$$

$$\mathrm{f(t)} = F(t)' = b^{-1}t^{-2}e^{-(bt)^{-1}} \tag{14}$$

Therefore, the performance attributes function of this model is as follows [11].

$$\mathrm{m(t)} = \theta e^{-(bt)^{-1}} \tag{15}$$

$$\lambda(\mathrm{t}) = \theta b^{-1}t^{-2}e^{-(bt)^{-1}} \tag{16}$$

Therefore, if applying the values of m(t) and λ(t) to Equation (6) and rearranging it, the following log-equation can be written.

$$\ln L_{NHPP}(\Theta|\underline{x}) = nln\theta - nlnb + 2\sum_{i=1}^{n} x_i$$
$$-\sum_{i=1}^{n}(bx_i)^{-1} - \hat{\theta}e^{-(bx_n)^{-1}} = 0 \tag{17}$$

Thus, the parameter estimators $\hat{\theta}_{MLE}$ and $\hat{b}_{MLE}$ of this model can be calculated in the following way after partial differentiation of Equation (17) with the parameters θ and b, respectively.

$$\frac{\partial \ln L_{NHPP}(\Theta|\underline{x})}{\partial\theta} = \frac{n}{\hat{\theta}} - e^{-(\hat{b}x_n)^{-1}} = 0 \tag{18}$$

$$\frac{\partial \ln L_{NHPP}(\Theta|\underline{x})}{\partial b} = -\frac{n}{\hat{b}} + \frac{1}{\widehat{b^2}}\sum_{i=1}^{n}\frac{1}{x_i}$$
$$-\theta\frac{1}{b^2x_n}e^{-(\hat{b}x_n)^{-1}} = 0 \tag{19}$$

2.4 NHPP Rayleigh Distribution Model

The Weibull distribution is a distribution designed to represent all the various types of probability distributions by making the exponential distribution more general. In particular, the Rayleigh distribution belonging to the Weibull distribution is well known as a lifetime distribution that is frequently used in reliability testing and reliability measurement fields.

$$F(\mathrm{t}) = \left(1 - e^{-\frac{t^\alpha}{2\beta^2}}\right) \tag{20}$$

If $\frac{1}{2\beta^2}$= b in Equation (20), it can be simplified as follows.

$$F(\mathrm{t}) = \left(1 - e^{-bt^\alpha}\right) \tag{21}$$

$$\mathrm{f(t)} = 2\mathrm{b}t^{\alpha-1}e^{-bt^\alpha} \tag{22}$$

Therefore, since the Rayleigh distribution to be proposed in this work is established when the shape parameter (α) is 2 in Equations (21) and (22), the attributes functions of the reliability performance are as follows [12].

$$m(t|\theta,b) = \theta\left(1 - e^{-bt^\alpha}\right) = \theta\left(1 - e^{-bt^2}\right) \tag{23}$$

$$\lambda(t|\theta,b) = \theta\left(2bt^{\alpha-1}e^{-bt^2}\right) \tag{24}$$

Note that $\theta > 0$, $b = \frac{1}{2\beta^2} > 0$, $t \in [0, \infty]$

Therefore, if applying the values of m(t) and λ(t) to Equation (6) and rearranging it, the following log-equation can be written.

$$\ln L_{NHPP}(\Theta|\underline{x}) = nln2 + nln\theta + nlnb + \sum_{i=1}^{n} lnx_i$$
$$-b\sum_{i=1}^{n} {x_i}^2 - \theta\left(1 - e^{-bx_n^2}\right) \tag{25}$$

Therefore, the parameter estimators $\hat{\theta}_{MLE}$ and $\hat{b}_{MLE}$ of this model can be calculated in the following way after partial differentiation of Equation (25) with the parameters θ and b, respectively.

$$\frac{\partial lnL_{NHPP}(\Theta|\underline{x})}{\partial\theta} = \frac{n}{\hat{\theta}} - 1 + exp\left(-\hat{b}x_n^2\right) = 0 \tag{26}$$

$$\frac{\partial lnL_{NHPP}(\Theta|\underline{x})}{\partial b} = \frac{n}{\hat{b}} - \sum_{i=1}^{n} x_i^2 - \hat{\theta}x_n^2\, exp\left(-\hat{b}x_n^2\right) = 0 \tag{27}$$

2.5 Software Development Cost Model Applying m(t) of the NHPP Reliability Model

When the $m(t)$ representing the performance attributes of the NHPP model proposed in this work is applied to Equation (28), it is said that the total software development cost (E_t) is calculated as the sum of each cost element ($E_1 \sim E_4$) [13].

$$E_t = E_1 + E_2 + E_3 + E_4 = E_1 + C_2 \times t + C_3 \times m(t) + C_4 \times [m(t+t') - m(t)] \quad (28)$$

Note that E_t is the estimated total cost of software development.

① E_1 is the initial development cost.

② E_2 is the testing cost per unit time.

$$E_2 = C_2 \times t \quad (29)$$

Note that C_2 is the cost per unit time.

③ E_3 represents the cost of detecting an inherent defect and removing one defect and is expressed by the following relationship.

$$E_3 = C_3 \times m(t) \quad (30)$$

Note that C_3 is the cost of eliminating one error found in the development test phase, and m(t) represents the reliability performance attributes of the NHPP model applied as an error occurrence expectation value.

④ E_4 means the cost (constant) of removing all remaining defects in the operation process.

$$E_4 = C_4 \times [m(t+t') - m(t)] \quad (31)$$

Note that C_4 is the cost of repairing flaws detected by the user during normal operation, and t' is the time that the system can be maintained with the released software after the developed software is released.

Also, software developers will want to release developed software at the point in time when the total software development cost is minimized. Therefore, the optimal release time should be equal to the point at which the total development cost (E_t) is minimized as follow.

$$\frac{\partial \mathrm{E_t}}{\partial t} = \mathrm{E}' = (\mathrm{E_1} + E_2 + E_3 + E_4)' = 0 \quad (32)$$

3. PERFORMANCE ATTRIBUTES ANALYSIS OF SOFTWARE DEVELOPMENT COST MODEL

In this work, the performance attributes of the proposed Weibull distribution (Goel-Okumoto basic, Inverse-exponential, Rayleigh) model were analyzed in the following order (from 3.1 to 3.5).

3.1. Laplace Trend Analysis to Verify Applicability of Software Failure Time Data

The failure time data shown in Table 1 [14] was used to compare and analyze the performance attributes of the proposed model which can predict future failures based on the number of failures.

Table 1 is the data collected for failure times that occurred randomly while the software operating system was operating normally, and it means that software failures occurred 30 times during a total of 187.35 testing hours.

The cited software failure time data was verified using Laplace trend analysis to determine whether it was applicable to this study.

If the data of the Laplace trend analysis is distributed between '-2 and 2', it is said to be reliable because the distribution of the cited data is stable [15].

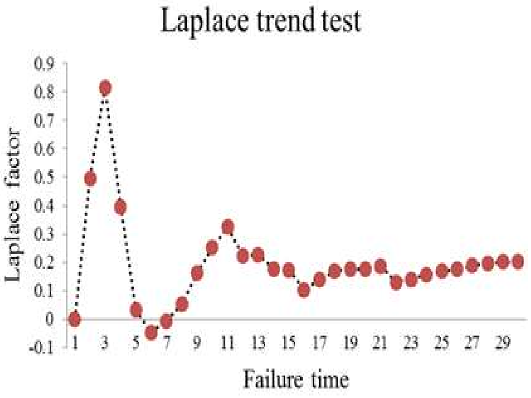

Figure 1: Analysis Results of Laplace Trend Test.

As shown in Figure 1, the estimated result value was distributed between 0 and 2. Therefore, it can be concluded that failure data such as Table-1 can be used in this work.

3.2 Calculate of Attributes Parameters ($\hat{\theta}, \hat{b}$) for the Proposed Model

In this work, parameter estimation applying maximum likelihood estimation (MLE) was performed, and the original failure time data was converted numerically (failure time × 10^{-1}) as shown in Table 1 to facilitate parameter calculation. Therefore, the bisection method, a numerical analysis method, was applied for the calculation of nonlinear equations, and parameter estimation was performed using C-language for these calculations.

The attribute variable $\hat{\theta}$ calculated in Table 2 is the residual failure, which is the expected value of software defects that can be found at the observation time (0, t), and $\hat{b}$ is the shape parameter [16].

Table 1: Software Failure Time Data

Failure number	Failure time (hours)	Failure time (hours)$\times 10^{-1}$
1	4.79	0.479
2	7.45	0.745
3	10.22	1.022
4	15.76	1.576
5	26.10	2.610
6	35.59	3.559
7	42.52	4.252
8	48.49	4.849
9	49.66	4.966
10	51.36	5.136
11	52.53	5.253
12	65.27	6.527
13	69.96	6.996
14	81.70	8.170
15	88.63	8.863
16	107.71	10.771
17	109.06	10.906
18	111.83	11.183
19	117.79	11.779
20	125.36	12.536
21	129.73	12.973
22	152.03	15.203
23	156.40	15.640
24	159.80	15.980
25	163.85	16.385
26	169.60	16.960
27	172.37	17.237
28	176.00	17.600
29	181.22	18.122
30	187.35	18.735

Table 2: Parameter Calculation Results using MLE

Type	NHPP model	MLE	
		$\hat{\theta}$	$\hat{b}$
Basic	Goel-Okumoto	32.9261	0.1297
Weibull Distribution	Inverse-exponential	41.2881	0.1692
	Rayleigh	30.0412	0.0188

3.3. Performance Attributes Analysis Applying Mean Value Function (m(t))

Table 3 shows the method of calculating the m(t) of the proposed NHPP model and the method of calculating the cost of the software development model by applying the m(t) as an equation. Therefore, the m(t) equation of the Weibull distribution model presented in Table 3 will be used as the m(t) function to calculate the cost performance attributes in this study [17].

Figure 2 shows the trend of the data analyzed for the reliability performance attribute using m(t) as a graph, which indicates the ability to predict the actual value. Also, referring to the data analyzed in Figure 2, the proposed models tended to overestimate the true value, but the Inverse-exponential model with the smallest error value was efficient. That is, the Rayleigh and Inverse-exponential models are suitable as a reliability model because the probability of failure in the future is low.

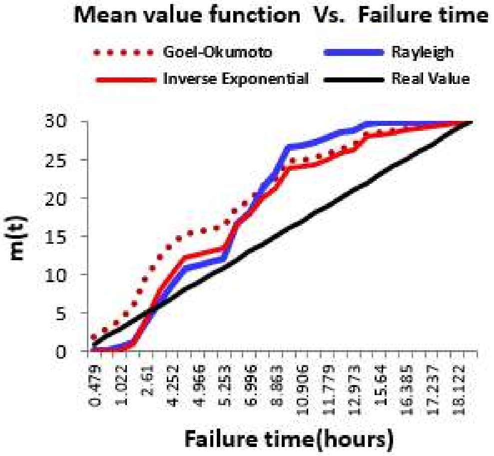

Figure 2: Performance Attributes Analysis using m(t)

Table 3: Software Development Cost Model Applying m(t)

Type	NHPP Model	$m(t)$ of Weibull Distribution	$m(t)$ of Software Development Cost Model
Basic	Goel-Okumoto	$m(t) = \theta(1 - e^{-bt})$	$E_3 = C_3 \times m(t)$ $E_4 = C_4 \times [m(t+t') - m(t)]$
Weibull Distribution	Inverse-Exponential	$m(t) = \theta e^{-(bt)^{-1}}$	
	Rayleigh	$m(t) = \theta\left(1 - e^{-bt^2}\right)$	

3.4. Performance Attributes Analysis for Efficient Model Selection

The smaller the MSE value, which is the criterion for selecting an efficient model, the more efficient it is.

3.4.1 Mean Square Error (MSE)

$$MSE = \frac{\sum_{i=1}^{n}\left(m(x_i) - \hat{m}(x_i)\right)^2}{n-k} \qquad (33)$$

Note that $m(x_i)$ represents the cumulative number of failures up to the observation point $(0, x_i)$.

That is, a model with a small mean square error value becomes an efficient model [18].
Figure 3 shows the performance attributes of MSE according to failure number.

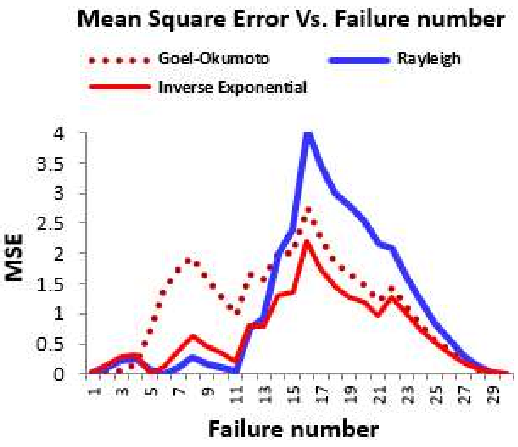

Figure 3. Attributes Analysis using MSE

That is, Figure 3 is the result of confirming the goodness of fit of the model using the reference value (MSE) of the models applied in this study.

Table 4: Detailed Analysis Data of MSE

Failure Number	MSE		
	Goel-Okumoto	Inverse-exponential	Rayleigh
1	0.03453	0.0357	0.0271
2	0.0381	0.1407	0.1018
3	0.0422	0.2948	0.2084
4	0.1556	0.3277	0.2469
5	0.7089	0.0180	0.0689
6	1.3612	0.1216	0.0048
7	1.7289	0.3852	0.0980
8	1.9404	0.6311	0.2668
9	1.5723	0.4524	0.1644
10	1.2910	0.3352	0.1088
11	0.9908	0.2062	0.0479
12	1.6536	0.7871	0.7410
13	1.5736	0.8022	0.9184
14	2.0168	1.2981	1.9962
15	2.0066	1.3704	2.3901
16	2.7545	2.2019	4.0499
17	2.2422	1.7572	3.4514
18	1.8545	1.4351	3.0093
19	1.6416	1.2851	2.7837
20	1.4851	1.1881	2.5657
21	1.2037	0.9583	2.1571
22	1.4368	1.2812	2.0910
23	1.1181	1.0013	1.6218
24	0.8167	0.7308	1.1990
25	0.5698	0.5118	0.8394
26	0.3835	0.3520	0.5450
27	0.2067	0.1895	0.3063
28	0.0877	0.0816	0.1361
29	0.0221	0.0228	0.0342
30	0.0001	0.0005	0.0000

Table 4 shows detailed analysis data of MSE, which is widely known as a reference value for selecting an efficient model in terms of reliability performance.

3.4.2. Coefficient of Determination (R^2)

When a model is least squares estimated in data analysis, the R^2 is a numerical value indicating how well the estimated model can explain the object of observation.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} \left(\mathrm{m}(x_i) - \hat{\mathrm{m}}(x_i)\right)^2}{\sum_{i=1}^{n} \left(\mathrm{m}(x_i) - \sum_{j=1}^{n} m(x_j)/n\right)^2} \quad (34)$$

Note that $\mathrm{m}(x_i)$ represents the cumulative number of failures up to the observation point $(0, x_i)$.

When comparing the efficiency of the model, the larger the value of the coefficient of determination, the smaller the error, and it is considered an efficient model [19].

Table 5 shows the results of calculating MSE and R, which are widely known as reference values for selecting an efficient model.

Table 5: Reference Values for Efficient Model Selection

Type	NHPP model	Model efficiency	
		MSE	R^2
Basic	Goel-Okumoto	32.9379	0.8956
Weibull Distribution	Inverse-exponential	20.2035	0.9359
	Rayleigh	32.1798	0.8980

3.5. Cost Attributes Analysis Applying Mean Value Function (m(t))

In this work, the cost conditions of the total software development cost model such as Equation (28) were set as [Supposition 1 to 3] in order to simulate in an environment similar to actual development conditions [20].

3.5.1 Supposition 1: Basic conditions.

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

Figure 4 shows the results of analyzing the development cost and release time by substituting the calculated value of the m(t) presented in Table 3 into Equation (28).

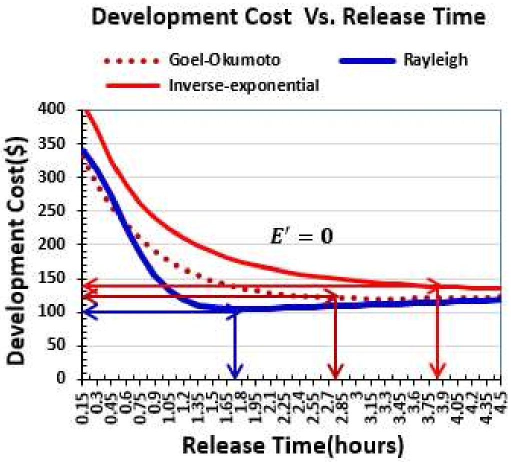

Figure 4. Cost Analysis Applying [Supposition 1]

Analyzing Figure 3, the trend of the cost curve showed a pattern of rapidly decreasing at the beginning and gradually increasing with time. This is because there is a high probability that defects that may occur in the early stage can be detected and removed, so the number of inherent defects is gradually reduced and the cost is drastically reduced. However, the probability that a defect can be detected and removed in the later stages becomes less and less, so the cost increases as time goes on.

Thus, development costs increase proportionately over time. After all, the pattern of the development cost curve has the attributes of increasing as the release time passes.

3.5.2 Supposition 2: Assume that only the cost C_3 has doubled compared to Supposition 1.

$$E_1 = 50\$,\ C_2 = 5\$,\ C_3 = 3\$,\ C_4 = 10\$\ ,\ t' = 50\mathrm{H} \quad (36)$$

The condition of [Supposition 2] is a situation in which all conditions are the same compared to the condition of [Supposition 1], but only the cost (C_3) of removing one error found in the development test stage is doubled (1.5$ → 3$).

Figure 5 shows the trend curve for analyzing the development cost property under the condition of Supposition 2.

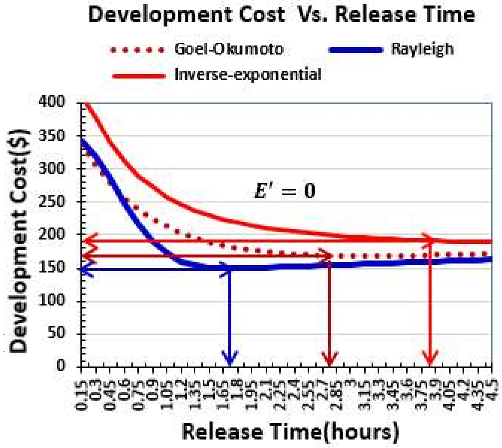

Figure 5: Cost Analysis Applying [Supposition 2]

In the same way, Figure 5 shows the results of analyzing the development cost and release time by substituting the calculated value of the m(t) presented in Table 3 into Equation (28). As shown in Figure 5, the analysis results of the simulation showed that the release time was 1.725H when the cost of the Rayleigh model was $150, and the release time was 2.775H when the cost of the Goel-Okumoto basic model was $170, and the release time was 3.825H when the cost of the Inverse-exponential model was $190. Therefore, it can be seen that the Rayleigh cost model shows the best performance.

3.5.3 Supposition 3: Assume that only the cost C_4 has doubled compared to Supposition 1.

$$E_1 = 50\$,\ C_2 = 5\$,\ C_3 = 1.5\$,\ C_4 = 20\$\ ,\ t' = 50\text{H} \quad (37)$$

The conditions of [Supposition 3] are all the same compared to the conditions of [Supposition 1], but only the cost (C_4) of repairing failures found by users in the actual operation stage after the release of the software is doubled ($10 → 20$).

Figure 6 shows the results of analyzing the performance attributes of the software development cost model under [Supposition 3] conditions after substituting the value of m(t) as described in the previous section. When evaluating the simulation results as shown in Figure 6, the Rayleigh model is the best in this study.

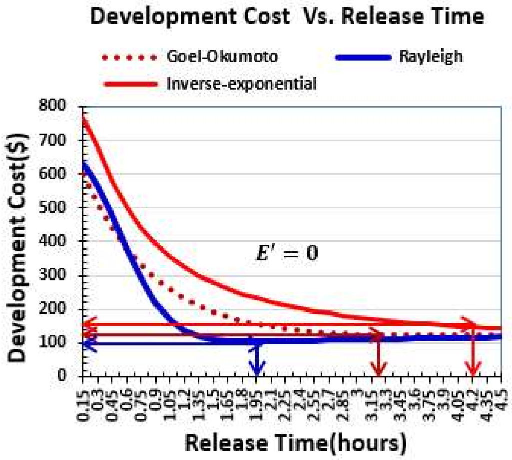

Figure 6: Cost Analysis Applying [Supposition 3]

Therefore, unlike Supposition 2 and 3, the situation of Supposition 3 showed a pattern trend in which the release time was delayed along with the increase in development cost. Thus, in this case, all possible defects should be eliminated in the testing process rather than in the operational process, so that defects can be reduced before the software is released.

3.6 Performance Evaluation on the Attributes of the Proposed Software Development Cost Model.

Table 6 shows the evaluation results of the performance attributes applying the proposed cost model. As shown in Table 6, the Rayleigh cost model was the best among the proposed Weibull lifetime distribution.

Table 6: Performance Attributes Evaluation.

NHPP model	Performance Attributes			
	m(t)	MSE, R^2	Cost	Release Time
Goel-Okumoto	Good	Good	Good	Good
Inverse-exponential	Best	Best	Worst	Worst
Rayleigh	Best	Good	Best	Best

Table 7 shows data analyzed in detail on the development cost attributes of the proposed models with [Supposition 1 to 3] presented in this study.

Table 7: Detailed Analysis Results of Software Development Cost

Failure Number	Release Time	[Supposition 1]			[Supposition 2]			[Supposition 3]		
		Development Cost			Development Cost			Development Cost		
		GO	IE	R	GO	IE	R	GO	IE	R
1	0.15	330.04	410.91	340.57	338.77	412.11	342.44	600.59	769.86	628.51
2	0.3	290.07	369.67	312.09	305.99	378.31	319.12	512.71	679.20	565.67
3	0.45	257.29	325.11	271.69	279.13	341.77	285.98	440.50	581.32	476.84
4	0.6	230.45	289.31	227.68	257.16	312.44	249.87	381.19	502.50	380.17
5	0.75	208.49	261.65	187.33	239.20	289.81	216.77	332.51	441.39	291.46
6	0.9	190.54	240.13	155.09	224.56	272.24	190.36	292.56	393.64	220.43
7	1.05	175.89	223.10	132.32	212.64	258.38	171.74	259.81	355.68	169.98
8	1.2	163.99	209.41	118.01	202.96	247.25	160.08	232.99	324.97	137.96
9	1.35	154.31	198.22	110.06	195.12	238.19	153.67	211.05	299.71	119.76
10	1.5	146.47	188.96	106.25	188.80	230.72	150.66	193.12	278.65	110.59
11	1.65	140.16	181.20	104.83	183.74	224.48	149.62	178.49	260.86	106.61
12	1.8	135.09	174.64	104.63	179.70	219.24	149.59	166.59	245.68	105.31
13	1.95	131.06	169.04	105.01	176.51	214.78	150.04	156.92	232.60	105.24
14	2.1	127.87	164.24	105.62	174.02	210.93	150.68	149.10	221.24	105.70
15	2.25	125.38	160.10	106.33	172.11	207.72	151.39	142.80	211.32	106.35
16	2.4	123.47	156.50	107.07	170.66	204.91	152.13	137.74	202.58	107.07
17	2.55	122.03	153.36	107.81	169.61	202.48	152.87	133.72	194.86	107.81
18	2.7	120.97	150.63	108.56	168.87	200.38	153.62	130.54	187.99	108.56
19	2.85	120.24	148.23	109.31	168.40	198.56	154.37	128.06	181.87	109.31
20	3	119.76	146.12	110.06	168.15	196.98	155.12	126.15	176.38	110.06
21	3.15	119.51	144.27	110.81	168.07	195.61	155.87	124.71	171.45	110.81
22	3.3	119.44	142.64	111.56	168.14	194.42	156.62	123.67	167.01	111.56
23	3.45	119.51	141.21	112.31	168.33	193.40	157.37	122.94	163.01	112.31
24	3.6	119.70	139.96	113.06	168.63	192.52	158.12	122.47	159.37	113.06
25	3.75	119.99	138.86	113.81	168.99	191.76	158.87	122.22	156.07	113.81
26	3.9	120.37	137.90	114.56	169.44	191.13	159.62	122.15	153.08	114.56
27	4.05	120.81	137.07	115.31	169.94	190.59	160.37	122.23	150.36	115.31
28	4.2	121.30	136.35	116.06	170.48	190.15	161.12	122.43	147.89	116.06
29	4.35	121.85	135.72	116.81	171.06	189.79	161.87	122.73	145.63	116.81
30	4.5	122.43	135.19	117.56	171.67	189.50	162.62	123.11	143.58	117.56

※ Notes> GO: Goel-Okumoto basic, IE: Inverse-exponential, R: Rayleigh.

4. CONCLUSION

If the data collected on the failure time of the software system from the initial process of software development can be used for the analysis of the development cost model, the performance attributes of the cost model used can be explored and analyzed more efficiently. Therefore, in this work, the performance attributes of the NHPP software development cost model with Weibull lifetime distribution characteristics were newly analyzed and related data were evaluated in detail.

The results of this study are as follows.
First, in the evaluation of the predictive power of the real value using the m(t), the proposed models showed a tendency to overestimate the true value. Also, in the performance attributes analysis for efficient model selection using MSE and R^2, the Rayleigh and Inverse-exponential models were evaluated as efficient.

Second, as a result of analyzing the cost and release time attributes under all assumptions [Supposition 1 to 3], the Rayleigh model showed the best performance.

Third, as a result of comprehensively evaluating the performance attributes data analyzed in this study, the Rayleigh cost model was found to be the best.

In conclusion, design data that can predict the release time along with an analysis of development cost and performance attributes can be presented to developers in the initial software development process. Also, it will be necessary to find an optimized development cost model suitable for the applied industry and follow-up studies to explore cost-related performance attributes data.

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