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Life Cycle Costing: Maintenance and Repair Costs of Hospital Facilities Using Monte Carlo Simulation

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Abstract

During the administration of a construction project, various types of participants are engaged in the project. From the design phase to the maintenance phase, these participants may confront many risks. To avoid these risks, participants should utilize an insurance company or a bond company. The types of risks and liability that a construction manager may face are listed in the construction law or contract. But there are some arguments related to risk transferring and the content of risks. For this reason, construction managers must carefully consider any possible risks in the contract and the construction law. Therefore, for construction managers to deal with risks appropriately, the introduction of a legal requirement to carry professional liability insurance, a defined compensation range for damages, a method of guarantee in the event of defects, a defined compensation claim period for damage, and a method of damage claim were suggested in this study.

Keywords : construction manager, negligence, insurance, risk

1. LCCA for facilities

The major consideration of stakeholders in maintaining their facilities is to anticipate the costs of building operations over the life of the building. The National Institute of Standards and Technology (NIST) has defined Life Cycle Cost Analysis (LCCA) as "a method for assessing the total cost of facility ownership." It takes into account all costs of acquiring, owning, and disposing of a building or building system[1]. LCCA enables stakeholders to make better-informed decisions on facility operations by estimating expected annual costs over a building's life cycle.

In order to predict the costs over the life of a building, the Net Present Value (NPV) and the Uniform Annualized Cost (UAC) methods are commonly used in LCCA[2]. The Present Value (PV) is determined for future expenses by taking the anticipated inflation of present dollars into account and discounting that amount by a predicted rate over the period between the anticipated time of future expenses and the present time. Therefore, the NPV represents today's sum of all present and future values, including discount and escalation factors, while the UAC method is used to transform present and future costs into a uniform annual cost series, as shown in Table 1. In this

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research, the NPV method was used to predict the average Maintenance and Repair costs (M&R) for hospital facilities. The formula of the NPV method is as follows[3]:

Table 1. NPV vs UAC

NPV	UAC
$PV = FV\left\{\frac{1}{(1+i)^n}\right\}$	$A = PV\left\{\frac{[i(1+i)^n]}{[(1+i)^n-1]}\right\}$
PV = present value FV = Future value of expenses n = number of years between time of analysis and time of expense i = discount rate	A = end of year expenses PV = Present value from n = number of years from time of analysis to end of life cycle i = discount rate

2. Literature review

2.1 Deterministic vs. probabilistic methods

For decades, the most commonly used LCCA method was the deterministic method. Utilizing historical data or expert knowledge, assumptions were made on both time and costs, which included the initial and operation costs of a building. In this method, these costs were kept as fixed. Therefore, using these fixed input variables, the expected costs could be easily calculated[4]. However, as it used fixed data, the method does not consider the uncertainty of a building' s environment. When it comes to future M&R costs, there are potential errors, such as interest rate and inflation rate. In the real world, the costs cannot be calculated accurately without the consideration of uncertainty[5]. Therefore, in order to solve the problems of uncertainty, a probabilistic approach has recently emerged in LCCA. The discount factor and M&R costs can be calculated by using probabilistic distributions[6].

For example, Muga et al.[7] compared the economic impact of two different roof systems, a green and a built-up roof, by using NPV calculation. In their research, a probabilistic method was used to more precisely predict the life cycle cost of these two different roof systems. By using Monte Carlo simulation, the results showed the variation range of the life cycle costs for each roof system. Herbold[8] used the probabilistic method for pavement cost analysis. The initial cost, future rehabilitation costs, discount rate, and year of rehabilitation were calculated using probability distributions. Random sampling was then used to compute NPV, and by conducting iterations, a probability distribution of results was obtained.

2.2 Using monte carlo simulation for probabilistic method

In order to predict maintenance and repair costs over the whole life span of a certain facility, it is essential to consider the uncertain environment of a certain project[7]. While in the deterministic method, input variables such as maintenance and repair costs are fixed, in the probabilistic method, the costs can be calculated using statistical methods that take into consideration the uncertainty conditions of a certain facility. In the method, to provide a probability confidence interval for predicting appropriate life cycle costs, Monte Carlo simulation is widely used. The simulation is defined by providing the probability distribution with a minimum, a most likely, and a maximum value. Distribution types include normal, triangular, uniform and log-normal[9]. In this research, the log-normal distribution was used to predict the M&R costs of a research hospital facility. A log-normal distribution is a probability distribution of a random variable whose logarithm is normally distributed. The major assumption of a log-normal distribution is that if X is a random variable distributed normally, then Y=Exp (X) has a log-normal distribution[10]. From Monte Carlo simulation,

log normal distribution of each variable is provided through multiple iterations. The probability density function of a log-normal is as follows:

$$f_x(x;\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(Inx-\mu)^2}{2\sigma^2}}, \quad x > 0 \quad --- \quad (1)$$

For normally distributed data, the interval μ ± a represents a probability of 68.3%, while μ± 2aand μ ± 3a represent confidence intervals of 95.5% and 99%, respectively[11]. This study provides a 99% confidence interval, the assumption, μ ± 3a, are established by applying to each M&R systems in the facility.

3. Research objectives and methods

Traditionally, designers and facility managers have focused on reducing the initial construction costs for their projects. However, this frequently leads to inefficient, short-lived facilities with unnecessarily high M&R costs[8]. Graham's study[10] reports the fact that over thirty years, M&R costs for buildings are generally five times more than the costs of initial construction. Therefore, predicting M&R costs over the whole life span of a building should be considered when major stakeholders such as owners and facility managers are planning new projects. Although many studies have attempted to predict M&R costs for buildings[7-8], quantitative studies for predicting the M&R costs of hospital facilities have been fairly limited.

In addition, to predict the asset value of companies, the log-normal distribution method of statistics has been used in the stock market rather than the normal distribution method. For example, in the normal distribution, the probability of an increase of 1,000 Won is the same regardless of whether the stock price is 100 or 96. Therefore, it cannot be represented the real price since, in the normal distribution, it is evaluated with the absolute flow. To address this issue, the log-normal distribution method has been used to predict the price with the relative flow of the stock market. In this respect, the log-normal distribution method is used in this study to predict the M&R costs, since the costs have the same probability at the relative flow of prices like the stock market.

Therefore, the main objective of the study is to develop a predictive model for M&R costs of hospital facilities. To accomplish this objective, the study consists of three parts: (1) predicting the costs of each major building system; (2) predicting costs related to four types of typical M&R activities: preventive, major, replacement, and unscheduled expenses; and (3) analyzing the distribution of Net Present Value (NPV) in expected M&R costs.

M&R is defined as the collection of activities necessary for keeping a building in good working order. Other tasks associated with building operation, such as custodial services, landscaping, waste disposal, and the provision of central utilities are not included for this study. The size is expressed in square meters, and includes the entire area within the asset's perimeter. The M&R costs are divided into the following four types:

- Preventive maintenance consists of scheduled tasks that sustain a component's level of service during a prescribed life time.
- Major maintenance consists of component overhaul or major repair tasks.
- Unscheduled maintenance consists of service calls, emergency response, and other tasks that cannot be individually anticipated.

· Replacement is the estimated cost to replace any component during the life time

The M&R costs are collected based on data obtained from the Whitestone maintenance and repair cost data. The costs obtained for each system are then classified into four types of activities to predict each system in specific detail. To develop a predictive model, a Monte Carlo simulation is performed to analyze how M&R costs are affected given various considered factors, based on the assumption established in this study, which is that the annual costs of M&R for each building system in a hospital facility are normally distributed. Finally, the validity of the results is examined by performing several sensitivity analysis tests.

The following list describes the process that is implemented to develop the predictive model, in detail:

1) M&R cost data are collected for each major building system (Exterior Enclosure, Roofing, Interior Construction, Interior Finishes, Conveying, Plumbing, HVAC, Fire Protection, Electrical, and Equipment) for a hospital facility;
2) The data are classified into four types of activities: preventive, major, replacement, and unscheduled maintenance, given the definitions provided above;
3) Monte Carlo simulations are performed to analyze the distribution of NPV for each of the ten major building systems for each type of activity, and for the combined M&R cost. For this purpose, discount and inflation factors are used based on appropriate sources; and
4) Sensitivity analysis tests are performed to examine the validity of the results. These include all of the following systems: Exterior Enclosure, Roofing, Interior Construction, Interior Finishes, Conveying, Plumbing, HVAC, Fire Protection, Electrical, and Equipment.

4. LCC Analysis for hospital facilities

In order to accomplish the objectives of this study, profile estimates of 50-year maintenance cost for a hospital facility were used. The profile estimates were made with the Whitestone facility cost forecast system, calibrated for the Washington, D.C. area. It includes a list of major components and their annual forecasting M&R costs. Table 2 presents the outline of the hospital facility for this study.

Table 2. Outline of hospital facility

Contents	Description
Square meter	540,200
Height in meter	18
Exterior	Clay Brick
HVAC	Vinyl Tile, Terrazzo, Carpet
Occupancy	Chilled Water, Gas Boiler, Fan Coil Units

Table 3 represents the expected profile estimates by applying the facility maintenance and repair cost forecast system (MARS). The estimates for 50-year M&R cost of the hospital facility consist of ten systems: exterior closure, roofing, interior construction, interior finishes, conveying systems, plumbing, HVAC systems, fire protection, electrical, and equipment. The estimated total M&R costs including all systems are 3,503,000 Won/m^2. The costs for each system ranged from 67,000 Won/m^2 for Fire protection to 1,206,300 Won/m^2 for HVAC systems. Based on the same data, the log-normal distribution method and the Monte Carlo simulation are performed to predict the M&R cost for 50 years of the same building.

Table 3. Cost per m^2 by system

Systems	Estimated costs for 50 years (Won/m^2)
Exterior closure	207,000
Roofing	109,300
Interior construction	141,000
Interior finishes	376,500
Conveying systems	141,700
Plumbing	274,000
HVAC systems	1,206,300
Fire protection	67,000
Electrical	509,500
Equipment	498,000
Total per m^2	3,503,000

4.1 Monte carlo simulation for M&R cost

The Monte Carlo simulation provides the entire range of possible values for uncertainty through the simulation. Of the four types of M&R costs for research hospital facility, unscheduled maintenance represents the uncertainty between M&R cost types, since unscheduled maintenance consists of unanticipated service calls and emergency response, which are difficult to forecast. In addition, the inflation and discount factors are uncertainty values for predicting future values.

Table 4. Mean and standard deviation of unscheduled cost for each system from Whitestone report

System	Mean(%)	Standard deviation(%)
Exterior closure	60	39
Roofing	52	39
Interior construction	63	41
Interior Finishes	40	37
Conveying systems	21	13
Plumbing	63	30
HVAC	44	28
Fire protection	24	28
Electrical	47	32
Equipment	50	35

Three assumptions are established to predict costs for each major building system. The assumptions are as follows:

1) Annual unscheduled maintenance cost of each system is normally distributed with mean and standard deviation based on the Whitestone report data as shown in Table 4. In the Whitestone data, to predict unscheduled costs, the unscheduled cost has been reported as the percentage of the average of each system by analyzing historical data.
2) Inflation and discount factor are assumed as the mean of 3% and 8%, respectively.
3) The standard deviations of inflation and discount factors are assumed as one-third of the mean. To prove whether or not there is difference according to different standard deviation of unscheduled maintenance costs, the sensitivity analysis is conducted with different standard deviations (one-third, one-fifth, one-tenth, one-second) of inflation and discount factors.

4.2 Predicting each system components

Table 5. Mean and standard deviation of unscheduled cost

System		Mean (Standard deviation)				
		PM	Major	Replacement	Unscheduled	Total
1. Exterior enclosure	Mean (SD)	1.99	0.77	0.03	3.54	6.33
	Std. dev.	1.5	0.81	0.05	2.05	4.41
2. Roofing	Mean	0.71	1.02	1.04	0.77	3.54
	Std. dev.	0.43	0.79	0.88	0.46	2.56
3. Interior construction	Mean	0.75	1.42	0.61	1.35	4.13
	Std. dev.	0.48	1.07	0.82	0.78	3.15
4. Interior finishes	Mean	7.03	0.14	5.2	4.89	17.26
	Std. dev.	4.35	0.12	3.92	2.85	11.24
5. Conveying	Mean	1.99	0.00	0.3	0.54	2.83
	Std. dev.	1.16	0.00	0.35	0.32	1.83
6. Plumbing	Mean	1.71	1.00	5.33	2.91	10.95
	Std. dev.	1.05	0.77	4.76	1.73	8.31
7. HVAC	Mean	10.59	2.58	8.21	8.27	29.65
	Std. dev.	6.38	1.87	7.17	5.00	20.42
8. Fire Protection	Mean	1.18	0.00	0.31	0.41	1.9
	Std. dev.	0.82	0.00	0.41	0.24	1.46
9. Electrical	Mean	19.7	1.13	15.65	17.8	54.28
	Stdev.	11.58	0.87	10.91	10.48	33.84
10. Equipment	Mean	4.57	0.19	9.62	4.53	18.91
	Stdev.	2.71	0.14	7.46	2.70	13.01

*PM: Preventive Maintenance

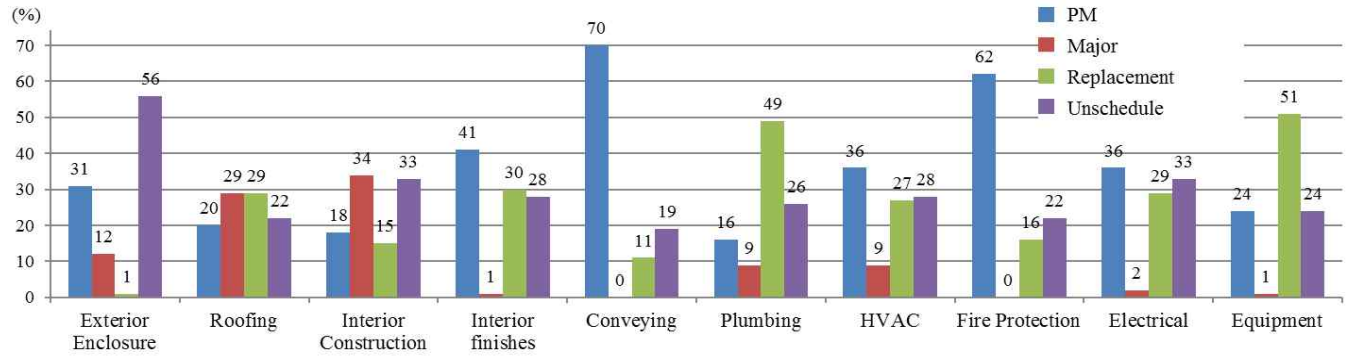

Figure 1. The proportion of four types for M&R cost

All ten systems are analyzed using Monte Carlo simulation with 10,000 iterations. Random numbers are generated for all systems. The following costs matrix is suggested to calculate all annual costs for 50 years. As shown in Table 5, the total NPV costs for each system are calculated. Of the ten systems, the electrical system has the highest total M&R costs, while the fire protection system has the lowest M&R costs.

Figure 1 shows the proportion of the four types of M&R costs in each system. In the exterior enclosure system, unscheduled maintenance cost represents more than 50% of the four types, while in the conveying system, unscheduled maintenance cost is 19%, which is the lowest proportion of unscheduled maintenance among the ten systems. In addition, there are no major M&R costs in the conveying and HVAC system.

4.3 Sensitivity analysis for inflation and discount factors

To prove the validity of this study, sensitivity analysis tests were performed with different standard deviations. The roofing system was selected to conduct the sensitivity analysis tests since the system has a relatively balanced proportion of the four types of M&R costs.

Table 6. Different standard deviation of unscheduled maintenance cost for roofing

System (Roofing) Unscheduled	Mean (Standard deviation)				
System (Roofing) Unscheduled	PM	Major	Replacement	Unscheduled	Total
Standard deviation = 1/10 mean	0.71 (0.43)	1.02 (0.79)	1.04 (0.88)	0.77 (0.45)	3.55 (2.55)
Standard deviation = 1/5 mean	0.71 (0.42)	1.01 (0.77)	1.03 (0.86)	0.77 (0.44)	3.52 (2.49)
Standard deviation = 1/4 mean	0.72 (0.44)	1.03 (0.81)	1.05 (0.90)	0.77 (0.46)	3.57 (2.61)
Standard deviation = 1/3 mean	0.71 (0.43)	1.02 (0.79)	1.04 (0.88)	0.77 (0.46)	3.55 (2.55)
Standard deviation = 1/2 mean	0.72 (0.44)	1.02 (0.80)	1.04 (0.88)	0.79 (0.47)	3.55 (2.56)

*PM: Preventive Maintenance

Table 6 represents the results of unscheduled maintenance cost for roofing with different standard deviations. All types had similar results despite having different standard deviations. Therefore, the sensitivity analysis test confirmed the validity of the results.

4.4 Log-normal distribution for total components

In this study, the log-normal distribution was used to predict the M&R costs of a research hospital facility. A log-normal distribution is a prob-

ability distribution of a random variable whose logarithm is normally distributed.

Table 7. Total NPV costs by using monte-carlo simulation

Total NPV cost for all systems (Won/M^2)	
Mean	3,204,000
Std. dev.	452,000
Max .	3,950,000
Median	2,954,000
Min.	2,654,000

By using the log-normal distribution, the total M&R costs were calculated in this study. Compared with the results of the MARS of Table 3, it can be predicted with more accuracy and reliability, and a decreased variation range.

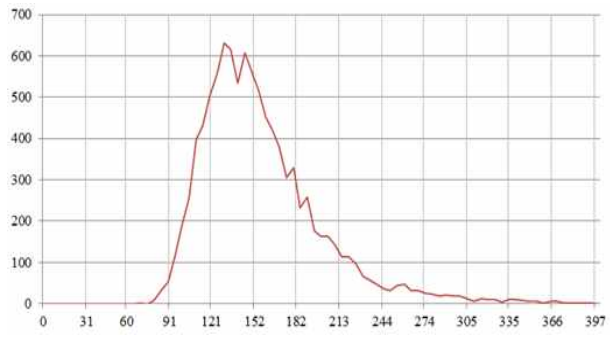

Figure 2. Log-normal distribution for total NPV of all systems

Table 7 represents the total NPV for all systems by using Monte-Carlo simulation. The total NPV cost had a mean of $154.66 and a standard deviation of 45.16. In addition, Figure 2 represents the log-normal distribution for total NPV of all systems.

5. Summary and conclusion

Historically, the estimation of life cycle cost has been performed using deterministic methods. However, these do not take into consideration the uncertainty in M&R costs. In this respect, to estimate life cycle cost more accurately and reliably, it is necessary to predict unscheduled maintenance cost. To address the uncertainty issue, in the stock market, the log-normal distribution method of statistics has been widely used to predict the asset value. It enables the uncertainty value to be considered. In this study, the log-normal distribution method is applied to estimate the M&R costs for 50 years with unscheduled maintenance costs.

In addition, although many studies have attempted to forecast M&R costs for buildings, no research has been conducted into predicting M&R costs by using log-normal distribution methods. To address this shortcoming, the objective of this study is to propose a predictive model for M&R costs using log-normal distribution method.

As a case study, the log-normal distribution method was applied to a hospital facility in Washington, DC. Compared with the MARS, it was found that the probability function for the cost of M&R in each building system matches a log-normal distribution. In addition, compared with the results of the MARS, it can be predictable with higher accuracy and reliability with a decreased variable range.

The findings of this study can provide a standard for M&R costs to help major stakeholders make better-informed decisions for anticipating the future costs of ownership of facilities. Furthermore, the predictive model established using a Monte Carlo simulation can be utilized as a guideline to accurately forecast the M&R costs of facilities.

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