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APPLICATION OF THE EXPONENTIAL GREY MODEL ON THE MAINTENANCE COST PREDICTION FOR A LARGE SCALE HOSPITAL

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ABSTRACT. Realizing the maintenance cost distribution and predicting the future tendency are important for facility managers to efficiently arrange the limited budget. This paper collects 16,228 maintenance records of a representative hospital in Taiwan and further analyzes the cost distribution. Besides, by calculating the maintenance cost of per square meter of floor area per year (dollar/m^2/year) and comparing with the previous studies, this paper also points out the relationship between maintenance cost and the operation ages. Moreover, this paper establishes a hybrid grey model termed as EGM(1,1), which adopting exponential series to identify the residual error series resulted from grey model, to predict the maintenance cost. The repair cost of hospital building from 1998 to 2006 is adopted to demonstrate the applicability and practicability of EGM(1,1). Results show that the proposed model can predict the tendency precisely.

KEYWORDS: Exponential series; Facility management; Grey model; Hospital building; Maintenance cost

1. INTRODUCTION

Only well-maintained hospital buildings can support increasing requirements of hospital functions, including medical cares, emergency refuges, medical research and education etc. Therefore, the healthcare facility management becomes a worth discussion topic in the field of property management (Lavy and Shohet, 2007a; Uhlik and Hinze, 1998). However, owing to the limited budget, realizing the historical cost distribution and predicting the future tendency of maintenance cost are important for facility managers to arrange reasonable budget to meet the required functions.

Nevertheless, the maintenance cost records of hospital buildings are difficult to collect. Most studies had conducted the investigations by questionnaires or interview. The previous studies can provide precious information and knowledge with respect to maintenance cost distribution of hospitals (Neely and Neathammer, 1991; Nesje, 2002; Lavy and Shohet, 2007b; Ciarapica et al., 2008) however, this paper aims to provide an alternative to realize this subject.

Therefore, this study collects more than 16,000 maintenance cost records of the National Taiwan University Hospital (NTUH), which is a representative hospital in Taiwan. Based on the collected data, this paper aims to: (1) analyze the actual cost distribution of NTUH and also compare the cost distribution of buildings with different life cycle stages; and (2) establish an effective prediction model to catch the development tendency of maintenance cost. The results of this paper aim to provide meaningful experience and information for the future studies.

In the aspect of prediction model establishment, this paper adopts the grey model to be the main algorithm because the grey model and its variants have demonstrated well performance on the various applications, ranging from economics through physics to engineering (Lin et al., 2007; Tien, 2003; Liu et al., 2004; Wu and Chen, 2005; Lin and Lee, 2007; Zhou et al., 2009). However, the performance of grey model still can to be improved when applying on the substantially vibrating time series (e.g., the quarterly maintenance cost) or center-symmetry curves (Bingqian, 1990; Tan and Chang, 1996; Tan and Lu, 1996; Chen and Tien, 1997; Cheng et al., 1997). Hence, this paper further employs the exponential series (Hildebrand, 1956) to identify the residual error series resulted from the grey model to further improve the accuracy.

The remaining paper is organized as follows. In section 2, the comparisons and analysis of maintenance cost are presented and discussed. Based on the collected data in section 2, a hybrid grey model named EGM(1,1) is proposed in section 3 as the prediction model of maintenance cost. Then, section 4 describes the evaluation criterion and prediction results of the illustrative example. Finally, section 5 concludes this paper.

2. INVESTIGATION OF MAINTENANCE COST

2.1. Description of NTUH and data collection

NTUH is the most prestigious and historical hospital in Taiwan. Owing to the outstanding facilities and experts, NTUH has been designated as the only one medical group to take care the President's health in Taiwan during the past decades. NTUH has two main buildings, i.e., the West-Site building (an old 86 year building) and the East-Site building (a new 17 year building). The total floor areas of the West-Site and East-Site buildings are 108,107 m^2 and 256,110 m^2, respectively. There are more than 4,000 employees in NTUH, and they have to serve averagely 2,000 inpatients, 7,000 outpatients, and 2,500 sickbeds daily. With the rapid growth of health insurance expenditure and limited budget, NTUH has to balance revenue/expenditure and become financial self-sustained.

NTUH has implemented e-system to store maintenance records since 1998. Before 1998, all maintenance records were stored in paper format, but the paper records were either contaminative or incomplete. Therefore, this study collects the complete maintenance records in computerization format from 1998 to 2006 (total 16,228 maintenance data) of the East-Site and West-Site buildings. The collected maintenance records are mainly from the maintenance and repair applications. The application serial number has to be in compliance with the account serial number recording the real expenditure on maintenance and repair, including material and outsourcing.

According to the interviews with the facility managers of NTUH, a classification matrix, as shown in Table 1, is suggested to allocate each maintenance record. This classification matrix is consisted of three categories (periodic maintenance, repair, and demand change) and seven main items (structure, interior/exterior, electricity, water supply and drainage, machinery, fire prevention, and others). Besides, Table 2 and Figure 1 also provide the overview of annual maintenance cost of NTUH.

Table 1. Maintenance records classification matrix

Main item	Category		
	Periodic maintenance	Repair	Demand change
Structure	None	Building demolition Building additions Structure reinforcement	Building demolition Building additions Structure reinforcement
Interior / Exterior	Painting Surgical lead door	Roof Building hardware Interior finishes Outdoor External walls Doors and windows	Roof Building hardware Interior finishes Outdoor External walls Doors and windows
Electricity	High voltage Low voltage Uninterruptible power supply (UPS)	High voltage Low voltage Thunder prevention system	High voltage Low voltage Thunder prevention system
Water Supply and Drainage	Water supply equipment Water treatment unit	Drainage equipment Sewage treatment facilities	Drainage equipment Sewage treatment facilities
Machinery	HVAC Boiler Elevator	HVAC Boiler and steam engine Elevator	HVAC Boiler and steam engine Elevator
Fire prevention	None	Fire fight equipment	Fire fight equipment
Others	Medical gas Medical facility Ward facility Kitchen facility Logistic facility Testing for pollution source	Medical gas Medical facility Ward facility Kitchen facility Logistic facility Design/technical service	Medical gas Medical facility Ward facility Kitchen facility Logistic facility Design/technical service

Table 2. Annual maintenance numbers and cost of NTUH

Year	Numbers		Cost		Sum	
	West-Site	East-Site	West-Site	East-Site	Numbers	Cost
1998	50	456	1,267	3,323	506	4,580
1999	25	59	3,165	1,562	84	4,727
2000	44	108	1,859	877	152	2,736
2001	44	60	5,038	3,531	104	8,569
2002	81	238	1,763	4,469	319	6,232
2003	870	1,229	3,913	6,281	2,099	10,194
2004	927	1,343	4,042	3,823	2,270	7,853
2005	844	1,055	3,463	4,688	1,899	8,151
2006	820	1,154	4,021	6,875	1,974	10,896
Total	3,705	5,702	28,531	35,409	9,407	63,938
Average	412	634	3,170	3,934	1,045	7,104

Note: The unit of cost is thousand dollars.

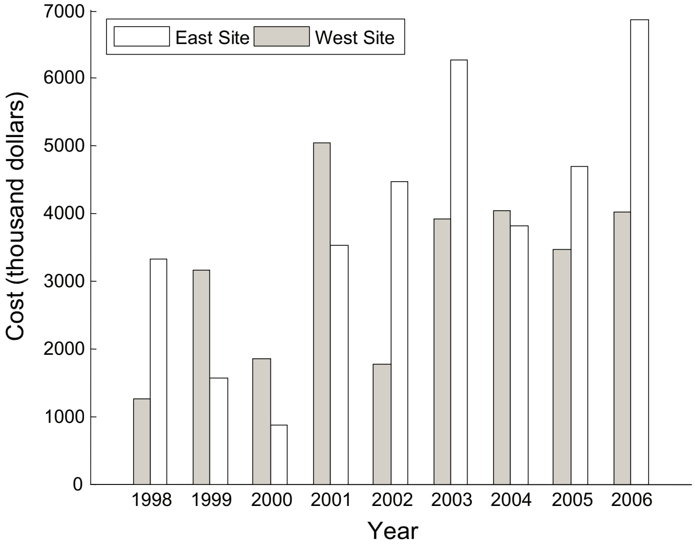

Figure 1. Maintenance cost of NTUH

Periodic maintenance can be defined as to deal with regular or routine works to maintain the basic functions and requirements of building service. Repair maintenance occurs when the physical components are either damaged, broken, or deteriorated, resulting in malfunction of building services. Demand change arises from altering space allocation, medical market changes, and customer requirement changes. Furthermore, the outsource service providers, and materials and supplies are also included in the scope of each maintenance cost, whether periodic maintenance, repair, or demand change. However, the item of in-house personnel salaries does not consider in this paper. Because, except the direct salaries, the labor insurances, health insurances, and retirement pays can not be analyzed from annual budget report.

2.2. Comparisons and analysis of the maintenance cost

Actually, in the view of building life cycle, the West Site building and the East Site building represent an old stage and a young adult stage, respectively. Further analysis of the West Site and East Site buildings is conducted based on an objective unit: the maintenance cost per square meter of floor area per year (dollar/m^2/year). The West Site building and the East Site building are 29.5 dollar/m^2/year and 15.4 dollar/m^2/year, respectively. Besides, this paper compares the results with the following studies to discuss the reasonableness of maintenance cost.

In Shohet's study (2003), 17 hospitals in Israel with an average age of 38 years and 658 sickbeds were analyzed. The mean maintenance cost is 37.20 dollar/m^2/year; however, the expenditures of permanent maintenance staff occupy 51.6% of the mean maintenance cost. Therefore, the maintenance cost except for staff is 19.2 dollar/m^2/year.

Besides, in another study (Lavy and Shohet, 2004), a 23 years hospital building with 1065 sickbeds was studied. The total maintenance cost is 38.50 dollar/m^2/year, but 39.4% of the total maintenance cost is used for maintenance staff. Therefore, the maintenance expenditure except for staff is 23.3 dollar/m^2/year. Integrating the results of above mentioned studies with this paper, the relationship can be simply found that the maintenance cost (dollar/m^2/year) will increase with the operation ages. Although this relationship may require further detailed analysis, this finding can provide precious information for hospital facility managers in making decisions regarding maintenance budgets.

Furthermore, the cost distribution of NTUH is collected in Table 3, Figure 2 and Figure 3. According to these analyses, the cost distribution of the old West Site building is quite different with that of the young East Site building no matter in categories or main items. The cost distribution will be adjusted to adapt to the building conditions of different life cycle stages.

Table 3. Cost distribution of NTUH

Main item	West Site		East Site	
	Total cost	Percentage	Total cost	Percentage
Structure	120	0.42%	72	0.20%
Interior /exterior	16,233	56.90%	10,237	28.89%
Electricity	6,028	21.13%	7,177	20.26%
Water supply and drainage	258	0.90%	1425	4.02%
Machinery	3,708	13.00%	12,503	35.29%
Fire prevention	23	0.08%	669	1.89%
Others	2,161	7.57%	3,346	9.44%
Sum	28,531	100.00%	35,429	100.00%

Note: The unit of cost is thousand dollars.

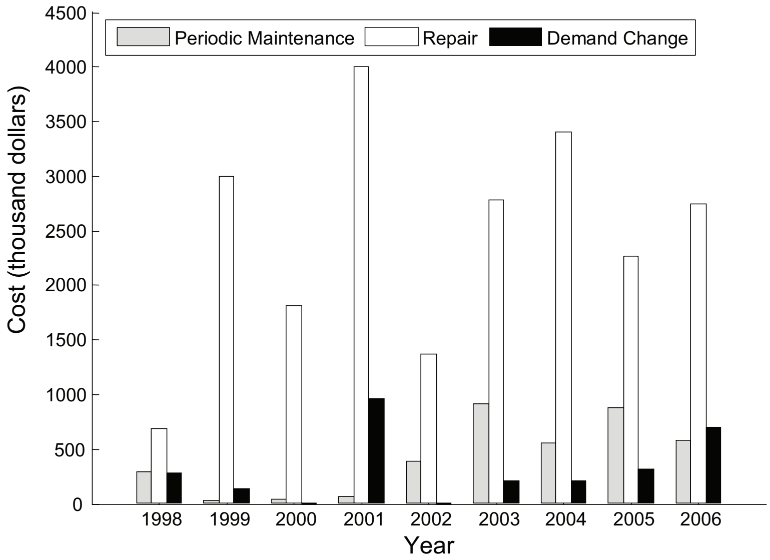

Figure 2. Cost histogram of the West Site building

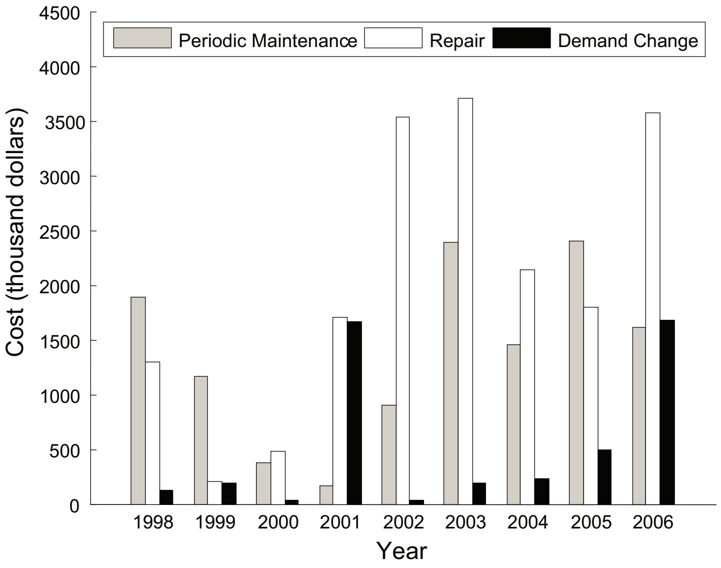

Figure 3. Cost histogram of the East Site building

3. METHODOLOGY

Owning to the difficulty in collecting maintenance records, traditional statistical methods or neural networks cannot be adopted to establish the general or well-trained prediction model by the insufficient data. Hence, this paper mainly employs the grey model as the maintenance cost prediction model owning to its advantage of establishing prediction equation by only few data. Grey model can also conduct self-validity and judge parameters by the rolling approach. In this section, the algorithm of grey model is presented first. Then, the hybrid grey model, EGM(1,1), and its operation procedure are discussed at the second part.

3.1. Grey model

In practice, the time series will vibrate irregularly with the variations of internal and external influences. To effectively define the phenomena of time series development, Deng (1982) proposed an accumulation-generating-operation (AGO) to reveal the hidden regular pattern in time series. Thus, the grey differential equation can be adopted to sufficiently reveal the regularity of time series development after using one-time or two-time AGO.

The most commonly employed grey model is GM(1,1), which indicates one variable and first order grey differential equation are adopted to match the time series. Let the raw time series be $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(j), \dots, x^{(0)}(n))$, where $x^{(0)}(j)$ means the datum at *j-th* time and n is the total number of modelling data. The following algorithm of GM(1,1) is described to predict the one-step ahead value and stated as follows.

Algorithm of GM(1,1)

Step 1: Establish the one-time AGO series.

$x^{(1)}(k)$ is the generated datum of $x^{(0)}(k)$ and can be defined as

$$x^{(1)}(k) = \sum_{j=1}^{k} x^{(0)}(j) . \tag{1}$$

Then, the generated series, $x^{(1)} = (x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(n))$, can be also obtained.

Step 2: Estimate the values of parameters a and b.

$x^{(1)}$ can be modelled by the first order grey differential equation as

$$\frac{dx^{(1)}(t)}{dt} + ax^{(1)}(t) = b . \quad (2)$$

In Eq. (2), parameters a and b are the developing coefficient and grey input, respectively. Because Eq. (2) is a continuous function, parameters a and b can not be calculated directly by Eq. (2). The definition formula is substituted to estimate the value of a and b, which is

$$x^{(0)}(k) + az^{(1)}(k) = b . \quad (3)$$

Therefore, the values of parameters a and b can be estimated by the least-squares error method as

$$\begin{bmatrix} a \\ b \end{bmatrix} = (B^T B)^{-1} B^T Y_N , \quad (4)$$

where

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \ldots & \ldots \\ -z^{(1)}(n) & 1 \end{bmatrix} \quad (5)$$

and

$$Y_N = (x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n))^T . \quad (6)$$

In Eq. (3), $z^{(1)}(k)$ is the background value of the *k-th* datum and defined as

$$z^{(1)}(k) = \alpha x^{(1)}(k) + (1-\alpha)x^{(1)}(k-1) , \quad (7)$$

where α is commonly defined as 0.5.

Step 3: Define the prediction model.

After obtaining a and b from Eq. (4), the solution of Eq. (2) can be further defined. The initial condition is set as $x^{(1)}(1)$, which is equal to $x^{(0)}(1)$, and the specified solution of Eq. (2) can be then defined as

$$\hat{x}^{(1)}(k) = (x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)} + \frac{b}{a} , \quad (8)$$

where: $\hat{x}^{(1)}(k)$ is the modelled value of $x^{(1)}(k)$. Because $\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1)$, the modelled value of $x^{(0)}(k)$ can be obtained by

$$\hat{x}^{(0)}(k) = (1-e)(x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)} ,$$
$$\hat{x}^{(0)}(k) = x^{(0)}(1) . \quad (9)$$

Finally, the one step ahead prediction of grey model can be calculated by substituting $k = n+1$ into Eq. (9), which is

$$\hat{x}^{(0)}(n+1) = (1-e)(x^{(0)}(1) - \frac{b}{a})e^{-an} . \quad (10)$$

In the above-mentioned algorithm, the number of data modelled in GM(1,1) is rather small because only two parameters are required to be estimated in Eq. (2). In other words, GM(1,1) is often adopted as a short-term prediction scheme.

3.2. Exponential grey model

As shown in Eq. (2), GM(1,1) is constructed of exponential function and may have unsatisfied results when employed in widely vibrating time series. Under this situation, this paper attempts to enhance the prediction accuracy by integrating the exponential series into grey model to establish a hybrid grey model named EGM(1,1) for maintenance cost prediction. The algorithm of EGM(1,1) can be drawn as follows.

Let the residual error series be $\varepsilon^{(0)} = (\varepsilon^{(0)}(1), \varepsilon^{(0)}(2), \ldots \varepsilon^{(0)}(n))$, where $\varepsilon^{(0)}(k)$ means the residual error at *k-th* time and $\varepsilon^{(0)}(k) = x^{(0)}(k) - \hat{x}^{(0)}(k)$ for $k = 1, 2, \ldots, n$. Then, for an equally spaced data of residual error series, an approximation of exponential series [15] can be written as

$$\varepsilon^{(0)}(k) = A_1 e^{S_1 k} + A_2 e^{S_2 k} + \ldots + A_m e^{S_m k}, \quad (11)$$

where: A_j and S_j are amplitude coefficient and exponent, respectively. Let $z_j = e^{S_j}$, then Eq. (11) can be simplified as

$$\varepsilon^{(0)}(k) = A_1 {z_1}^k + A_2 {z_2}^k + \ldots + A_m {z_m}^k. \quad (12)$$

Eq. (12) can be further deployed as

$$ZA = E, \quad (13)$$

where

$$Z = \begin{bmatrix} z_1^1 & z_2^1 & \cdots & z_m^1 \\ z_1^2 & z_2^2 & \cdots & z_m^2 \\ \cdots & \cdots & \cdots & \cdots \\ z_1^n & z_2^n & \cdots & z_m^n \end{bmatrix}, \quad (14)$$

$$A = (A_1, A_2, \ldots, A_m)^T$$

and

$$E = (\varepsilon^{(0)}(1), \varepsilon^{(0)}(2), \ldots, \varepsilon^{(0)}(n))^T.$$

If $z_1, z_2, \ldots, z_m$ indicate the roots of polynomial, the polynomial can be presented as

$$P(z) = \prod_{j=1}^{m} (z - z_j) = z^m + c_1 z^{m-1} + \ldots +$$

$$c_{m-1} z^1 + c_m. \quad (15)$$

Then, to multiply $c_m, c_{m-1}, \ldots, c_1$, and 1 by $\varepsilon^{(0)}(1), \varepsilon^{(0)}(2), \ldots, \varepsilon^{(0)}(m+1)$ separately, the following equation can be obtained as

$$\varepsilon^{(0)}(1)c_m + \varepsilon^{(0)}(2)c_{m-1} + \ldots +$$

$$\varepsilon^{(0)}(m-1)c_2 + \varepsilon^{(0)}(m)c_1 + \varepsilon^{(0)}(m+1) = 0. \quad (16)$$

Use the same procedure, similar equations can be also obtained and further yielded a matrix expression of equations as

$$QC = Y, \quad (17)$$

in which

$$Q = \begin{bmatrix} \varepsilon^{(0)}(1) & \varepsilon^{(0)}(2) & \cdots & \varepsilon^{(0)}(m) \\ \varepsilon^{(0)}(2) & \varepsilon^{(0)}(3) & \cdots & \varepsilon^{(0)}(m+1) \\ \cdots & \cdots & \cdots & \cdots \\ \varepsilon^{(0)}(n-m) & \varepsilon^{(0)}(n-m+1) & \cdots & \varepsilon^{(0)}(n-1) \end{bmatrix}, \quad (18)$$

$$C = (c_m, c_{m-1}, \ldots, c_1)^T$$

and

$$Y = (-\varepsilon^{(0)}(m+1), -\varepsilon^{(0)}(m+2), \ldots, -\varepsilon^{(0)}(n))^T.$$

By adopting the pseudo inverse technique in Eq. (17), the coefficients $c_1, c_2, \ldots, c_m$ can be calculated. Afterward, the roots of polynomial, $z_1, z_2, \ldots, z_m$, can be determined via solving Eq. (15). Then, the amplitude coefficients in Eq. (13), $A_1, A_2, \ldots, A_m$, can be further calculated by least-squares error method. Therefore, the residual error can be approximated and predicted by the following equation:

$$\hat{\varepsilon}^{(0)}(k) = A_1 {z_1}^k + A_2 {z_2}^k + \ldots + A_m {z_m}^k. \quad (19)$$

Finally, the approximated value of EGM(1,1), $\hat{x}_e^{(0)}(k)$, can be calculated by

$$\hat{x}_e^{(0)}(k) = \hat{x}^{(0)}(k) + \hat{\varepsilon}^{(0)}(k). \quad (20)$$

In Eq. (20), $\hat{x}^{(0)}(k)$ and $\hat{\varepsilon}^{(0)}(k)$ are the approximated values of GM(1,1) and exponential series, respectively.

4. QUARTERLY MAINTENANCE COST PREDICTION OF NTUH

According to the above-mentioned classification, maintenance cost can be divided into three categories in this study, i.e., periodic maintenance, repair, and demand change. However, in practice, the periodic maintenances are implemented by contracts and the demand changes are required by hospital strategies, this paper only focuses on the prediction of repair cost.

Table 4 shows the quarterly repair cost of the East Site building of NTUH from 1998 to 2006 (total 36 seasons), and Figure 4 also provides the overview of the vibrations. As shown in Table 4, the range of quarterly repair cost is very wide (from 10^4 to 10^7 dollars), and it's difficult to predict the quarterly repair cost directly.

Table 4. Quarterly repair cost of the East Site building

Year	Season	Repair cost
1998	1	22,702
	2	616,598
	3	295,313
	4	16,450
1999	1	131,135
	2	41,511
	3	25,591
	4	6,859
2000	1	208,529
	2	100,319
	3	143,044
	4	29,870
2001	1	8,707
	2	304,466
	3	1,381,796
	4	12,977
2002	1	23,483
	2	734,511
	3	99,087
	4	2,688,435
2003	1	296,267
	2	286,942
	3	1078,021
	4	2048,271
2004	1	749,354
	2	378,476
	3	431,764
	4	624,720
2005	1	216,019
	2	1,005,590
	3	359,280
	4	245,352
2006	1	769,993
	2	713,352
	3	1,729,069
	4	379,355

The quarterly repair cost has to be pre-processed before prediction. Therefore, the raw repair cost data are pre-processed by the logarithmic function in this paper as

$$y = \log(x)\,, \qquad (21)$$

where: x and y are the raw repair cost and pre-processed value, respectively. However, the pre-processed values still vibrate irregularly, as shown in Figure 5.

Then, EGM(1,1) can be employed to calculate the prediction value ($\hat{y}$) of pre-processed repair cost (y). Afterward, the prediction values have to be inverse pre-processed for further comparisons with the raw repair cost data. The inverse pre-procession equation can be established as

$$\hat{x} = 10^{\hat{y}}\,, \qquad (22)$$

in which $\hat{x}$ is the predicted value of x.

Besides, the prediction accuracy is measured by the criterion of relative-absolute-error (RAE), which can be calculated by

$$RAE = \frac{|x - \hat{x}|}{x}\,. \qquad (23)$$

Notice that few numbers of data are required to establish the proposed EGM(1,1) model and test its ability, owing to the inherent algorithm of grey model. The method of 8-points (two seasons) rolling is adopted to test and validate the performance. Table 5 yields the prediction results of the quarterly repair cost. As shown in Table 5, the first 8 points are adopted to establish the EGM(1,1) model and the average RAE is 13.10%, which is acceptable for prediction. The last 28 points are employed to validate the performance and the average RAE is 11.05%, which is applicable in practice.

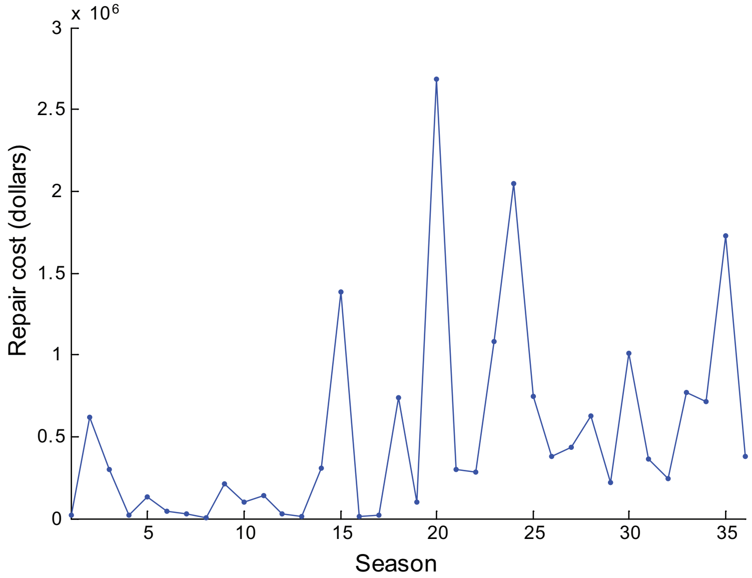

Figure 4. Repair cost of the East Site building

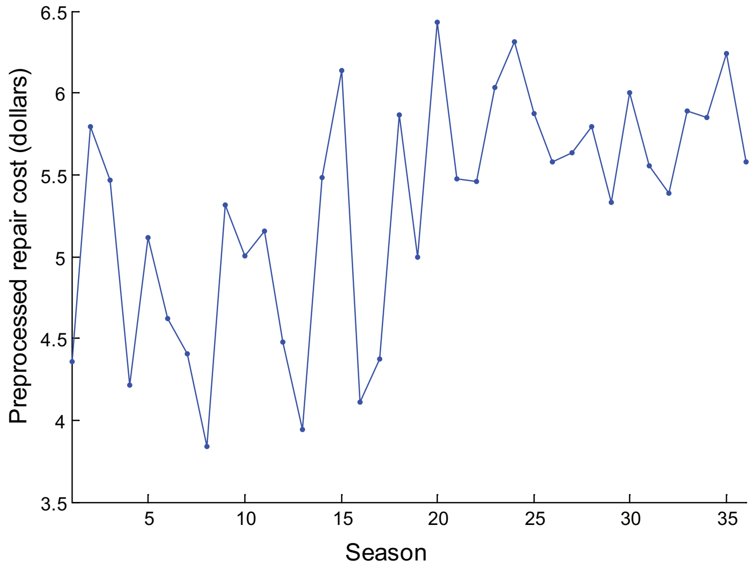

Figure 5. Preprocessed repair cost of the East Site building

Table 5. Prediction results of the repair cost

x	y	$\hat{y}$	$\hat{x}$	RAE
22,702	4.356	4.409	25,654	13.00%
616,598	5.790	5.816	655,283	6.27%
295,313	5.470	5.549	353,621	19.74%
16,450	4.216	4.276	18,862	14.66%
131,135	5.118	5.166	146,524	11.74%
41,511	4.618	4.662	45,917	10.61%
25,591	4.408	4.446	27,925	9.12%
6,859	3.836	3.914	8,209	19.68%
208,529	5.319	5.392	246,787	18.35%
100,319	5.001	5.091	123,372	22.98%
143,044	5.155	5.258	180,928	26.48%
29,870	4.475	4.531	33,999	13.82%
8,707	3.940	4.011	10,259	17.82%
304,466	5.484	5.510	323,855	6.37%
1,381,796	6.140	6.217	1,646,996	19.19%
12,977	4.113	4.159	14,434	11.23%
23,483	4.371	4.437	27,372	16.56%
734,511	5.866	5.929	849,006	15.59%
99,087	4.996	5.072	117,919	19.01%
2,688,435	6.429	6.461	2,893,388	7.62%
296,267	5.472	5.527	336,886	13.71%
286,942	5.458	5.456	285,430	0.53%
1,078,021	6.033	6.011	1,026,719	4.76%
2,048,271	6.311	6.351	2,245,138	9.61%
749,354	5.875	5.903	799,612	6.71%
378,476	5.578	5.553	356,993	5.68%
431,764	5.635	5.604	401,524	7.00%
624,720	5.796	5.753	566,398	9.34%
216,019	5.334	5.314	206,044	4.62%
1,005,590	6.002	5.961	913,336	9.17%
359,280	5.555	5.561	364,321	1.40%
245,352	5.390	5.425	266,337	8.55%
769,993	5.886	5.873	746,610	3.04%
713,352	5.853	5.772	592,242	16.98%
1,729,069	6.238	6.168	1,471,466	14.90%
379,355	5.579	5.554	358,001	5.63%

Furthermore, Figure 6 compares the prediction results ($\hat{y}$) with the pre-processed values (y). As shown in Figure 6, although some change-points can not be approximated very precisely owing to their acute vibrations. EGM(1,1) still has well performance on the prediction of quarterly repair cost.

5. CONCLUSIONS

From the results in this study, the following five conclusions can be drawn,

1. This study has provided a comprehensive data analysis of practical historical maintenance records (16,228 data numbers from 1998 to 2006) form NTUH rather than questionnaires. A classification matrix has also been proposed in this paper, as shown in Table 1. This classification matrix is useful and practical for hospital building maintenance.

2. Two buildings of NTUH with different life cycle stages, the West Site building (86 operation ages) and the East Site building (17 operation ages), have been analyzed in this study, as shown in Table 2 and Figure 1. Besides, the cost distribution of both buildings has been compared in Table 3, Figure 2 and Figure 3. The results have demonstrated that the cost distribution will be various to adapt to the building conditions of different life cycle stages. Especially note that the percentage of repair cost of the old West Site building is higher than that of the young East Site building.

3. The results of this paper have been compared with related studies, and have shown that the relationship can be simply found that the maintenance cost (dollar/m^2/year) will increase with the operation ages in different stages of building life cycle. Although the relationship between the age and the maintenance cost still needs to be examined more carefully if more case data can be obtained, this paper still can provide valuable knowledge exchange with the other countries.

4. In the aspect of developing the maintenance cost prediction model, this paper has

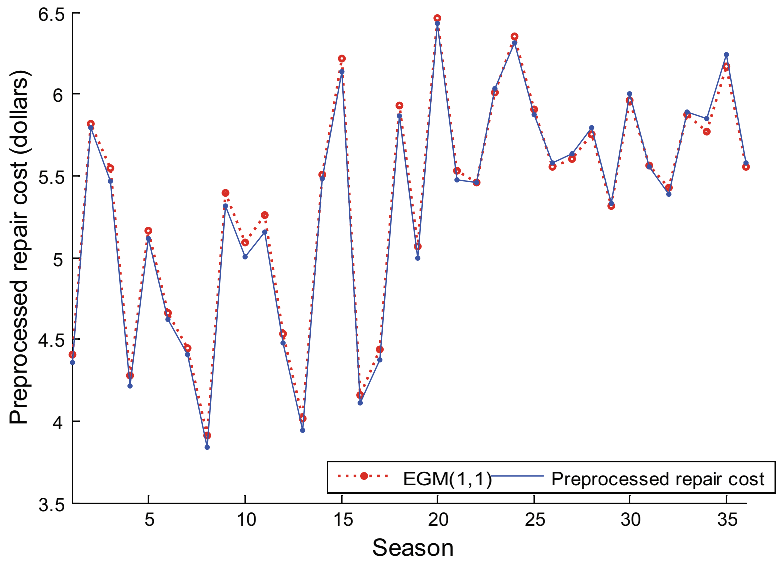

Figure 6. Prediction results of the quarterly repair cost

adopted the grey model as the main algorithm of the prediction model. However, the performance of grey model still can be improved when employed in widely vibrating time series or center-symmetry curves. Therefore, this paper has adopted the exponential series to improve the precision of grey model and established the hybrid exponential-grey-model, which is termed as EGM(1,1).

5. The quarterly repair cost of the East Site building has been employed to demonstrate the effectiveness and applicability of EGM(1,1). Results have shown that EGM(1,1) can provide well performance on the prediction of repair cost. Besides, EGM(1,1) can be employed in various areas with similar prediction problems.

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SANTRAUKA

EKSPONENTINIO PILKOJO MODELIO TAIKYMAS PROGNOZUOJANT DIDELĖS LIGONINĖS EKSPLOATACINES SĄNAUDAS

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Norint efektyviai išdėstyti ribotą biudžetą, pastatų ūkio valdytojai turi suprasti eksploatacijos sąnaudų pasiskirstymą ir sudaryti ateities tendencijų prognozes. Šiame darbe surinkti 16 228 įrašai apie reprezentacinės Taivano ligoninės eksploataciją ir jais remiantis analizuojamas sąnaudų pasiskirstymas. Apskaičiavus metines eksploatacijos sąnaudas vienam kvadratiniam metrui (doleriai/m^2/metus) ir palyginus jas su ankstesniais tyrimais, darbe taip pat parodomas ryšys tarp eksploatacijos sąnaudų ir objekto amžiaus. Be to, darbe sudaromas hibridinis pilkasis modelis, pavadintas EGM(1,1), kuriame naudojant eksponentines eilutes nustatomos liktinės paklaidų eilutės, gautos pilkajame modelyje, taip siekiant prognozuoti eksploatacines sąnaudas. Naudojant 1998–2006 m. ligoninės pastato remontui išleistą sumą pristatomas EGM(1,1) taikymas ir praktiškumas. Rezultatai rodo, kad pasiūlytas modelis tendencijas gali prognozuoti tiksliai.