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Design and Implementation of Optimum Management System using Cost Evaluation and Financial Analysis for Prevention of Building Failure

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Abstract: Building management is complex as the implementation of the engineering management system and is subjected to require the top management for supporting the construction industry. To achieve this management must use a system to control the preventive management of building failure. The purpose of the paper is to develop a new approach to optimize the management process for systematic prevention of building failure. To optimum the management of building elements and equipments, the data from 4 case studies are used. These data are analyzed by computation of financial and economical systems. For building managers seeking to expand their knowledge of a particular process or preventive management systems in general, the paper provides a practical understanding. The process developed in this research will help firms of engineering/managing with a reliable implementation tool for their buildings installation and this will promote engineering management development.

Keywords: Engineering Management, Case Study, Building Management, Cost Evaluation, Process Analysis

Introduction

The most important issue of successful component maintenance activities is a suitable cost allocated to a project. One of the reasons for change in component maintenance management and planning is due to the limited allocation of cost (Boyle, 2003). Furthermore, lack of suitable cost allocation in a component maintenance work can affect the maintenance implementation (Tilley and McFallen, 2000). Therefore building managers or owners are responsible for management and allocation of maintenance costs for good maintenance outcomes.

Quality of maintenance works on the building components is dependent on the amount of cost allocation in this sector. Sufficient capital includes staffing, inspecting and financials which are required for components maintenance works in the buildings (Lee and Scott, 2009). Maintenance and repair planning for upgrading components and material conditions in the building need regularly programmed condition assessment. These inspections and assessments should be designed and classified by inspectors and engineers. This goal needs the inspector of the components and elements to provide suitable information for the computation of a condition assessment. Lack of information and knowledge about the important building component can result in mismanagement in the field of components maintenance and can affect increasing cost of building and building age reduction. A comprehensive process should be established for monitoring the most important building component. A literature review on previous research indicates that there are issues of cost and planning optimization of components maintenance (Boyle, 2003; Mohd-Noor *et al*., 2011; Ali, 2009; Lam *et al*., 2010). Eventually, the limited budget must be used for the most important components and materials in buildings. The objective of this study is to develop a new model to optimize the management of public building facilities using the Condition Category Guides (CCG) as a measurement method.

Scope of the Study

The analysis is done on the waste-water installation system of four hotels in Tehran. The material used for waste-water systems is cast iron pipes. The analysis will be done on the waste-water networks of five-star hotels in Tehran. Instances will show how a best time approach to waste-water networks maintenance can help the owner with decision making regarding component maintenance time based on existing costs. This system controls existing budget in part of component maintenance and increases component service life and, finally, prevents early deterioration and wastewater plumbing systems replacement in four- and five-stars hotel buildings in Tehran (capital of Iran).

The scope is highlighted by the Tehran Area Hotel Union (TAHU), which is the largest hotel union in Iran. The TAHU divided the Tehran area into three smaller areas: North (N), Centre (C), and East (E). As shown in Fig. 1, the north area consists of five hotels, while the east area has only one hotel. The largest number of hotels is in centre area which includes 15 hotels.

Presently, the condition of hotel buildings in Tehran, including four- and five-star hotels, is continuous altering- that is, declining- for the following reasons:

- Age: The average age of four- and five-star hotels in Iran is more than 30 years old (TAHU, 2011)
- Tourist capacity: Presently, four- and five-star hotels in Iran are encountering extra pressure due to the lack of hotels with luxury class and first class in the country. This pressure will be increased with passing time, increasing population and tourism industry development, that puts great pressure on hotel components maintenance and repair programmes
- Incompetent maintenance: Research has shown that, in Iran, more than 30% of five-star hotels need to be repaired or upgraded to good comprehensive condition (Farokhmehr, 2009)

Limitation within the Building Component Maintenance Management Domain

In reviewing the available literature on the maintenance management of building components, there is a lack of strategy of the maintenance of the building component based on limited cost can result in an inefficient usage of the scarce resources available for maintenance (renewal, service, inspecting, repairing, replacement, etc.). Maintenance cost allocation monitoring at the component level can provide much needed information to the facilities manager and owner about the building components; a methodology for monitoring the important building components with respect to the sensitive condition of components in a building; a methodology for determining the appropriate assessment method of building components and forecasting component future conditions; and a decision support tool that can use the collected data to assist the building manager and owner to make meaningful maintenance management decisions regarding the continued usage of the components and materials.

The Case Study

This part identifies the important building component with respect to defects and indications and its effect on clients, staff and users of building. First, the top nine building components include interior surface, exterior surface, mechanical system, electrical system, communication system, clean water system, waste-water plumbing system, structural system and roof were identified through the literature and through discussion with engineers and inspectors in the industry (Arditi and Nawakorawit, 1999). Second, information that is related to the sensitivity of the building components was collected from a large owner organization, the Iranian Society of Consulting Engineers (ISCE). A comprehensive survey was then performed between experienced personnel at the ISCE in order to understand the various problems of component and statistics related to difficult percentages of replacing, repairing, cleaning and inspecting among components. The respondents indicated the most difficult to replace, clean and inspect associated with the selected building component, which was derived through a questionnaire. This methodology is a quantitative method and formed the background information for the selected component described.

The Analysis of the Selection of Waste-water Plumbing System as the Most Important Component

In May 2010 a survey was conducted on the largest 100 building Companies in the Iran to investigate the problems related to Component Condition Assessment (CCA) science of buildings. Questionnaires were distributed in big cities of Iran including Tehran, Isfahan and Yazd. The findings identified the level of difficulty in cleaning, inspecting, repairing and replacing various building components. Statistical analysis shows that the three most difficult components to repair and replace that were indicated by the respondents are the mechanical system, the waste-water system and the electrical system, as shown in Fig. 2. The waste-water plumbing system appears to be one of the major areas of difficulty because it was ranked by the assessors and engineers.

Assessments show that mismanagement in maintenance of waste-water plumbing affects the increasing cost of building and reducing building’s age. Most firms were faced with this kind of problem concerning repair of waste-water plumbing includes reproductive equipment, heat equipment, fittings equipment and transfer equipment and distribution.

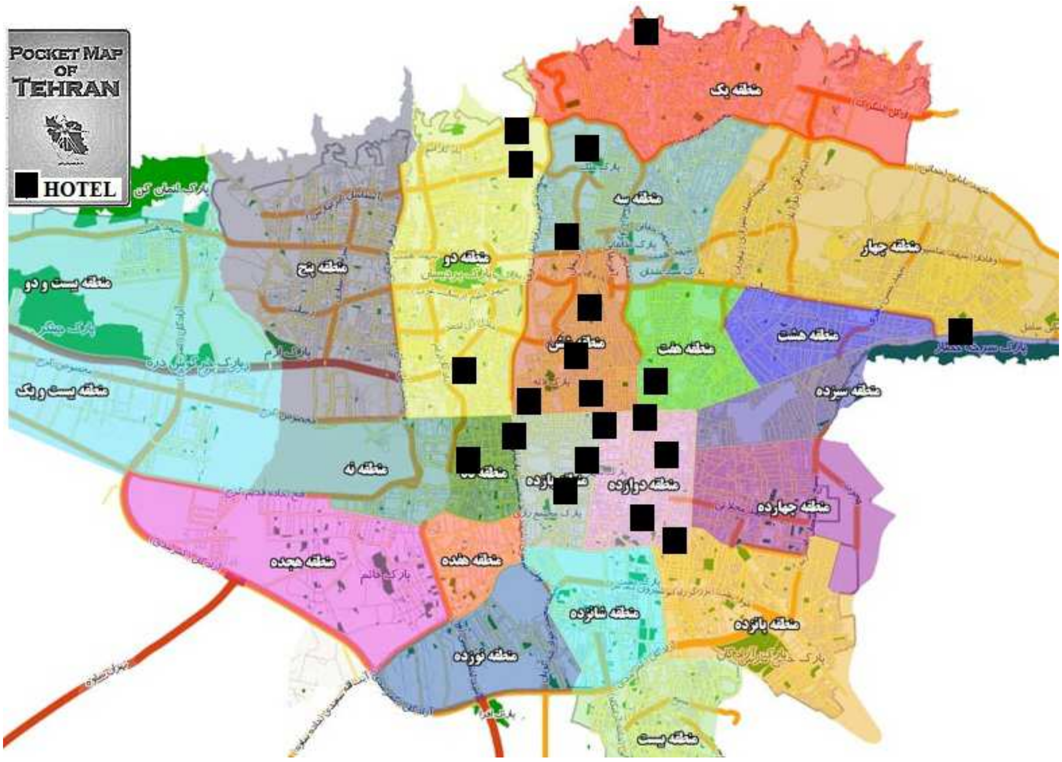

Fig. 1. Locations of the hotels at the TAHU (2011)

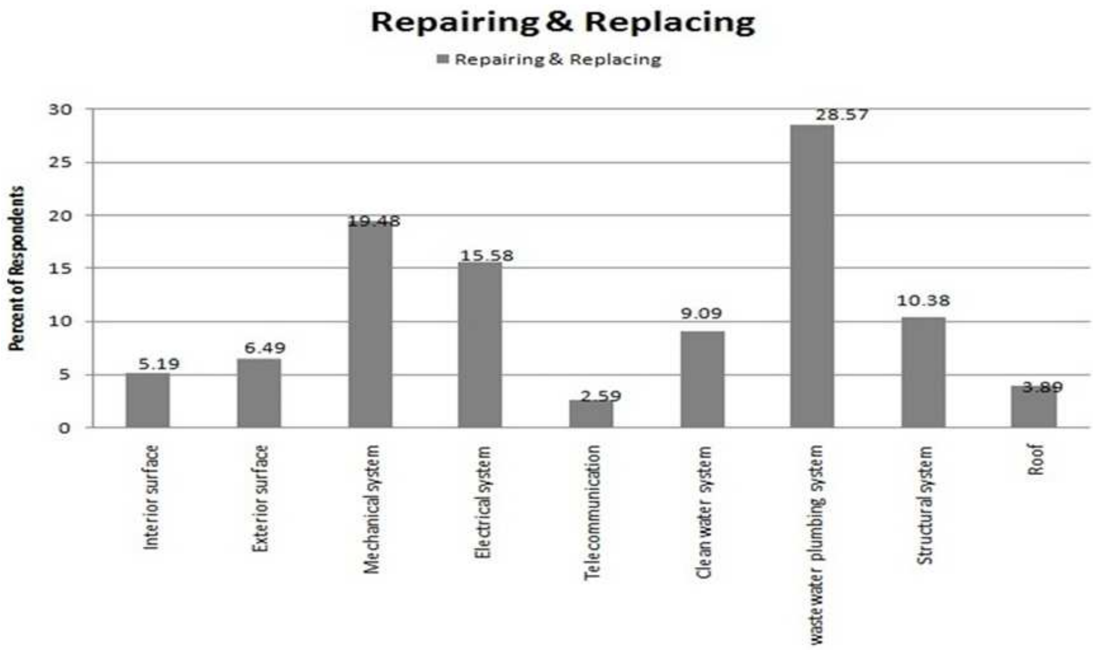

Fig. 2. Difficulties of building component maintenance (repairing, replacing, inspecting, cleaning and other activities) (Amani *et al*., 21012)

In addition, the ISCE personnel reported that, for technical reasons, the plumbing system, which is part of the waste-water service, there is the most important in the case of hotels. Other findings related to ISCE by Amani *et al*. (2012) that investigated the comparative effect of a component's failure on cost and safety building activities and on other components, verified the importance of the waste-water plumbing system, as it obtained the highest score. Based on these reasons, the plumbing system was selected for this research: Cast iron pipes in waste-water systems.

Component Condition Assessment System (CCAS)

USACERL (Uzarski, 1993) has been developed by the U.S. Army corps engineers at the Engineering Research and Development Center. Construction Engineering Research Laboratories (CERL) in plain. This method supports engineers, assessors and component managers with a toll that provides decisions regarding when and where is the best to maintain and repair buildings and their key components. USACERL condition index method is condition-based with functions which comprise an asset of major building components; condition indices; condition prediction skill; and comprehensive condition description for each CI value (Builder, 2008). The USACERL condition indices were designed to support a purpose and quantitative means for component condition assessment while supporting and assessors. The scale used in all of the USACERL indices ranges from 0 to 100 and is divided into seven condition categories (Table 1). This method is used for every component in a building system or non-building system. This method has a comprehensive condition description for assessing component condition (Table 1); predicting the future component condition; and predicting the suitable time for repair and maintenance. This model is extendable, as it has amplitude 0 to 100. Namely, each range has a domain. For example, (100-85), (85-70), … and (10-0). Therefore, component with long service life can use this method by selecting more properties. In fact, it can have one hundred properties for assessment of component.

Research Methodology

This comprehensive study surveys hotel area repair and maintenance suitability through analysis of technical resource models, financial plan (budget), structured and unstructured estimates and direct field observation within hotels and hotel areas from the standpoint of engineers and installation inspectors with more than 30 years experience in the field of piping system inspection and repairs in Tehran.

The Building Component Assessment Process (BCAP) was developed in three main stages:

- Stage 1: Data collection
- Stage 2: Data analysis
- Stage 3: Verification of data analysis

Stage 1: Data Collection-Technical and Financial Information

Stage I, involves gathering of information and data on existing practices from two levels of sources, technical and financial. Two information gathering techniques used were questionnaires and interviews. Documents analyzed include engineers and inspectors' experiences and knowledge and financial reports. Thirty installation companies and four hotels were included in the questionnaire and interview samples respectively.

The technical data was collected based on engineers and inspectors' experiences and knowledge. This sheet was distributed among inspectors and engineers for collecting and computing component repair time during its service life over time. Technical data instruction is method of rating and determination of maintenance time of component in its service life based on condition category guidelines. The rating panel that contributed to this development is formed through contractors firms and related consultants with the component of public building. These panels are 30 installation consultant firms. As depicted in Table 2, this data is to achieve the information related to the maintenance time of cast iron pipe from stand point of engineers and inspectors' experiences in past years with respect to the moving the index from 100 to 0 during components' service life. These data (maintenance year) will be used for analysis research case studies in this study. Each firm has predicted the times of cast iron pipe maintenance in waste-water system based on CCG from index 85 to index 10. The maintenance times are based on a period of 50 years that corresponds to the service life of cast iron pipes in waste-water plumbing systems which is approximately 50 years (HOAM, 1993). These predictions were done based on CCG condition discretion as a guide and the engineer's experiences. After a given set of sheets was completed, the researcher has reviewed the data during the session. The rating average was computed in each condition index value. Next, the process of standard deviation was calculated in each condition index (85, 70, 55, 40 and 25) from rating corrections and accurate responses by engineers and assessors. Any rating that is more than the required standard deviation in each index value from the average was flagged for a re-rate. When the re-rate process was done (re-rate in Table 2), researcher computed the average of responses in each index value. These averages are the maintenance year during service life of cast iron pipe.

Table 1. Condition Category Guidelines (CCG)

Condition rating	Category	Condition description: Amount of distress	Functionality	Type of M&R
71-85	Very good	Minor deterioration	Slightly impaired	Preventive or minor maintenance, or minor repair
56-70	Good	Moderate deterioration	Somewhat impaired	Moderate maintenance or minor repair
41-55	Fair	Significant deterioration	Seriously impaired	Significant maintenance or moderate repair
26-40	Poor	Server deterioration over small portion of sample unit	Critically impaired	Major repair
11-25	Very Poor	Server deterioration over moderate portion of sample unit	Barely exists	Major repair but less than total restoration
0-10	Failed	Server deterioration over large portion of sample unit	Lost	Total restoration

Table 2. Technical data collection and re-rate based on CCG

Firms no. Index	85	70	55	40	25	10	Firms no. Index	Rerate 85	70	55	40	25	10
1	8.0	15.0	24.0	32	41.0	50	1				33.0	42.0	
2	5.0	18.0	29.0	38	45.0	50	2	7					
3	9.0	13.0	22.0	37	40.0	50	3		15.0	23.0		42.0	
4	5.0	15.0	26.0	30	42.0	50	4	8			33.0		
5	8.0	12.0	21.0	34	41.0	50	5		15.0	23.0		42.0	
6	8.0	18.0	27.0	37	45.0	50	6						
7	9.0	16.0	26.0	36	41.0	50	7					42.0	
8	10.0	17.0	27.0	33	45.0	50	8						
9	11.0	19.0	26.0	33	44.0	50	9						
10	9.0	21.0	29.0	37	44.0	50	10		19.0				
11	8.0	15.0	28.0	36	46.0	50	11						
12	11.0	22.0	34.0	39	45.0	50	12		19.0	30.0			
13	9.0	16.0	22.0	31	42.0	50	13			23.0			
14	10.0	21.0	34.0	39	44.0	50	14		19.0	30.0			
15	9.0	17.0	28.0	38	45.0	50	15						
16	6.0	15.0	24.0	37	42.0	50	16	7					
17	9.0	18.0	21.0	35	43.0	50	17		23.0				
18	7.0	14.0	20.0	34	45.0	50	18		15.0	23.0			
19	6.0	16.0	29.0	37	44.0	50	19	8					
20	10.0	17.0	26.0	38	44.0	50	20						
21	9.0	18.0	25.0	33	41.0	50	21					42.0	
22	11.0	19.0	28.0	36	46.0	50	22						
23	12.0	25.0	32.0	39	47.0	50	23		19.0	30.0		45.0	
24	10.0	20.0	33.0	39	44.0	50	24		19.0	30.0			
25	8.0	16.0	27.0	38	46.0	50	25						
26	6.0	14.0	22.0	34	45.0	50	26	7	15.0	23.0			
27	11.0	17.0	28.0	29	44.0	20	27						
28	8.0	16.0	26.0	34	41.0	50	28					42.0	
29	10.0	19.0	28.0	39	46.0	50	29						
30	9.0	17.0	25.0	38	44.0	50	30						
Average	8.7	17.0	26.5	36	43.8	50	Average	9	16.9	26.5	36.1	43.9	50
Standard division	2.0	2.5	3.5	3	2.0	-							

Table 3 shows the maintenance year data based on Condition Category Guidelines (CCG). Maintenance year has been predicted by engineers and inspectors in 30 firms based on the condition description column as a guide and engineers' experiences over the past years. This prediction is based on the period of 50 years (service life of cast iron pipe) with respect to moving the index from 100 to 10 during service life of cast iron pipe. For example, engineers predicted the cast iron pipe needs routine maintenance or minor repair after 36 years (index 40) and the waste-water plumbing system needs major repair after 43 year (index 25).

Table 3. Data collection of maintenance predictive year based on CCG

Condition rating	Category	Maintenance year	Condition description: Amount of distress	Functionality	Type of M&R
71-85	Very Good	9.0	Minor deterioration	Slightly impaired	Preventive or minor maintenance, or minor repair
56-70	Good	16.9	Moderate deterioration	Somewhat impaired	Moderate maintenance or minor repair
41-55	Fair	26.5	Significant deterioration	Seriously impaired	Significant maintenance or moderate repair
26-40	Poor	36.1	Server deterioration over small portion of sample unit	Critically impaired	Major repair
11-25	Very Poor	43.9	Server deterioration over moderate portion of sample unit	Barely exists total restoration	Major repair but less than
0-10	Failed	50.0	Server deterioration over large portion of sample unit	Lost	Total restoration

Financial information is related to the annual maintenance cost allocated for waste-water plumbing system in hotels that is analyzed through data collection by financial managers. Financial sheet was designed based on the data gathering process covering annual cost information for maintenance of waste-water piping system in hotel building. The financial information is in two situations of historical and predictive data. In this study, financial managers fill financial information from 1990 to 2009 for historical data (existing financial documents) and from 2011 to 2060 for predictive data. The historical data was collected for annual maintenance cost allocated at various condition index values for the cast iron pipe component in the waste-water plumbing system based on maintenance cost information in past 20 years. The predictive data is selected based on period of 50 years that corresponds to the useful lifespan of cast iron pipe which is approximately 50 years (HOAM, 1993) using the prediction process and the average inflation rate computed from 1990 to 2009.

Stage 2: Data Analysis

The process was developed through calculations and simulation based on existing data and information. These calculations include four steps and were done in MS Excel software:

- Step 1: Calculation of saving estimate;
- Step 2: Calculation of replacement cost estimate
- Step 3: Calculation of repair cost estimate
- Step 4: Financial analysis

Step 1: Calculation of Saving Estimate

The saving is computed based on the maintenance cost allocated for service, repair, inspection and clean annually in part of component maintenance until year i. The saving is estimated based on Condition Category Guidelines (CCG) and maintenance year (technical data) for waste-water plumbing system in hotels through the following formula:

Saving calculation for predictive data:

$$\left[\sum_{i=2011}^{n} FI_i\right] \tag{1}$$

Where:
FI = Financial information
n = Year-end of annual maintenance cost in desired index (index 85 to index 10)

Saving calculation for historical data:

$$\left[\sum_{i=1990}^{n} FI_i\right] \tag{2}$$

Where:
FI = Financial information
n = Year-end of annual maintenance cost in desired index (index 85 to index 10)

Step 2: Calculation of Replacement Cost Estimate

The unit replacement cost is according to the current price of pipe in the Iran's market. The replacement cost is calculated based on dimension of waste-water plumbing system (size and length) of hotels, price of cast iron pipe in the Iran's market and average inflation rate for calculation of predictive data. The predictive data is calculated with inflation rate of 8% based on average inflation rate of cast iron pipe in Iran's market from 2000 to 2010 (Index Mundi, 2011; Price Index, 2011). The replacement cost is based on price index in Iran and including labor cost, transportation cost and the total cost of works (Price index, 2011). The replacement cost is estimated through following formula:

$$Rpc = Lp \times Cp \tag{3}$$

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Where:
Rpc = Replacement cost in desired year
Lp = Length of pipe
Cp = Cost based on \$/m

Step 3: Calculation of Repair Cost Estimate

Repair cost is computed based on a standard equation. From these CI values, a parametric model of material repair cost, which is a comprehensive estimation of the corrective repair cost, is described as a percentage of the total replacement cost. Repair and maintenance calculations are based on American Society of Engineers formulas (Lazarus, 2012). There are other studies in the field of repair cost computations including Sajadi and Moghadam (2005) and RSMC, (2008). This section defines the repair cost using the existing statistics of construction industry. The repair cost is analyzed by using the economic techniques and financial issues in repair and maintenance based on existing definitions. This equation is linear and using the virtual variable:

$$Rc = Rpc * (100 - N / 90) \tag{4}$$

Where:
Rc = Estimated unit repair cost in year i
Rpc = Estimated unit replacement cost in year i
N = Desired condition index in situations of 10 to 100

Step 4: Financial Analysis and Simulation

Financial analysis is computed based on the benefit to cost ratio for optimum maintenance cost at various condition index values for the cast iron pipe in the waste-water plumbing system in hotels. Benefit to Cost Ratio (BCR) analysis is a technique for estimating a project or investment by comparing the economic benefits with the economic costs of the activity. BCR analysis has several objectives. First, BCR can be used to estimate the economic value of a project. Second the results from a series of BCR analyses can be used to compare competing projects (Ruegg and Marshall, 1990). The BCR is the benefit to cost ratio method recast to fit the situation that an investment's primary advantage is lower costs. BCR system illustrates that a ratio less than 1.0 indicates an uneconomical investment; a ratio of 1.0 Indicates an investment that benefits or savings just equal its costs; and a ratio greater than 1.0 illustrates an economic project. BCR is Comparison of the present value of an investment decision or project with its initial cost. Researchers can use BCR to combine interdependent building systems whether or not there is a budget constraint. But a primary application of BCR is the set funding priorities among projects when there is a limited budget. BCRs can guide the allocation of limited budgets among competing building components investments (Ruegg and Marshall, 1990). Benefit is computed based on total annual maintenance cost allocated for cast iron pipe per year until repair time at year i based on saving estimation for waste-water network of hotels (step 1). Also, for a maintenance performance, the cost is the parametric evaluation of repair cost based on the condition index at year i (step 3). The data, information and calculations are implemented based on value of money and inflation rate computed of Iranian Rials currency (1 IRR = 0.0001 USD). To account for the time value of money, an inflation rate is used in this analysis for financial data of each hotel in saving estimation and an inflation rate of 8% for replacement cost in cost estimation. All benefits and costs are expressed in discounted present value terms. The BCR is calculated with following equation:

$$BCR = Benefit / Cost \tag{5}$$

Where:
Benefit = Total annual maintenance budget until repair time
Cost (\$) = Repair cost in the year i

Analysis of Case Studies

The process is tested in four steps for four case studies. These steps is analyzed and simulated in two situations of historical and predictive data for each case-study. The purpose of data analysis in two situations of historical and predictive data was the verification of data analysis. This model is for the prediction of optimum maintenance time of the waste-water network in hotel buildings with respect to the limited cost allocated to the department of component maintenance. If the optimum condition index is the same in two situations of historical and predictive data, it implies the workable capability of the process for accurate prediction in the future. The analysis results show that the process was tested for all case studies one by one.

In the verification of data analysis process, at first, the historical data have been considered and run for each case study and then the predictive data will be run in the process. In the next stage, the simulated results are compared in situations of historical and predictive data together. If the optimum condition index and also ascending and descending diagrams of condition indices are the same in two situations of historical and predictive data, it results in a workable process. Table 4 shows the pipe dimension information for waste-water network of case studies.

Analysis of Historical Data

Table 5 shows the financial historical data for case studies in the past 20 years. The financial information is related to the annual maintenance cost allocated for waste-water plumbing system in hotel buildings that were collected through gathering data by financial managers. In this table, annual maintenance costs are approximately 0 for first three years of operation in waste-water network of hotels from 1990 to 1992 because the maintenance cost is 0 approximately in first years. This information is based on existing financial documents in case studies.

Step 1 is calculation of financial historical data to achieve the saving estimate. The saving is calculated based on the budget collected for maintenance annually in part of component inspection until year i. The saving is estimated based on CCG condition index and maintenance year (accidental) for waste-water plumbing system in case studies (Table 6).

Table 4. Pipe dimension data of case studies

Case Study 1	Diameter (inch)	2	3	4	5	6
	Length (m)	1100	750	650	200	150
Case Study 2	Diameter (inch)	2	3	4	5	6
	Length (m)	1300	850	800	200	150
Case Study 3	Diameter (inch)	2	3	4	5	6
	Length (m)	1000	600	750	300	150
Case Study 4	Diameter (inch)	2	3	4	5	6
	Length (m)	3200	2500	2700	600	400

Table 5. Financial historical data for case studies

	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)
Case Study 1	1990	-	1994	1700	1998	3000	2002	4500	2006	5600
	1991	-	1995	2300	1999	3300	2003	4700	2007	5800
	1992	-	1996	2500	2000	3800	2004	4900	2008	5900
	1993	1400	1997	2700	2001	4100	2005	5200	2009	6100
Case Study 2	1990	-	1994	2000	1998	3600	2002	5100	2006	6500
	1991	-	1995	2500	1999	3900	2003	5400	2007	6800
	1992	-	1996	2800	2000	4200	2004	5800	2008	7200
	1993	1600	1997	3200	2001	4700	2005	6200	2009	7600
Case Study 3	1990	-	1994	1000	1998	2000	2002	2700	2006	3900
	1991	-	1995	1100	1999	2200	2003	2900	2007	4200
	1992	-	1996	1300	2000	2400	2004	3300	2008	4650
	1993	800	1997	1800	2001	2500	2005	3600	2009	5000
Case Study 4	1990	-	1994	5100	1998	7900	2002	10600	2006	13000
	1991	-	1995	5900	1999	8700	2003	11200	2007	13800
	1992	-	1996	6500	2000	9200	2004	11700	2008	14700
	1993	4300	1997	7000	2001	9900	2005	12100	2009	15600

Table 6. Computation of saving estimate in situation of historical data

Historical data

Saving condition index	Maintenance year/accidental	Computation basing on the maintenance year	Result ($) Case study 1	Result ($) Case study 2	Result ($) Case study 3	Result ($) Case study 4
Saving in Index 85	3.3	$\left(\sum_{i=1990}^{1992} FI_i\right)+\left(\left(FI_{1993}\right)\times\left(\frac{4}{12}\right)\right)$	466.66	533.3	266.67	1433.33
Saving in Index 70	6.6	$\left(\sum_{i=1990}^{1995} FI_i\right)+\left(\left(FI_{1996}\right)\times\left(\frac{6}{12}\right)\right)$	6858.30	7733.3	3658.30	19091.67
Saving in Index 55	9.9	$\left(\sum_{i=1990}^{1998} FI_i\right)+\left(\left(FI_{1999}\right)\times\left(\frac{11}{12}\right)\right)$	16625.00	19275.0	10016.67	44675.00
Saving in Index 40	13.2	$\left(\sum_{i=1990}^{2002} FI_i\right)+\left(\left(FI_{2003}\right)\times\left(\frac{2}{12}\right)\right)$	30083.33	34500.0	18283.30	76966.67
Saving in Index 25	16.5	$\left(\sum_{i=1990}^{2005} FI_i\right)+\left(\left(FI_{2006}\right)\times\left(\frac{6}{12}\right)\right)$	46900.00	54250.0	29550.00	116600.00
Saving in Index 10	20.0	$\left(\sum_{i=1990}^{2009} FI_i\right)$	63200.00	79100.0	45350.00	167200.00

The predictive data is verified by historical data based on the past 20 years. Second column of Table 6 (maintenance year-historical data) shows that the period of 20 years is divided into six parts based on the CCG system. These data are accidental for verification of predictive data and prediction process during future years. The computation of saving estimate is done based on the maintenance year in each condition index. For example in Table 6, in the fifth row (index 25) the saving is equal to sum of the financial information of historical data (Table 5) from 1990 to 2005 (16 years) plus 6/12 of 2006 (5/10 = 6/12).

Step 2 is presentation of replacement cost data in the past 20 years (Table 7). The unit replacement cost is according to the current price of cast iron pipe in the Iran's market.

Table 7. Computation replacement cost estimate in situation of historical data

	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)
Case Study 1	1990	2961.511	1994	6140.991	1998	12733.959	2002	22638.150	2006	34126.000
	1991	3553.814	1995	7369.189	1999	15280.750	2003	25153.500	2007	53232.500
	1992	4264.577	1996	8843.027	2000	18336.901	2004	27505.500	2008	58555.750
	1993	5117.492	1997	10611.632	2001	20374.335	2005	31913.000	2009	64411.325
Case Study 2	1990	3421.657	1994	7095.148	1998	14712.500	2002	26134.650	2006	39403.000
	1991	4105.988	1995	8514.178	1999	17655.000	2003	29038.500	2007	61400.000
	1992	4927.186	1996	10217.013	2000	21186.000	2004	31755.000	2008	67540.000
	1993	5912.623	1997	12260.416	2001	23521.000	2005	36849.000	2009	74294.000
Case Study 3	1990	2991.476	1994	6203.125	1998	12862.800	2002	22867.200	2006	34417.500
	1991	3589.771	1995	7443.750	1999	15435.360	2003	25408.000	2007	53910.000
	1992	4307.725	1996	8932.500	2000	18522.432	2004	27778.500	2008	59301.000
	1993	5169.270	1997	10719.000	2001	20580.480	2005	32192.500	2009	65231.100
Case Study 4	1990	9797.495	1994	20316.085	1998	42127.435	2002	76461.300	2006	115007.000
	1991	11756.994	1995	24379.302	1999	50552.922	2003	84957.000	2007	179970.000
	1992	14108.392	1996	29255.163	2000	63191.157	2004	92890.000	2008	197967.000
	1993	16930.071	1997	35106.195	2001	69510.273	2005	107641.000	2009	217763.700

Table 8. Computation of repair cost estimate in situation of historical data

	Replacement cost ($)	Index	Maintenance year	Calculation	Repair cost ($)
Case Study 1					
	4264.577	85	3.3	4264.577× ((100-85)/(100-10))	710.762
	7369.189	70	6.6	7369.189× ((100-70)/(100-10))	2456.396
	12733.959	55	9.9	12733.959× ((100-55)/(100-10))	6366.979
	22638.150	40	13.2	22638.15× ((100-40)/(100-10))	15092.100
	31913.000	25	16.5	31913× ((100-25)/(100-10))	26594.166
	64411.325	10	20.0	64411.325× ((100-10)/(100-10))	64411.325
Case Study 2					
	4927.186	85	3.3	4927.186× ((100-85)/(100-10))	821.200
	8514.178	70	6.6	8514.178× ((100-70)/(100-10))	2838.600
	14712.500	55	9.9	14712.5× ((100-55)/(100-10))	7356250.000
	26134.650	40	13.2	26134.65× ((100-40)/(100-10))	17423.100
	36849.000	25	16.5	36849× ((100-25)/(100-10))	30707.500
	74294.000	10	20.0	74294× ((100-10)/(100-10))	74294.000
Case Study 3					
	4307.725	85	3.3	4307.725× ((100-85)/(100-10))	717.950
	7443.750	70	6.6	7443.75× ((100-70)/(100-10))	2481.250
	12862.800	55	9.9	12862.8× ((100-55)/(100-10))	6431.400
	22867.200	40	13.2	22867.2× ((100-40)/(100-10))	15244.800
	32192.500	25	16.5	32192.5× ((100-25)/(100-10))	26827.100
	65231.100	10	20.0	65231.1× ((100-10)/(100-10))	65231.100
Case Study 4					
	14108.392	85	3.3	14108.392× ((100-85)/(100-10))	2351.398
	24379.302	70	6.6	24379.302× ((100-70)/(100-10))	8126.434
	42127.435	55	9.9	42127.435× ((100-55)/(100-10))	21063.717
	76461.300	40	13.2	76461.3× ((100-40)/(100-10))	50974.200
	107641.000	25	16.5	107641× ((100-25)/(100-10))	89700.833
	217763.700	10	20.0	217763.7× ((100-10)/(100-10))	217763.700

The replacement cost is calculated based on dimension of waste-water plumbing system (size and length) of case studies, price of cast iron pipe in the Iran's market.

Step 3 is calculation of repair cost estimate to achieve the cost data in BCR (Table 8). Repair cost is computed based on standard Equation 4. Between these condition index scales a parametric model of component repair cost is described as a comprehensive estimation of the corrective repair cost as a percentage of the total replacement cost in waste-water plumbing system of case studies.

Table 9 and Fig. 3 depict the analysis of optimum maintenance management of cast iron pipe in waste-water plumbing system for case studies based on a period of 20 years.

Analysis of Predictive Data

Table 10 shows the financial predictive data for case studies. The predictive data is selected based on period of 50 years that corresponds to the useful lifespan of cast iron pipe which is approximately 50 years using the prediction process and the average inflation rate computed from 1990 to 2009 (historical data) (Table 5).

This information is based on existing historical documents in case studies.

Table 11 presents the calculation of financial predictive data to achieve the saving estimate. For example in Table 11, in the second row (index 70) the saving is equal to sum of the financial information of predictive data (Table 10) from 2011 to 2026 (16 years) plus 11/12 of 2027 (9/10 ≈ 11/12).

Table 12 is calculation of replacement cost data for the future 50. The predictive data of replacement cost is calculated with inflation rate of 8% based on average inflation rate of cast iron pipe in Iran's market from 2000 to 2010 (Index Mundi, 2011).

Table 13 presents the calculation of repair cost estimate to achieve the investment information.

Table 14 and Fig. 4 depict the analysis of optimum maintenance management of cast iron pipe in waste water plumbing system for case studies based on a period of 50 years.

Stage 3: Verification of Data Analysis

Verification of data analysis is concerned with identifying historical data in the model by comparing historical data and predictive data to analytical or workable capability for process. Verification of analysis process is required when a predictive process is the end product. The workable process must then reflect the strength of the inference being made from the historical database to the prediction. The verification of data analysis process is motivated by the need for practical process for making predictions to support the maintenance management process and by the current lack of guidelines, standards and procedures for performing model.

Table 9. Financial analysis of historical data

	CCG index	Maintenance year	Cost estimation($)	Saving estimation($)	BCR
Case Study 1					
	85	3.3	710.762	466.66	0.66
	70	6.6	2456.396	6858.30	2.79
	55	9.9	6366.979	16625.00	2.61
	40	13.2	15092.100	30083.33	1.99
	25	16.5	26594.166	46900.00	1.76
	10	20.0	64411.325	63200.00	1.05
Case Study 2					
	85	3.3	821.200	533.30	0.65
	70	6.6	2838.600	7733.30	2.72
	55	9.9	7356250.000	19275.00	2.62
	40	13.2	17423.100	34500.00	1.98
	25	16.5	30707.500	54250.00	1.77
	10	20.0	74294.000	79100.00	1.06
Case Study 3					
	85	3.3	717.950	266.67	0.37
	70	6.6	2481.250	3658.30	1.47
	55	9.9	6431.400	10016.67	1.56
	40	13.2	15244.800	18283.30	1.20
	25	16.5	26827.100	29550.00	1.10
	10	20.0	65231.100	45350.00	0.70
Case Study 4					
	85	3.3	2351.398	1433.33	0.61
	70	6.6	8126.434	19091.67	2.35
	55	9.9	21063.717	44675.00	2.12
	40	13.2	50974.200	76966.67	1.51
	25	16.5	89700.833	116600.00	1.30
	10	20.0	217763.700	167200.00	0.77

Table 10. Financial predictive data for case studies

	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)	Year	Annual maintenance cost ($)
Case study 1										
	2011	-	2021	9100	2031	13800	2041	20500	2051	30400
	2012	-	2022	9500	2032	14400	2042	21300	2052	31600
	2013	-	2023	9900	2033	15000	2043	22200	2053	32900
	2014	-	2024	10300	2034	15600	2044	23100	2054	34200
	2015	-	2025	10800	2035	16200	2045	24000	2055	35600
	2016	-	2026	11300	2036	16800	2046	25000	2056	37000
	2017	-	2027	11800	2037	17500	2047	26000	2057	38500
	2018	7900	2028	12300	2038	18200	2048	27000	2058	40000
	2019	8300	2029	12800	2039	18900	2049	28100	2059	41600
	2020	8700	2030	13300	2040	19700	2050	29200	2060	43300
Case study 2										
	2011	-	2021	12200	2031	19800	2041	32200	2051	52700
	2012	-	2022	12800	2032	20800	2042	33800	2052	55300
	2013	-	2023	13400	2033	21800	2043	35500	2053	58100
	2014	-	2024	14100	2034	22900	2044	37300	2054	61000
	2015	-	2025	14800	2035	24000	2045	39200	2055	64100
	2016	-	2026	15500	2036	25200	2046	41200	2056	67300
	2017	-	2027	16300	2037	26500	2047	43300	2057	70700
	2018	10500	2028	17100	2038	27800	2048	45500	2058	74200
	2019	11000	2029	18000	2039	29200	2049	47800	2059	77900
	2020	11600	2030	18900	2040	30700	2050	50200	2060	81800
Case study 3										
	2011	-	2021	10700	2031	23300	2041	50300	2051	108600
	2012	-	2022	11600	2032	25100	2042	54300	2052	117300
	2013	-	2023	12500	2033	27100	2043	58600	2053	126600
	2014	-	2024	13500	2034	29300	2044	63300	2054	136800
	2015	-	2025	14600	2035	31700	2045	68400	2055	147700
	2016	-	2026	15800	2036	34200	2046	73900	2056	159600
	2017	-	2027	17100	2037	36900	2047	79800	2057	172300
	2018	-	2028	18500	2038	39900	2048	86200	2058	186100
	2019	-	2029	19900	2039	43100	2049	93100	2059	201000
	2020	-	2030	21500	2040	46500	2050	100500	2060	217100
Case study 4										
	2011	-	2021	32200	2031	57700	2041	103300	2051	185100
	2012	-	2022	34100	2032	61100	2042	109500	2052	196200
	2013	-	2023	36200	2033	64800	2043	116100	2053	208000
	2014	-	2024	38300	2034	68700	2044	123100	2054	220500
	2015	-	2025	40600	2035	72800	2045	130500	2055	233700
	2016	-	2026	43100	2036	77200	2046	138300	2056	247700
	2017	-	2027	45700	2037	81800	2047	146600	2057	262600
	2018	27000	2028	48400	2038	86800	2048	155400	2058	278300
	2019	28600	2029	51300	2039	92000	2049	164700	2059	295000
	2020	30400	2030	54400	2040	97500	2050	174600	2060	312700

Table 11. Computation of saving estimate in situation of predictive data

Predictive data

Saving Condition Index	Maintenance Year	Computation basing on the Maintenance Year	Result ($) Case study 1	Result ($) Case -study 2	Result ($) Case study 3	Result ($) Case study 4
Saving in Index 85	9.0	$\left(\sum_{i=2011}^{2019} \mathrm{FI}_i\right)$	16200.00	21500.00	0	55600.00
Saving in Index 70	16.9	$\left(\sum_{i=2011}^{2026} FI_i\right)+\left(\left(FI_{2027}\right)\times\left(\frac{11}{12}\right)\right)$	96616.66	130841.67	94375	352391.66
Saving in Index 55	26.5	$\left(\sum_{i=2011}^{2036} FI_i\right)+\left(\left(FI_{2037}\right)\times\left(\frac{6}{12}\right)\right)$	236550.00	333950.00	344850	953500.00
Saving in Index 40	36.1	$\left(\sum_{i=2011}^{2046} FI_i\right)+\left(\left(FI_{2047}\right)\times\left(\frac{1}{12}\right)\right)$	440366.66	657708.30	868250	2003716.66
Saving in Index 25	43.9	$\left(\sum_{i=2011}^{2053} FI_i\right)+\left(\left(FI_{2054}\right)\times\left(\frac{11}{12}\right)\right)$	674750.00	1062916.67	1699100	3424225.00
Saving in Index 10	50.0	$\left(\sum_{i=2011}^{2060} FI_i\right)$	913600.00	1504000.00	2794300	5072600.00

Table 12. Computation replacement cost estimate in situation of predictive data

	Year	Replacement cost ($)	Year	Replacement cost ($)	Year	Replacement cost ($)	Year	Replacement cost ($)	Year	Replacement cost ($)
Case study 1										
	2011	66725	2021	144054	2031	311002	2041	671430	2051	1449568
	2012	72063	2022	155578	2032	335882	2042	725145	2052	1565534
	2013	77828	2023	168024	2033	362753	2043	783156	2053	1690776
	2014	84054	2024	181466	2034	391773	2044	845809	2054	1826039
	2015	90778	2025	195984	2035	423115	2045	913474	2055	1972122
	2016	98040	2026	211662	2036	456964	2046	986552	2056	2129891
	2017	105884	2027	228596	2037	493521	2047	1065476	2057	2300283
	2018	114354	2028	246883	2038	533003	2048	1150714	2058	2484306
	2019	123503	2029	266634	2039	575643	2049	1242771	2059	2683050
	2020	133383	2030	287965	2040	621695	2050	1342193	2060	2897694
Case study 2										
	2011	76375	2021	164887	2031	355980	2041	768535	2051	1659210
	2012	82485	2022	178078	2032	384459	2042	830018	2052	1791947
	2013	89083	2023	192325	2033	415215	2043	896419	2053	1935302
	2014	96210	2024	207711	2034	448433	2044	968133	2054	2090127
	2015	103907	2025	224328	2035	484307	2045	1045583	2055	2257337
	2016	112219	2026	242274	2036	523052	2046	1129230	2056	2437924
	2017	121197	2027	261656	2037	564896	2047	1219569	2057	2632958
	2018	130893	2028	282588	2038	610088	2048	1317134	2058	2843594
	2019	141364	2029	305195	2039	658895	2049	1422505	2059	3071082
	2020	152673	2030	329611	2040	711606	2050	1536305	2060	3316769
Case study 3										
	2011	68950	2021	148857	2031	321372	2041	693820	2051	1497905
	2012	74466	2022	160766	2032	347082	2042	749325	2052	1617738
	2013	80423	2023	173627	2033	374849	2043	809271	2053	1747157
	2014	86857	2024	187518	2034	404837	2044	874013	2054	1886929
	2015	93805	2025	202519	2035	437224	2045	943934	2055	2037884
	2016	101310	2026	218721	2036	472202	2046	1019449	2056	2200914
	2017	109414	2027	236218	2037	509978	2047	1101005	2057	2376988
	2018	118168	2028	255116	2038	550776	2048	1189085	2058	2567147
	2019	127621	2029	275525	2039	594838	2049	1284212	2059	2772519
	2020	137831	2030	297567	2040	642426	2050	1386949	2060	2994320
Case study 4										
	2011	223450	2021	482411	2031	1041490	2041	2248500	2051	4854344
	2012	241326	2022	521004	2032	1124810	2042	2428380	2052	5242691
	2013	260632	2023	562685	2033	1214794	2043	2622651	2053	5662107
	2014	281482	2024	607699	2034	1311978	2044	2832463	2054	6115075
	2015	304001	2025	656315	2035	1416936	2045	3059060	2055	6604281
	2016	328321	2026	708821	2036	1530291	2046	3303785	2056	7132624
	2017	354587	2027	765526	2037	1652715	2047	3568087	2057	7703234
	2018	382954	2028	826769	2038	1784932	2048	3853535	2058	8319493
	2019	413590	2029	892910	2039	1927726	2049	4161817	2059	8985052
	2020	446677	2030	964343	2040	2081945	2050	4494763	2060	9703856

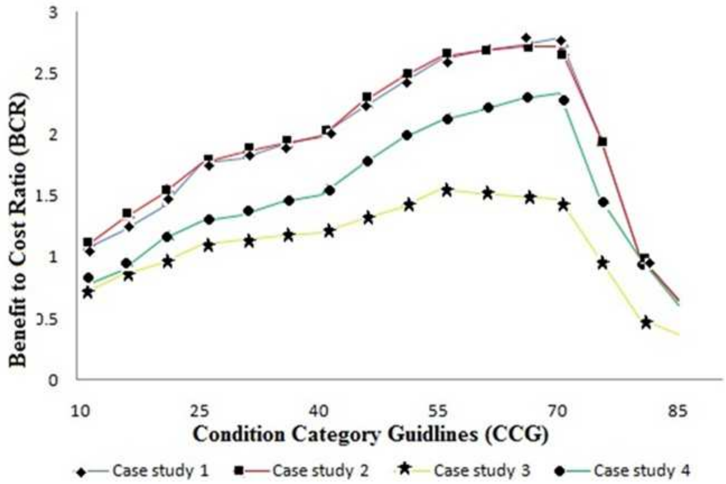

Fig. 3. Optimum facilities maintenance time based on highest BCR (historical data)

Table 13. Computation of repair cost estimate in situation of predictive data

	Replacement Cost ($)	Maintenance index	Year	Calculation	Repair Cost ($)
Case study 1					
	123503	85	9.0	123503× ((100-85)/(100-10))	20583.83
	211662	70	16.9	211662× ((100-70)/(100-10))	70554.00
	456964	55	26.5	430769× ((100-55)/(100-10))	228482.00
	986552	40	36.1	456964× ((100-40)/(100-10))	657701.33
	1690776	25	43.9	1690776× ((100-25)/(100-10))	1408980.00
	2897694	10	50.0	2897694× ((100-10)/(100-10))	2897694.00
Case study 2					
	141364	85	9.0	141364× ((100-85)/(100-10))	23560.67
	242274	70	16.9	242274× ((100-70)/(100-10))	80758.00
	523052	55	26.5	523052× ((100-55)/(100-10))	261526.00
	1129230	40	36.1	1129230× ((100-40)/(100-10))	752820.00
	1935302	25	43.9	1935302× ((100-25)/(100-10))	1612751.67
	3316769	10	50.0	3316769× ((100-10)/(100-10))	3316769.00
Case study 3					
	127621	85	9.0	127621× ((100-85)/(100-10))	21270.17
	218721	70	16.9	218721× ((100-70)/(100-10))	72907.00
	472202	55	26.5	472202× ((100-55)/(100-10))	236101.00
	1019449	40	36.1	1019449× ((100-40)/(100-10))	679632.67
	1747157	25	43.9	1747157× ((100-25)/(100-10))	1455964.17
	2994320	10	50.0	2994320× ((100-10)/(100-10))	2994320.00
Case study 4					
	413590	85	9.0	413590× ((100-85)/(100-10))	68931.67
	708821	70	16.9	708821× ((100-70)/(100-10))	236273.67
	1530291	55	26.5	1530291× ((100-55)/(100-10))	765145.50
	3303785	40	36.1	3303785× ((100-40)/(100-10))	2202523.33
	5662107	25	43.9	5662107× ((100-25)/(100-10))	4718422.50
	9703856	10	50.0	9703856× ((100-10)/(100-10))	9703856.00

Table 14. Financial analysis of predictive data

	CCG index	Maintenance year	Cost estimation ($)	Saving estimation ($)	BCR
Case Study 1					
	85	9.0	20583.83	16200.00	0.79
	70	16.9	70554.00	96616.66	1.37
	55	26.5	228482.00	236550.00	1.04
	40	36.1	657701.33	440366.66	0.67
	25	43.9	1408980.00	674750.00	0.48
	10	50.0	2897694.00	913600.00	0.32
Case Study 2					
	85	9.0	23560.67	21500.00	0.91
	70	16.9	80758.00	130841.67	1.62
	55	26.5	261526.00	333950.00	1.28
	40	36.1	752820.00	657708.3	0.87
	25	43.9	1612751.67	1062916.67	0.66
	10	50.0	3316769.00	1504000.00	0.45
Case Study 3					
	85	9.0	21270.17	0.00	0.00
	70	16.9	72907.00	94375.00	1.29
	55	26.5	236101.00	344850.00	1.46
	40	36.1	679632.67	868250.00	1.28
	25	43.9	1455964.17	1699100.00	1.17
	10	50.0	2994320.00	2794300.00	0.93
Case Study 4					
	85	9.0	68931.67	55600.00	0.81
	70	16.9	236273.67	352391.66	1.49
	55	26.5	765145.50	953500.00	1.25
	40	36.1	2202523.33	2003716.66	0.91
	25	43.9	4718422.50	3424225.00	0.73
	10	50.0	9703856.00	5072600.00	0.52

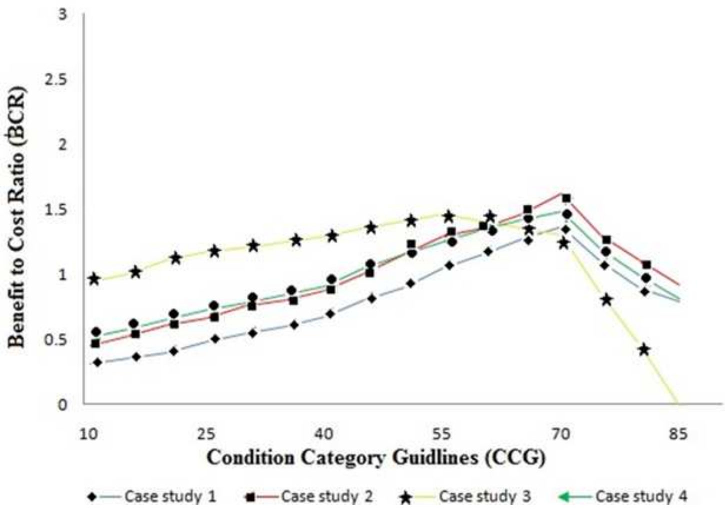

Fig. 4. Optimum facilities maintenance time based on highest BCR (predictive data)

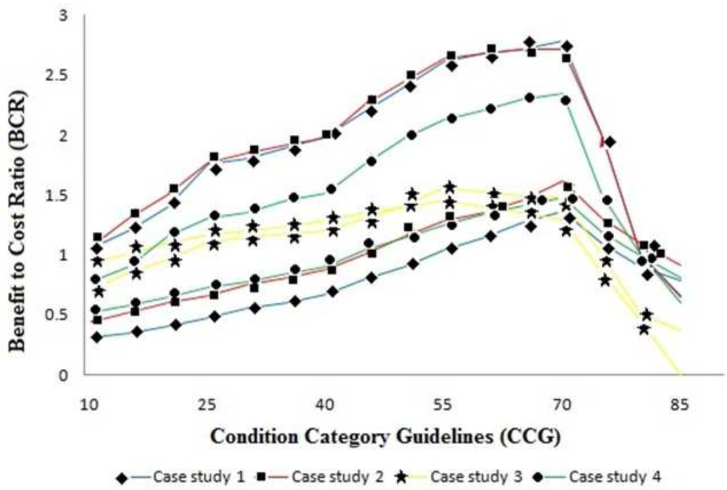

Fig. 5. Verification of data analysis in two situations of historical and predictive data

This information is used to decide whether or not the process has resulted in workable capability with the verification of process in two situations of historical and predictive data. The workable capability decision focuses only on the level of match between the analysis outcome of historical data and predictive data.

Figure 5 illustrates the financial analysis simulation of optimum index based on highest BCR in two situations of historical and predictive data for case studies. The similarity of optimum index in two situations of historical and predictive data shows that this process is acceptable for prediction of maintenance process in waste-water network of case studies.

Discussion

The process framework was tested in four steps for 4 case studies. These steps were analyzed and simulated in two situations of historical and predictive data for each case-study. The purpose of data analysis in two situations of historical and predictive data was the testing of process. This process is for the prediction of optimum maintenance time of the waste-water network in hotel buildings with respect to the limited cost allocated to the department of component maintenance. If the optimum condition index is the same in two situations of historical and predictive data, it implies the workable capability of the process for accurate prediction in the future. The analysis results show that the process was tested for all case studies one by one.

In the verification of data analysis process, at first, the historical data have been considered and run for each case study and then the predictive data will be run in the process. In the next stage, the simulated results are compared in situations of historical and predictive data together. If the optimum condition index and also ascending and descending diagrams of condition indices are the same in two situations of historical and predictive data, it results in a workable process model.

The highest BCR occurs in index 70 for the case studies 1, 2 and 4. This condition index is the same in situations of historical and predictive data (Fig. 5). In referring to Fig. 5 it can be noticed that the ascending and descending diagrams are the same from index 85 to index 10 in two situations of historical and predictive data for all case studies. The diagram traverses an upward trend from index 85 to index 70 and after that traverses a downtrend from index 70 to index 10 for six case studies 1, 2 and 4. This process is the same in both historical and predictive data for these hotels. This process traverses an uptrend from index 85 to index 55 and after that traverses a downtrend from index 55 to index 10 for case study 3. The optimum index is 55 in both the historical and predictive data for this hotel.

The closeness of the diagrams show that the financial managers present accurate predictions for maintenance costs allocated to future years. Figure 5 illustrates that case study 3 has the most accurate predictive data in the process model analysis. After that, the case studies 4, 2 and 1 are in the next places, respectively, according to the accurateness of predictive data. The results show that the predictive data presented from the financial managers of case study 1 seem to be changed in the future. These changes are because of remoteness of historical and predictive data diagrams. If the agreement between the analysis outcome of historical data and predictive data is unacceptable, the predictive data can be revised. Data revision is the process of changing the cost, or budget allocated to improve agreement with experimental outcomes. The revision process is out of this study area.

The data analysis has been done based on limited (existing) cost of maintenance in waste-water network. Therefore, the amount of maximum BCR is not important in optimum indices. The objective is identification of optimum index based on the highest BCR. The optimum index shows the suitable time of maintenance, service, cleaning, comprehensive inspecting and repairing in waste-water networks of hotels during 50 years. In an economical system, the maximum BCR should be more than 1 and this issue is very important related to the optimization subject (Ruegg and Marshall, 1990). In referring to Fig. 5 it can be found that the maximum BCR is more than 1 for identifying the optimum maintenance time for all case studies.

When the optimum maintenance time was identified and maintenance activities were performed basically, the financial managers can transfer the remaining annual maintenance cost allocated in the waste-water department to other organizations and installation in a building. This cost transmission results in cost optimization in the department of building installation and facilities.

Findings

In this study, the Maintenance Management Process Analysis (MMPA) was tested for waste-water plumbing system in four case studies during future 50 years. These results illustrate the relationship between maintenance times of waste-water systems and its economical ratio. The results are variable because of the existing costs of maintenance for each hotel individually. Table 15 shows the relationship between BCR and condition index value when the engineers do maintenance in waste-water system for 4 case studies.

The most economical maintenance is when the BCR is highest. Therefore, maintenance of waste-water system in index 70 is most economical in case studies 1, 2 and 4. For case study 3, the most economical maintenance is in index 55.

The resulted process model is an integrated and comprehensive model that is able to clarify the process of wastewater system maintenance. The strength of the model in the fact that it can provide a detailed wastewater systems evidence of the relationships between maintenance management parameters namely maintenance times and maintenance existing costs. This study will be useful to researchers, maintenance professionals and others concerned with maintenance management of waste-water plumbing systems in hotel building.

Table 15. Optimum management of facilities maintenance using the CCG

		BCR in hotels			
Indices	Maintenance Year	Case study 1	Case study 2	Case study 3	Case study 4
85	9.0	0.79	0.91	0.00	0.81
70	16.9	1.37	1.62	1.29	1.49
55	26.5	1.04	1.28	1.46	1.25
40	36.1	0.67	0.87	1.28	0.91
25	43.9	0.48	0.66	1.17	0.73
10	50.0	0.32	0.45	0.93	0.52

Conclusion

This research described a new, systematic framework for developing a suitable maintenance process model for wastewater plumbing system in a hotel building. Introducing this process model to building maintenance management is expected both to reduce building maintenance costs and to improve the service life, health and safety of the wastewater systems in hotel building. The proposed process consists of three main steps: (1) Component condition assessment (based on the available information records about component condition) in order to highlight the component that most needs to be assessed as a case study; (2) a comprehensive survey on the existing condition assessment methods of building components in order to identify the appropriate assessment method that can be used to measure building components; and (3) financial computations based on data collected in order to optimize facilities maintenance management in hotel building installations. The framework is focused on a process analysis to optimize building component maintenance time that has limited cost with respect to component condition assessment methods and economical management. The results and findings of the survey described in this study provide a better understanding of prediction mechanisms with respect to the existing resources. This understanding could be the starting point for extensive work related to the maintenance management scenario of the component management system.

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Ethics

The author addresses any ethical issues that may arise after the publication of this manuscript.

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