Abstract

Life cycle costing is the technique of considering the initial and subsequent running costs and residual costs of an asset over the life of a project. Running costs are defined as the total cost of operations and maintenance costs of a building. The technique is accepted to be of theoretical merit but its practical development is hindered by two extreme factors i) the absence of data in the right form and ii) difficulties in handling the plethora of data when exists. This paper describes the use of a novel approach, known as the cost-significance, for the development of simple models for running and maintenance costs in buildings. The models focus design and management effort on the high cost items. The results are drawn from analysis of operation and maintenance costs for university buildings over a period of 18 years demonstrating the feasibility of deriving a small number of items, 16% of the total number of items occurring in running costs and 30% in maintenance costs, which consistently represent some 87% of the total running costs of buildings and 70% of the total maintenance costs. The model can calculate the costs to an average accuracy of ±5% and ±13% for total running and maintenance costs respectively. The models were tested on new information and proved to be effective and consistent. The paper also discusses the major applications of the developed methodology and models particularly considering data collection, recording and analysis for use in life cycle costing applications in buildings.

Keywords: building economics, cost modelling, Life-cycle costs, maintenance costs, operation costs, running costs, facilities management.
1 Introduction

Life cycle costing is the process of economic analysis to assess the overall cost of an asset including the cost of acquisition and the subsequent costs of operation, maintenance and disposal. When attempts have been made to apply life-cycle costing concepts in the building industry, owners, and managers have been thwarted by the lack of both well-accepted methodology of documentation of information and sound data from which to arrive at appropriate decisions.

Investment decisions in the construction and property industries continued to be made mainly on the basis of minimal capital costs being the driving factor to many promoters. There is, therefore, no lack of information on construction processes and costs during the initial stage compared to the little information available, on operation and maintenance costs of buildings. This may be blamed on the lack proper monitoring techniques and the feedback of information on the performance of materials and systems in a building over its life cycle. Even those with the will to embark on total life cycle costing were thwarted by the lack of useable information either about the real costs of operating and maintaining buildings or about the lives of different components fulfilling the same function (Spedding 1987, Mcdermott et al 1987). As a result, the output from total life cycle cost models is notoriously unreliable. (Ashworth 1993, Grover & Grover 1987).

This paper focuses attention on buildings’ running costs which is an integral part of the overall life cycle costing study of any building project. The paper describes, using a new approach, the development of a model for running costs and another more specific model for maintenance costs in buildings from different categories. These models which would by their very simplicity facilitate and encourage data collection and analysis for Life Cycle Costing in buildings and might serve to improve our understanding of how to identify those costs which contribute most to the overall cost of buildings.

2 Definitions

BS3843 (1992) defined the life cycle costs as:
‘the costs associated with acquiring, using, caring for and disposing of physical assets, including feasibility studies, research, development, design, production, maintenance, replacement and disposal; as well as all the support, training and operations costs generated by the acquisition, use, maintenance and replacement of permanent physical assets.’

The life cycle cost (LCC) of a building is defined as all costs that emerge throughout its entire life cycle- from construction, through operating and maintenance, to disposal. The maintenance costs are defined as the cost of keeping the building in good repair and working condition. They include painting, decorating and repairs. Operating costs are defined as the costs associated with operating the building itself (RICS 1983). They include the cost of cleaning, rates, energy and security. Running costs are defined as the sum of maintenance and operating costs.
3 Data collection and preparation

Data used for model development was obtained from York University. A minimum of 18 years' records dating from 1971 was available for 20 buildings made from residential, teaching and laboratory buildings. 15 further buildings from the Estate Management Office at Birmingham University, were used to test the accuracy of the developed models. In preparation of data there were four problems to resolve:

1. Data collected was converted to a standard structure and coding based on the Building Maintenance Information (BMI) framework (1988).
2. All costs were expressed in terms of £ per 100 m$^2$.
3. The data was discounted, to take account of inflation, to the year 1988 using the indices published by the BMI.
4. Different periodicities of the data were taken into account by aggregating it into a series of moving averages ranging in duration from 1 to 10 years. (Al-Hajj, 1991 PhD)

4 Methodology for models development

The methodology adopted involves checking the feasibility of applying Pareto's 80/20 rule to identify a small number of cost elements which represent a consistent and high proportion of the total running costs and total maintenance costs. The procedure is as follows. (Al-Hajj & Horner, 1998)

- Collect and record data in a readable and useful form.
- Plot in descending order of magnitude a graph of cumulative percentage cost versus cumulative percentage number of items.
- Determine the point beyond which each percentage increase in number causes a smaller percentage increase in cost. This is the point of maximum efficiency.
- Identify all the items whose cost is greater than or equal to the mean. The mean is the total of annual cost divided by the number of occurring items, the so-called cost-significant items, for each building.
- Determine the cost-significant items recurring most frequently.
- Development of models by progressively adding those cost-significant items progressively recurring less frequently until their total cost represents a sufficiently consistent proportion of the total running and maintenance costs.
- Test the models on new data, that is, data not used in their development.

4.1 The principles of cost-significance

Figure 1 shows the relationship between cumulative cost and cumulative number of items for the general category of buildings under consideration. The data is derived from the average annual cost for all cost items incurred annually. The curves clearly illustrate that: i) for running costs, 10% to 20% of the items contribute to 80 % to 90 % of the costs; ii) for maintenance costs, 30% to 40% of the items contribute to 80% to 90% of the maintenance costs. Both curves give a clear indication that a high proportion of costs is focused in a small number items with significant costs. These cost significant items were then identified (Al-Hajj, 1991)
to be those items whose costs were greater than the mean incurring over the years and showing noticeable consistencies. These consistencies of the data allowed the research to contemplate the development of models which can represent the total running and maintenance costs sufficiently accurate for all practical purposes, yet which contains only the cost-significant items.

Table 1 illustrates the consistency of the relationship between $V_v$ /$V$ and $N_v$/$N$ for both types of costs:

![Graph showing cumulative cost vs number for running and maintenance costs](image)

**Fig. 1: Cumulative value vs cumulative number of running and maintenance costs for the general building category**

Where $V$ is the total cost

$V_v$ is the total cost of items whose cost is greater than the mean

$N$ is the total number of items

$N_v$ is the number of items whose cost is greater than the mean

Table 1: Average value and average number of annual running and maintenance cost-significant items for all buildings

<table>
<thead>
<tr>
<th>Building</th>
<th>Total Cost (V) £/100m²</th>
<th>Total Number (N)</th>
<th>Mean V/N</th>
<th>Vv/V %</th>
<th>Nv/N %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Running Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>3601</td>
<td>63</td>
<td>56.8</td>
<td>88</td>
<td>19</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>585.82</td>
<td>3.84</td>
<td>8.32</td>
<td>1.93</td>
<td>2.48</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>16.71</td>
<td>16.36</td>
<td>16.5</td>
<td>2.19</td>
<td>13.28</td>
</tr>
<tr>
<td><strong>Maintenance Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>559.44</td>
<td>51</td>
<td>10.89</td>
<td>78</td>
<td>27</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>243.39</td>
<td>2.93</td>
<td>4.66</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>43.5</td>
<td>5.7</td>
<td>42.8</td>
<td>3.8</td>
<td>11.1</td>
</tr>
</tbody>
</table>

The models are will be developed based on the following concept:

$$T_c = \frac{1}{CMF} \sum_{i=1}^{n} CSI_i$$
Where,
\( T_c \) = total cost
\( \text{CMF} \) = cost model factor (ratio of the cost of the cost-significant items to the total cost)
\( \text{CSI} \) = cost of the \( i \)th cost-significant item (any item whose cost exceeds the mean).

### 4.2 Selection of CSI’s for inclusion in the models

Items that consistently recurred in every year were automatically selected for inclusion in the model. As more cost-significant items that intermittently occurred are added to the model, its consistency, and its accuracy increased as expected. However, so does its complexity. We therefore progressively added to the core items those additional items which recurred progressively less frequently. In this way, a number of alternative models were developed for both the running and maintenance costs, each containing a different number of items and each with a different cost model factor. This is illustrated in (Al-Hajj & Horner, 1998 & Al-hajj 1991). As expected, in general, the accuracy of the model expressed in terms of the coefficient of variation of the CMF improves as the number of items increases. The models with CMF having the smallest coefficient of variation (\( C_v \)), were selected for further testing. These models are as expressed in Table 2:

### Table 2: Cost models

<table>
<thead>
<tr>
<th>Running Costs Model</th>
<th>Maintenance Costs Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_c = (1.1494) \sum_{i} \left[ (c_1 + e_1) + (c_2 + e_2) + (a_1 + a_2) + (m_1 + m_2) \right] )</td>
<td>( M_c = (1.37) \sum_{i} (d + f + s) )</td>
</tr>
</tbody>
</table>

where
- \( R_c \) = Total running cost
- \( \text{cmf} \) = Cost model factor (\( \text{cmf} = 0.87 \))
- \( n \) = Time in years
- \( c_1 \) = Internal cleaning
- \( c_2 \) = Laundry
- \( e_1 \) = Gas expenditure
- \( e_2 \) = Electricity expenditure
- \( e_3 \) = Fuel oil expenditure
- \( a_1 \) = Management fees
- \( a_2 \) = Porterage (security)
- \( o_1 \) = Rates
- \( o_2 \) = Insurance
- \( m_1 \) = Internal decoration
- \( m_2 \) = Roof repair

- \( M_c \) = Total maintenance cost
- \( \text{cmf} \) = Cost model factor (\( \text{cmf} = 0.73 \))
- \( t \) = Time in years
- \( d \) = Decoration
- \( f \) = Fabric maintenance
- \( s \) = Services maintenance

Items in module contribute to about 16% of total running cost items.

Items in module contribute to about 30% of total maintenance cost items.
5  Accuracy of the models

The accuracy of the running and maintenance costs calculated using the models is the percentage difference between the cost predicted by the model and the actual costs.

The accuracy was tested in two ways: first, the models were tested on the information used in their development. This accuracy was called ‘the expected accuracy’. Both models were used to calculate the total costs over 18 years and for a series of moving averages with periodicity ranging from 2 to 10 years. Figures 2 and 4 show the results of this exercise for running and maintenance models respectively. The figures also show that the expected accuracy applied using the moving average technique clearly improves considerably as the periodicity increases. Running cost model accuracy ranges between ±5% at annual level to ±7% at 10 years moving average level. For maintenance costs, accuracy is shown to be less consistent due to the nature of maintenance items occurrence. The expected accuracy of the maintenance model, as shown in figure 4, fluctuated between ±30% at the annual level and ±13% with 10 years moving average period.
The models were then tested by using data from new buildings not been used in their development. Data from 12 additional buildings for the running costs model and further data of 15 buildings were used to test the maintenance costs model. Figures 3 & 5 show that the achieved accuracy, from both cost models, was within the expected range.

6 Applications

The changing nature of the maintenance and operation in buildings has been one of the main causes for the lack of uniformity in the method of collecting and recording data and lack of feedback of information on the performance of materials, building components and buildings. This in turns makes the analysis into life cycle costing unreliable which brings about the demand for a review of the methodology for collecting, modelling and analysing data, on maintaining and operating buildings, for life cycle costing analysis purpose.

The models developed provide a focus of attention on the main cost items over the operating life cycle of buildings. This in turn provides simpler tool for conducting occupancy cost analysis and reducing costs associated with data gathering. This simplistic approach allows a user-friendly mechanism for incorporating information on main cost areas of facilities management, and directs the designer to cost significant parts of the building. The described methodology provides decision makers with a simple tool to evaluate and assess buildings using the concept of life cycle costing as an effective and useful tool to aid the decision-making process.

7 Conclusions

The paper described and presented the methodology for developing simple cost models for running and maintenance costs in buildings. The models are shown to be easy to use, simple in structure, and simple in concept and capable of achieving reasonably accurate representation of the real data used in their development.

The paper also shows that the methodology can provide a simplistic analysis of alternatives based only on the most significant items of cost since only a small number of items are involved in the models without loss in the accuracy of predictions. The remarkable consistency of cost-significant elements across a range of building types allowed the development of simple models of operating and maintenance costs.

Because the models contain only a small number of items they can considerably simplify the process of monitoring, collecting and feedback of data for quick but sufficiently accurate performance evaluation in buildings.
8 References


