FUZZY LOGIC APPROACH TO A GENERIC ELEMENTAL WHOLE LIFE COSTING MODEL

N. Wang,[1] R.M.W. Horner, and M. El-Haram

[1]*Construction Management Research Unit, Civil Engineering Division, University of Dundee, Dundee, DD1 4HN, UK*

The purpose of this research is to develop a generic model that can facilitate the forecasting of the whole life costs of building elements. The relationship between the context of use and the cost items, such as cleaning costs, is modelled by using linguistic data of experts. Fuzzy logic is used to represent experts' knowledge. The model has been developed in such a way as to resolve the problem of lack of historical data on running costs of building elements. It is anticipated that the model could have a very wide range of use in estimating whole life costs of public service buildings, such as hospital, school, etc. Users of this model would be the design teams of building projects, who wish to take into consideration the long term interests of capital investment.

Keywords: construction design, context of use, fuzzy logic, whole life costing.

INTRODUCTION

Whole life costing

Whole life costing (WLC) is an essential decision-making tool for the design team of public private partnerships (PPP) and private financial initiative (PFI) projects, as they take into consideration not only the construction cost but also the future maintenance and operating costs of projects. Whole life costing encourages decision makers to take account of 'durability, future running costs, maintenance and refurbishment requirements' (Clift and Bourke 1999), as well as energy consumption and environmental performance assessment (Azapagic and Clift, 1999). When the owners of a building analyse the financial feasibility of a project, they have to balance facility income, construction costs, and facility management costs (Dell'Isola and Kirk, 1981). When PPP/PFI projects were introduced into the construction industry, clients realised that construction should be 'designed and costed as a total package, including costs in use and final decommissioning' (Egan, 1998). At the design stage, whole life costing can help to evaluate the alternative options in order to assess their economic impact during the building's life (Ashworth, 1999). A construction projects' whole life cycle cost can be divided into three main elements: capital costs, facility management/ running costs, and disposal costs (El-Haram and Horner, 1998).

The most important and difficult work in whole life costing is to forecast the whole life cost items of building elements, since some items are involved in future usage of elements. The characteristics of construction projects, which decide the usage of element, therefore need to be considered in estimating. In addition, the different functions of the spaces in the building will also affect whole life cost items such as the

[1] n.wang@dundee.ac.uk

Wang, N, Horner, R M W and El-Haram, M (2004) Fuzzy logic approach to a generic elemental whole life costing model. *In:* Khosrowshahi, F (Ed.), *20th Annual ARCOM Conference*, 1-3 September 2004, Heriot Watt University. Association of Researchers in Construction Management, Vol. 1, 383-91.

facility management costs. A particular option may be the optimum choice in one project but it is not necessarily the best in another (Dell'Isola and Kirk, 1981). For example, there can be a 40% difference in the 25-year whole life costs per m^2 of one type of floor finishing in the two different situations of classroom and corridor. A good design may reduce the potential maintenance and operating costs of buildings in future use (Dell'Isola and Kirk, 1981).

Cost studies should be undertaken at the elemental level, since various building elements and their alternatives have different life expectancies and maintenance schedules. It may be true that under a given condition one alternative is economically the best; but in other circumstances another alternative is preferred (Ashworth, 1999), since the circumstances can affect the cost-in-use. Therefore, the particular circumstances of a project also need to be considered in estimating whole life costs for building elements before all the alternatives of building element are evaluated and compared.

Obstacles to implementing model development

There are some difficulties that constrain the application of whole life costing in practice. The key obstacle to the development of the elemental model is lack of reliable historical data. Therefore, a statistical method cannot facilitate this research. Another difficulty lies in forecasting future events (Ashworth, 1999) which include many uncertainties. Therefore the experience of experts such as facility managers seems critical in the case of forecasting future events (Ghalia and Wang, 2000). Experts' opinions can help to define the relationship between cost factors and cost items. This process can be achieved by using fuzzy logic, which transfers human language into a numerical format by generating fuzzy membership functions (Klir et al, 1997).

Fuzzy logic approach to whole life costing model

Fuzzy logic was originally developed by Zadeh in 1965 and deals with uncertainties that may not be statistical in nature (Zadeh, 1965). In information processing, fuzzy logic provides a way to cope with fuzziness in a quantitative manner in the condition where the source of imprecision is not a random variable or a stochastic process but a set of classes without sharply defined boundaries (Zadeh, 1968).

The estimate of cost items in elemental WLC is a process of approximate estimate and adjustment. Firstly, the average value of a cost item is estimated defined here as the cost in a medium scenario of context of use. The better the scenario of use, the lower the whole life costs. In this research the average value of a cost item will be the one recommended by manufacture, or estimated by experts on the basis of their experience. Secondly, this average value is adjusted according to the context of future use of the element. In this model, fuzzy logic will be used to produce a multiplier which is given by experts according to the different context of use. The context of use is measured by factors such as frequency of use, hygiene requirement and so on, because these factors affect the future running costs of buildings. After all the cost items are estimated, the running cost items are discounted to present value. The sum of all cost items is the estimated whole life cost of the element in the context of use.

THE PROCESS OF DEVELOPING THE FUZZY LOGIC COST ESTIMATING MODEL

The advantage of a fuzzy model is that it can manipulate linguistic variables (Cox, 1994). Fuzzy approximate reasoning method is used in this research to model the relationship between the whole life cost items of building element and the context of use. The linguistic evaluation of experts is transferred to numerical information on which the membership function and if-then rule are based. The fuzzy sets and if-then rules are manipulated by fuzzy reasoning by three main steps, which are fuzzification, implication and defuzzification

The factors affecting whole life cost items, as the input of the model, are fuzzified to fuzzy sets, as well as the output variable-cost deviation. The model estimates expected deviation of cost items from the average value according to a particular context of use. Finally, the numerical multiplier in a percent style will be produced to adjust the expected cost on the basis of average value. The process of development of the model is shown in Figure 1.

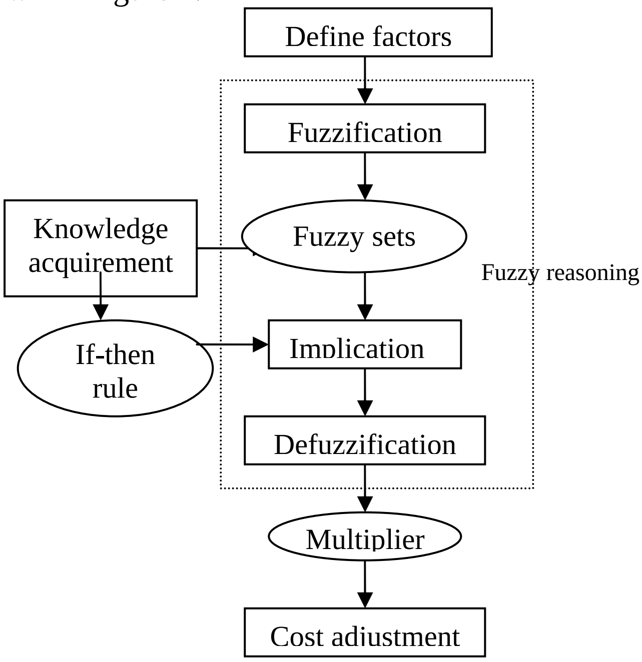

Figure 1. Model development process

As an illustration example, the model for estimating the cleaning cost of floor finishing is shown bellow. The factors that affect floor cleaning cost are traffic condition and hygiene requirement. The relations between factors and cleaning cost deviation is evaluated by experts and stored in if-then rules.

Fuzzy approximate reasoning

Fuzzy approximate reasoning is a way to model human common-sense reasoning (Klir et al, 1997). The experts' judgements, such as 'if x is A, then y is B', are manipulated as fuzzy relations, which can be explained by the mathematical expression:

$$R: X \times Y \rightarrow [0, 1]$$
$$(x, y) \rightarrow R(x, y)$$

This relation set *R* between X and Y is crucial for this model, which shows the strength of relationship between fuzzy sets. The experts' judgements are used to generate the fuzzy relations in the form of 'if-then rules'. These rules constitute an if-then rule-base, which represents the relationship between the factors and the deviation of cost items. The implication method associates the degree of truth to the output fuzzy region (Cox, 1994). Then the defuzzyfication derives the solution point, i.e. the deviation in this case, from the output fuzzy region. The whole process of fuzzification, implication and defuzzification constitutes the fuzzy reasoning.

Fuzzification of the variables

The variables in the model are described by linguistic concepts. Each linguistic concept is represented by a fuzzy set, which is the distribution of the concept on the universe of all possible values the variable could take. Each element in the universe is assigned a degree of truth, to which the value belongs to the fuzzy concept.

The membership function for each fuzzy set is constructed as experts assign the degree of truth to all elements. The method used in this research to establish membership functions is the exemplification method (Klir, et al, 1997). A finite number of samples are chosen as the elements within the universe (*U*). The experts assess the degree to which the samples belong to the fuzzy set. The membership functions in this research are in the form of triangular functions, which are expressed as,

$$\mu_e(x)=\begin{cases} L(x) & e_1 < x < e_2 \\ U(x) & e_2 < x < e_3 \\ 1 & x = e_2 \\ 0 & otherwise \end{cases}$$

where, $L(x)$ is the lower side of the membership; $U(x)$ is the upper side; d_i is a fuzzy concept without precisely defined boundaries. Figure2 shows a fuzzy set $\mu_d(x)$ in a series of fuzzy sets which comprise the universe of a fuzzy variable. The triangular domain defines all elements' membership of this concept.

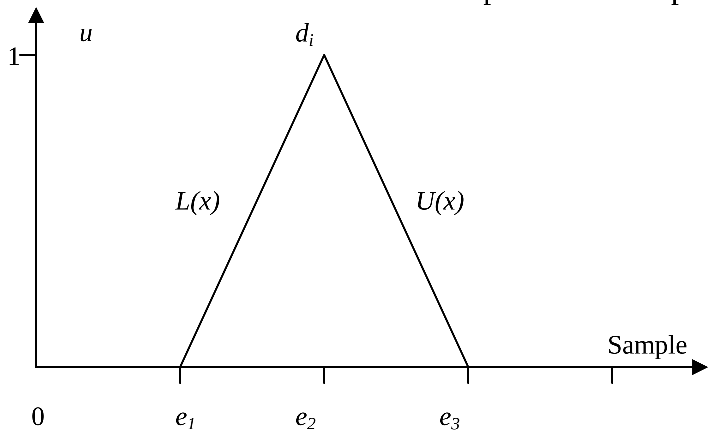

Figure 2. Membership function of a fuzzy set

The input variables of this cost estimate model are the factors that most affect the whole life cost items. These factors describe the contexts of use of the elements including the frequency of use, the hygiene requirement, the traffic condition, the location of the project, and so on. These factors are expressed by fuzzy sets:

$f_1(x_i)$={'frequency of use'}={least frequent, less frequent, average, frequent, very frequent}

$f_2(x_i)$={'location'}={ x_1, x_2, x_3}={by the sea, near the sea, far from sea}

$f_3(x_i)$={'traffic condition}={ light traffic, average, heavy traffic}

$f_4(x_i)$={' hygiene requirement'}={ low, medium, high }

…

The output fuzzy variables, expected deviation of cost items, are described in linguistic fuzzy sets, ***E***={enormously below average, below average, slightly below, just about average, slightly higher than average, higher than average, enormously higher than average}. The membership functions for deviation are also in triangular form.

If-then rules

The factors and estimated costs of items are connected by if-then rules. One if-then rule is a proposition, which is the statement of knowledge (Cox, 1994). An if-then rule-base contains all propositions that establish relationships between the factors and the fuzzy region of the predicted result. The form of the 'if-then' rule is :

Rule 1. If the traffic condition is *heavy* and if the hygiene requirement is *medium*, then the annual floor cleaning cost is *above average*.

Rule 2. If the traffic condition is *medium* and if the hygiene requirement is *medium*, then the annual floor cleaning cost is *just about average*.

…

The antecedent sentence, '*if…*', indicates the condition, i.e. the context of use. The second half sentence, '*Then…'* is the consequent impact of the factors on cost items.

Implication method

The interaction of many propositions creates a fuzzy output region in the universe of cost deviation. This fuzzy region is a combination of truncated domains of output variable. These domains are cut by the α-values, which denote the degree of truth of the output domains. The correlation minimum method (Cox, 1994) is chosen as the way to implicate fuzzy output region.

Defuzzification of the fuzzy output

The output of the implication on the graphical membership function of an estimated output variable is a region that seems like a distribution curve in statistics. The last step is to defuzzify this region to a point, which is the final estimated result. Defuzzification translates linguistic descriptions of judgement into numerical information. The most widely used method is the composite moments (centroid) method (Cox, 1994), which takes the value of the balance point of the solution fuzzy region. Another defuzzification method is maximum decomposition, but its use is narrower (Cox, 1994). But this way of defuzzification is suitable for solving qualitative problems. According to the centroid method, the solution point of fuzzy output region *A* is formulated as,

$$Z \sim \frac{\sum_{i=0}^{n} d_i \mu_A(d_i)}{\sum_{i=0}^{n} \mu_A(d_i)}.$$

Where d_i is the i'th domain value, and $\mu(d)$ is the truth membership value for that domain point.

Finally, the solution point is produced as a multiplier in the form of a percentage style to represent the deviation of a cost item in a particular context of use. The deviation is defined as a percentage above or below the average value of this cost item, for instance annual cleaning cost of wooden floor.

AN ILLUSTRATIVE EXAMPLE

A simple example demonstrates how a fuzzy logic model can be used to predict the cleaning cost of floor finishes.

Modelling cleaning costs of floor finishing

Fuzzification

The factors need to be denoted by qualitative values such as 'big', 'small', in order to become valid input to the fuzzy model as fuzzy variables. Structured interviews have been used to generate membership functions of these factors.

A list of samples, which represent different scenarios, are given to the experts to evaluate the degree to which the samples belong to each concept. A fuzzy universe is defined between two extreme scenarios, the best scenario=0, and the worst scenario=10. For example, 10 represents the worst traffic conditions the floor would suffer, i.e. 24 hours heavy traffic. Conversely, 0 represents the best traffic conditions, i.e. no traffic at all. The exemplification points within this range (0, 10) are given to experts as a set of samples: {1=the traffic condition in bedroom, 3=in living room, 5=in office, 7=in school classroom, 9=in airport}. The experts assess to what degree these scenarios in the exemplification do belong to every fuzzy set.
The factors that affect floor cleaning costs are hygiene requirements and traffic conditions. Their graphical membership functions, defined by using experts' opinions, are shown in Figure 3 and 4.

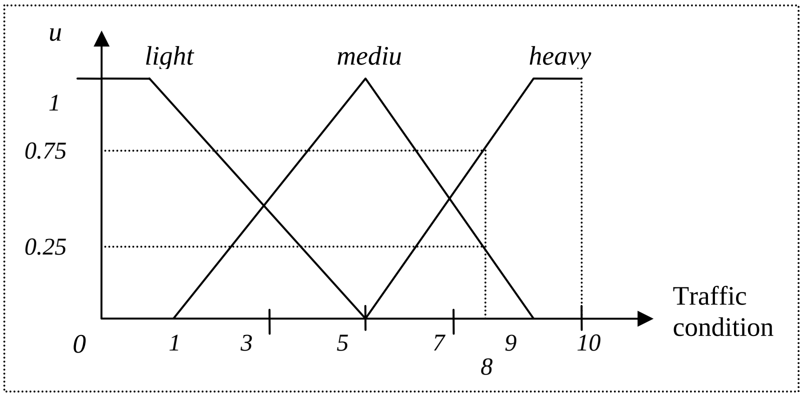

Figure 3. Membership function of traffic condition of a space
Where,
1—bedroom
3—living room
5—office
7—school classroom
9—airport passageway

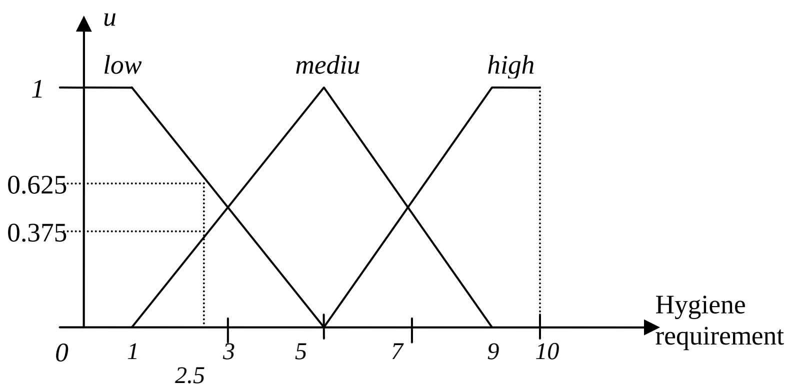

Figure 4 Membership function of 'hygiene requirement'
1—storeroom
3—classroom
5—office
7—restaurant
9—hospital operating theatre
The output variables of the model are variation of annual cleaning cost. The experts also evaluated these variables with linguistic concepts.

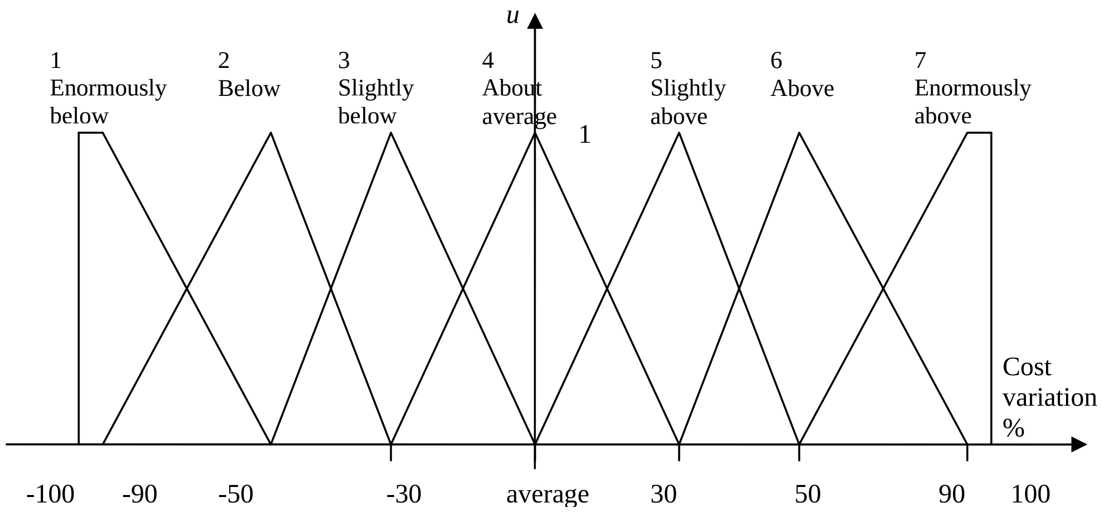

Figure 5. Membership function of variation

Figure5 shows the membership function of the fuzzy set 'variation of annual floor cleaning cost', which is also defined by experts' opinion.

If-then rules

The relationship between context of use and whole life costing items is depicted by if-then rules. The questions asked are in the form of

'If the traffic condition is *heavy*; the hygiene requirement is *medium*, what will the cleaning cost be? (Choose from 7-point scale)'.

Table 1 shows the evaluation of experts of the cleaning costs of a floor finishing on 7-point scale as the consequence of if-then judgements.

1. enormously below average
2. below average
3. slightly below average
4. about average
5. slightly above average
6. above average
7. enormously above average

Table 1. 'if-then' rules of cleaning cost

Traffic / Hygiene	Light	Medium	Heavy
Low	below average	slightly below average	about average
Medium	about average	slightly about average	above
High	slightly above average	above average	enormously above average

The application of the model

The model will help the user to estimate the whole life costs of element more accurately. They will set a value to the input factors according to a particular given scenario, comparing to the samples.

Implication method
The use of the model involves implication and defuzzification processes. The model user, cost estimator, will be asked to input the value of these factors according to a particular scenario. For example, if the cost estimator is to estimate cleaning cost of hardwood floor finishing in a small shop, he/she will evaluate the expected traffic condition and hygiene requirement. In the example, the floor finishing is difficult to clean. The model user estimate the traffic condition in this context as between classroom and airport, while hygiene requirement is much higher than storeroom and slightly lower than classroom. Therefore, the two factors are assigned as 8 and 2.5 respectively by model user shown in Figure 3 and 4. The correspondingly *y* value 0.25, 0.75, 0.375, and 0.625 mean that this context of use of floor is 0.75 degree of '*heavy traffic condition'*, 0.25 degree of '*medium traffic condition*'; and also show 0.625 degree of '*low hygiene requirement'*, 0.375 degree of '*medium hygiene requirement*'. Therefore, 4 if-then rules are involved out of 9 rules:
If the traffic condition is *heavy*, and if the hygiene requirement is *low*; then the cleaning cost is '*just about average'*.
If the traffic condition is *heavy*, and if the hygiene requirement is *medium*; then the cleaning cost is '*above average'*.
If the traffic condition is *medium*, and if the hygiene requirement is *low*; then the cleaning cost is '*slightly below average'*.
If the traffic condition is *medium*, and if the hygiene requirement is *medium*; then the cleaning cost is '*slightly above average'*.

Therefore the cost range is distributed in the 4 regions in the 7-point scale. The truncated fuzzy region is produced by the correlation minimum method shown in Figure 6. The α-cuts to truncate fuzzy sets are defined by formulas:
α_4=Min [$u(_1), u(_2)$]=min(0.75, 0.625)=0.625
α_6=Min[$u(_1), u(_2)$]=min(0.75, 0.375)=0.375
α_3 =Min[$u(_1), u(_2)$]=min(0.25, 0.625)=0.25
α_5=Min[$u(_1), u(_2)$]=min(0.25, 0.375)=0.25
These α-cuts indicate the degree to which the cost distributes in each domain.
Defuzzification
The next step is to defuzzify the truncated fuzzy region, as shown in Figure 6. Using the centroid method, we get the multiplier as the centre of gravity *Z*=20%. This percentage result suggests the deviation from average cleaning cost of floor finishing according to this context of use.

$$Z \sim \frac{\sum_{i=0}^{n} d_i \mu_A(d_i)}{\sum_{i=0}^{n} \mu_A(d_i)} = \frac{40\times 1.56 + 49.16\times 0.468 + 75\times 9.375 + 80\times 2.8}{1.5625 + 0.468 + 9.375 + 2.8 + 23.75 + 12.65} = +20\ (\%)$$

As an illustrated example, suppose the average annual cleaning cost of wooden floor per square meter is estimated by the estimator as £10.96/m^2. The multiplier adjusts the average of wood floor cleaning cost according to the specified circumstance more accurately. The expected cost by this model is 20% above the average value. Therefore, the expected annual cleaning cost of wooden floor under this condition is £13.15/m^2.

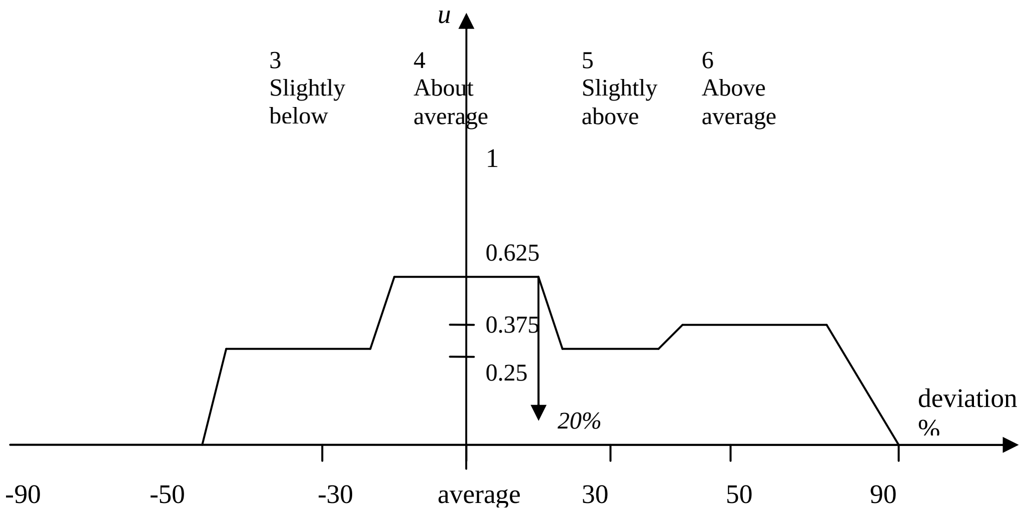

Figure 6. Defuzzification

CONCLUSIONS

This research demonstrates a process of developing a generic elemental whole life costing model by using the fuzzy logic method. This model, taking the project's characteristics into account, is generated from experts' knowledge. It models the relationship between factors such as the characteristics of the project and cost items. The estimate will be more accurate and experiential than the traditional model. A fuzzy logic approach, which uses experts' knowledge, overcomes lack of data and the uncertainty in forecasting future events.

REFERENCES

Ashworth, A. (1999) *Cost Studies of Buildings*. London: Longman Ltd.

Azapagic, A. and Clift, R. (1999) Life cycle assessment and multiobjective optimisation. *Journal of Cleaner Production*, 7, 135-143.

Clift, M. and Bourke, K. (1999) *Study on Life Cycle Costing*. Report Number CR366/98. Watford: Building research establishment Ltd.

Cox, E. (1994) *The Fuzzy Systems Handbook*. Academic Press, Inc. USA.

Dell'Isola, A. and Kirk, A.J. (1981) *Life Cycle Costing for Design Professionals*, McGraw-Hill, Inc.

Egan,J. (1998) *Rethinking Construction, Department of the Environment*. London: Transport and the Regions.

El-Haram, M. A. and Horner, R.M.W. (1998) *Factors affecting life cycle cost in the construction industry*. M.I.R.C.E., SOLE South West Chapter.

Ghalia, M.B. and Wang, P.P. (2000) Intelligent System to Support Judgmental Business Forecasting: the Case of Estimating Hotel Room Demand. *IEEE Transactions on Fuzzy Sytems*, 8, 380-397.

Kirkham, R.J., Boussabaine, A.H. and Awwad, B.H. (2002) Probability distributions of facilities management costs for whole life cycle costing in acute care NHS hospital buildings, *Construction Management and Economics*, 20, 251-261.

Klir, G., StClair, H. and Yuan, B. (1997) *Fuzzy Set Theory: Foundations and applications,* USA: Prentice Hall Inc.

Misumoto, M. and Tanaka, K. (1976) Some Properties of Fuzzy Sets of Type 2. *Information and Control*, 31, 312-340.

Zadeh, L. A. (1965) Fuzzy Set. *Information and Control,* 8 (3), 338-353.

Zadeh, L. A. (1968) Fuzzy Algorithms. *Information and Control,* 12 (2), 94-102.