A GENERIC APPROACH TO MINIMIZE WHOLE LIFE COSTS IN THE BUILDING INDUSTRY

Sasa Marenjak, Mohamed A. El-Haram and Malcolm R. W. Horner

Construction Management Research Unit, Division of Civil Engineering, University of Dundee, Dundee, UK

Although whole life costing (WLC) is playing an increasingly important part in evaluating the procurement of building projects, the lack of reliable and consistent data for accurate WLC analysis is still a serious concern. This paper presents the preliminary outputs of a research project which is supported by the EPSRC at the University of Dundee. It seeks to quantify the benefits of applying Integrated Logistic Support, ILS, at the design stage of building projects and its impact on whole life costs and performance. The development of a consistent and comprehensive WLC data structure and application of the "theory of significance", Failure Mode and Effects Analysis (FMEA) and Reliability Centred Maintenance (RCM) to identify the most cost-effective and applicable maintenance tasks in order to minimize WLC of building elements are discussed.

Keywords: FMEA, RCM, theory of significance, whole life cost analysis, WLC process.

INTRODUCTION

Whole life costing is not a new approach, but its implementation is becoming much more important as long-term building owners and clients start to demand evidence of what their costs of ownership will be (Egan 1998). More private companies are investing in the Private Finance Initiative (PFI), Public Private Partnership (PPP) and Prime Contracting (PC) projects, and the increasing Government demand to concentrate on reducing WLC (Construction Productivity Network 2000) all contribute to its growing importance. From 2002, "all Government departments have to use whole life cost assessment as part of the technical appraisal for decisions to build new or refurbish" (Construction Productivity Network 2000). The new Treasury Procurement Guidance Note – No. 7; "Whole Life Costs" (HMSO 2000) states that "… all procurement must be made solely on the basis of value for money in terms of whole life costs". The new types of procurements (PFI, PPP and PC) require the companies involved to take long-term responsibility for building operation and maintenance.

Whole life costing includes the systematic consideration of all costs and revenues associated with the acquisition, maintenance, use and disposal of a building. According to BS ISO 15686, service life planning (BSI 2000) WLC can be defined as:

"a tool to assist in assessing the cost performance of construction work, aimed at facilitating choices where there are alternative means of achieving the client's objectives and where those alternatives differ, not only in their initial costs but also in their subsequent operational costs."

Clients want the best possible value for money from their assets. One of the ways to achieve this is to reduce whole life costs. One way of reducing WLC is by implementing a systematic approach which allows the project team to trade-off between the client's requirements, operational performance and availability of the facility, capital cost and future running costs. A technique which has been successfully applied in other industries such as aviation, petrochemical and defence (Kumar *et al.* 2000) is Integrated Logistic Support (ILS). It is a structured management approach aimed at influencing the design of the facility and ensuring that all the elements of design are fully integrated to meet the client's requirements and asset's operational and performance requirements, including availability, reliability, durability, maintainability, and safety at minimum whole life cost (US DoD 1983). The principal objective of ILS is to develop a package of logistics resources that optimizes the operation, maintenance and support of the project.

In order to apply ILS techniques in the construction industry, there is a need to tailor them to its specific requirements. Recently, the Construction Management Research Unit (CMRU) at the University of Dundee has carried out research under an EPSRC programme to test the potential application of ILS techniques to develop cost-effective maintenance strategies for existing building stock (El-Haram and Horner 2002). When ILS techniques such as FMEA and RCM were tailored and applied to a sample of residential buildings in the operational phase, potential savings in maintenance costs amounting to 18.5% were identified (El-Haram and Horner 2002). However, in common with other studies (US DoD 1983), (UK DoD 1996), it was concluded that the greatest scope for savings arises when ILS is applied at the design stage so that the concept of logistics support is built into the entire process from project inception to eventual demolition.

This paper reports part of a research project carried out by the University of Dundee. The aim of the research project is to develop a generic approach to minimizing WLC in the construction industry. The purpose of this paper is to introduce the steps of WLC processes that are based on the application of the "theory of significance", FMEA and RCM at the design stage, and to demonstrate and evaluate the benefits of its application through a case study, high school.

WLC TOOLKIT FOR THE BUILDING INDUSTRY

Flanagan *et al.* (1999) and El-Haram *et al.* (2002) suggested that application of WLC and ILS techniques for every project is time and resource consuming and therefore there is a need to find a way of simplifying its application. One possible solution is to apply WLC and ILS techniques only to significant elements. The WLC toolkit developed in this project involves the application of the "theory of significance" and FMEA and RCM techniques. The WLC toolkit has the following steps.

Identify all anticipated project phases and activities that will generate cost in the life cycle

A typical life cycle of a building consists of three phases: capital, facility management and disposal. The capital phase includes land acquisition, design, construction and commissioning. The facilities management phase includes operation, maintenance, replacement, refurbishment and support of a building during its life. The disposal phase includes demolition and site clearance of a building.

Create or adopt WLC data structure
Once the WLC team has identified the anticipated project phases, the next step is to create or adopt WLC data structure. The WLC data structure, whether new or adopted, is the key to successfully implementing WLC. In collaboration with industrial partners, the CMRU at the University of Dundee has developed a framework for a WLC data breakdown structure for the building industry which has been accepted by the BS/ISO 15686, Part 5: Whole Life Costing. The WLC data structure is reported by El-Haram and Horner (2002).

Identify objectives and constraints for the project
The objectives of the project should be established through discussion between the project team stakeholders; client, designers, constructors, facilities managers, and other members of the team particularly bankers and project advisors. The relevant constraints may be budgetary (e.g. cost-target and affordability), technical, time, and quality related.

Identify potential cost drivers – WLC significant elements
The philosophy of whole life cost significance hinges on the CMRU's findings that data can be analysed most effectively and usually sufficiently accurately simply by operating on those elements whose value is grater than the mean (Al-Hajj 1991). The cost significant elements are those elements whose cost is higher than the mean. The idea of using a cost significant model is to identify a small number of building elements which represent a high proportion of total WLC. This will reduce the time and effort to estimate the project WLC by estimating the cost of only a few elements. It also focuses the attention of WLC team on the elements where a great saving can be made.

Identify requirements, constraints and alternatives of WLC significant elements
Once WLC significant elements are selected, the next step is to identify and consider all the requirements and constraints of each WLC significant element.

Determine the data required to estimate each alternative option of WLC significant elements
Reliable, consistent data and information is the key to successfully implementing WLC. In this step the WLC team establishes assumptions and determine the data and information which is needed to estimate the WLC elements of every WLC significant element. This data includes the cost of materials, manpower, equipment and/or plant that are directly required to estimate the cost of construction, maintenance, replacement and operation tasks, and other data which supports the estimation of WLC elements such as life expectancy, required level of performance, the physical characteristics of a building, etc.

Select method(s) for estimating costs of each alternative option of WLC significant elements
The choice of estimating method depends on the type of each cost element (e.g. construction, replacement etc.) and the availability of data and information. The methods which can be used to estimate cost elements are operational costing or unit rate costing.

Estimate WLC of each alternative option of WLC significant elements
In order to estimate WLC of each alternative option, it is necessary to identify the tasks such as construction, replacement, planned preventive maintenance, reactive maintenance, inspection, operating, etc. that generate costs. A WLC toolkit has been developed by the authors, which consists of a series of spreadsheets to estimate each WLC elements including:

a. Construction costs
b. Maintenance and Life Cycle Replacement (LCR) costs
   - Planned preventive maintenance costs
   - Reactive maintenance costs
   - Inspection costs
   - LCR costs
c. Operating costs

Compare various alternatives for each WLC significant element
The primary aim of WLC is to evaluate and optimize WLC of the significant elements while satisfying the user and the projects requirements. This step provides an equitable comparison on a quantitative basis amongst competing designing options of WLC significant elements in order to select the lowest WLC (NPV) option.

Evaluate results for uncertainty and risk
WLC deals with the future and the future is unknown. There are many factors such as expected physical life, expected economic life, discount rate, inflation etc., to which WLC analysis is very sensitive (Flanagan *et al.* 1989, Kirk and Dell`Isola 1995, El-Haram and Horner 1998). WLC decisions therefore involve a considerable amount of uncertainty which makes it very difficult to carry out economic evaluations with a high degree of reliability. Therefore there is a need to critically review uncertainty associated with the selected discount rate, economic life and physical life. Examples of the techniques which can be used to deal with uncertainty are sensitivity analysis and probability-based techniques (Flanagan *et al.* 1987).

Compile WLC for the whole project
Once the lowest WLC (NPV) alternative of WLC signification elements is selected, the next step is to estimate WLC (NPV) of the project using significance theory model (Al-Hajj 1991).

Report findings and conclusion
The WLC report includes outcomes, assumptions, limitations and uncertainties for every WLC significant element used in the analysis. There are many ways in which the results of WLC analysis can be presented. The results can be presented in a variety of forms for each alternative, including cumulative WLC (NPV), cash flow of WLC (NPV), contribution of each WLC element to total WLC and/or WLC (NPV)/m^2.

PRACTICAL APPLICATION

To illustrate the use of the WLC toolkit, a high school project for 1050 pupils was provided by the industrial partners. The project is a new development under PFI procurement for a 30 year concession period. WLC toolkit was implemented using the steps described in the previous section as follows.

Identify all anticipated project phases and activities that will generate cost in the life cycle

The capital and facility management phases are considered. The disposal phase was not considered because after the end of concession period the school will be handed back to the Government.

Create or adopt WLC data structure

The WLC data structure developed by the authors during this research project was used.

Identify objectives and constraints for the project

The project documents (e.g. project agreement and "Invitation to Negotiate" document) and drawings were reviewed and objectives of the project and operational scenario were identified.

Identify potential cost drivers – WLC significant elements

WLC of the elements used in the original design were reviewed. In this case study, 29 building elements were identified. Cost data and estimates related to construction and replacement tasks were provided by the industrial partner. Maintenance and operating costs were not available at an elemental level, but only at the project level (£/m2). The first step was to estimate maintenance and operating costs at the elemental level. The next step was to apply "the theory of significance" on construction, replacement, planned preventive, inspection and operating costs. The source of data used is from HAPM (1999), SPON's Price Book (2002), HMSO (1991), BMI Maintenance Price Book (2002a) and BMI (2002b).

The distribution of WLC (NPV) at 3.5% discount rate, for all building elements is shown in Figure 1. Total WLC of all building elements was equal to £ 8 269 542, with an average WLC equal to £ 285 156. This shows that 38% of all elements contribute to 82.4% of total WLC. This method might reduce effort required to estimate WLC of future similar projects by some 60%. Eleven WLC significant elements were identified, whose total costs were higher than the average WLC for all building elements. Three WLC significant elements were selected for further WLC analysis: floor finishes, wall finishes and windows. To demonstrate the practical application in this paper, the rest of the process is based on one WLC significant element, "windows".

Identify requirements, constraints and alternatives for each alternative option of WLC significant elements

For each element, depending on requirements (e.g. double glazed windows), a few alternatives such as softwood high quality, aluminium and uPVC windows were selected for each functional area. There were no constraints related to windows.

Determine the data required to estimate each alternative option of WLC significant elements

For example physical life expectancy and planned preventive maintenance tasks, e.g. frequency of painting, were taken from HAPM (1999), for both the original and alternative options. Data related to cleaning frequencies for each cleaning task were taken from BMI (2002b). The discount rate for this analysis was assumed to be 3.5%, as suggested by HMSO (2003).
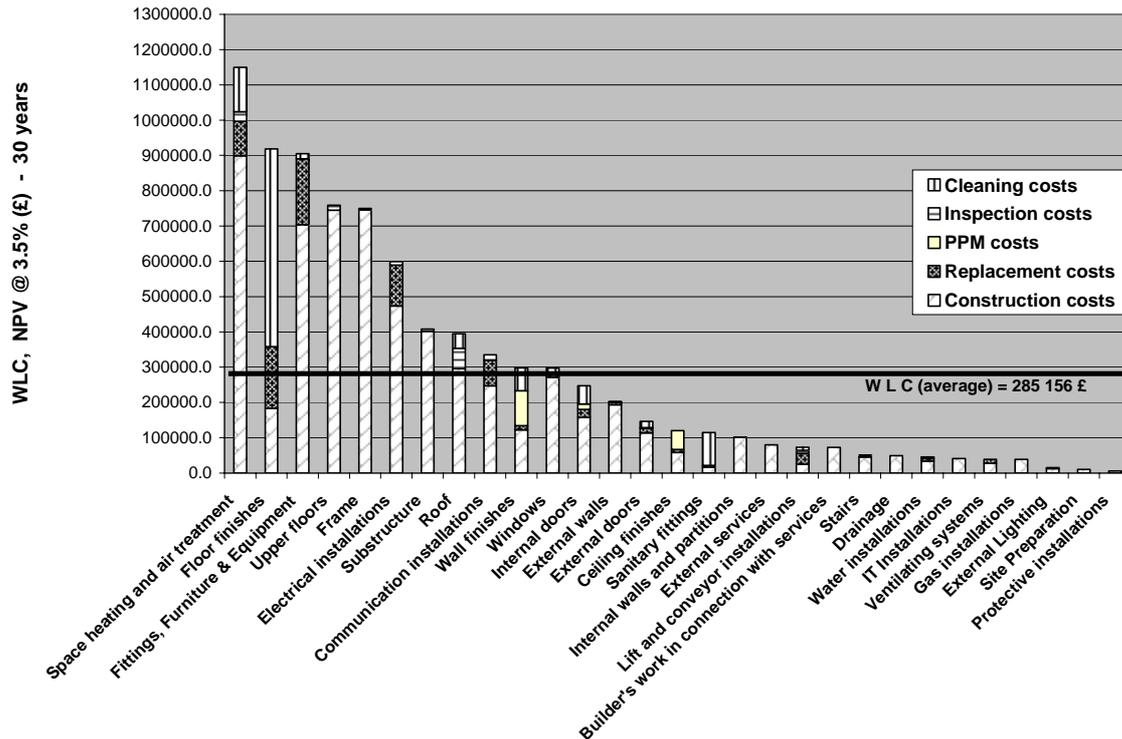
Figure 1: Distribution of Whole Life Costs, NPV, at 3.5%, for 30 years.

Select method(s) for estimating costs of each alternative option of WLC significant elements

Both methods, operational costing and unit rate costing were used to estimate cost elements.

Estimate WLC for each alternative option of WLC significant elements

Construction costs

Construction tasks were identified from the original project. Construction costs of the selected WLC significant elements and their alternatives were estimated using Spon's price book (2002).

Maintenance and Life Cycle Replacement costs

To identify the maintenance tasks for each WLC significant element, FMEA and RCM were applied. Failure modes of each component of different window options (e.g. failure mode of softwood window is decay of frame surface, deformation and underlying areas are soft and break off easily) and failure causes related to each failure mode (e.g. woodworm, untreated timber etc.) were identified. Then failure effects and corrective actions needed to eliminate or reduce the occurrence of the failure modes were identified. The failure consequences for each failure mode were identified and the most appropriate maintenance task was selected.

- Planned preventive maintenance costs: Life expectancies for all alternatives were taken from HAPM (1999) and BMI (2001). For example, frequency of painting of softwood framed windows was planned every 5 years. The cost of planned preventive maintenance was based on BMI rates (2002a).

- Reactive maintenance costs: Historical data related to failure modes from which probability distributions of failure can be defined, were not available. This led to difficulty in estimating the number of reactive maintenance tasks

for each alternative for the concession period. Therefore, an annual percentage of repair was assumed for every reactive maintenance task identified by RCM. The annual percentage of repair represents the annual probability of carrying out repairs due to the occurrence of considered failure mode. For example, for the reactive maintenance task "replace damaged area of decayed frame", an annual percentage of 2% was assumed. The reactive maintenance cost was based on BMI rates (2002a).

- Inspection costs: There were no any inspection tasks for all alternatives of windows and therefore there were no inspection costs.

- Life cycle replacement costs: For aluminum and softwood timber windows there were no LCR costs, because the life expectancy of these types of windows was longer than concession period. For uPVC windows LCR costs were estimated using the operational costing method, taking into consideration construction costs and adding costs related to removal of existing and preparation of surfaces for installation of new windows, including support costs (e.g. scaffolding).

- Operating costs: Operating costs related to windows were identified in terms of cleaning. The cleaning costs of WLC significant elements were estimated using frequencies of cleaning from BMI (2002b). Costs were estimated using operational costing method.

Compare various alternatives for each WLC significant element

Once the cost of each WLC significant element and its alternatives had been estimated, ranking was carried out based on the least expensive WLC (NPV). The ranking of window alternatives is shown in Table 1. The WLC saving between the original variant (Aluminium) and the alternative which has the lowest WLC (Softwood) is 13.4%.

Table 1: Ranking of window's alternatives.

Concession period 30 years, d = 3.5%							
Alternatives of Windows	Cc (£)	R c, NPV (£)	PPM c, NPV (£)	RM c, NPV (£)	Oc, NPV (£)	Total WLC, NPV (£)	Ranking of alternatives
Softwood, high quality, double glazed windows	179,317	0	26,479	19,886	13,480	239,162	**1**
Aluminium, double glazed windows	246,272	0	0	16,451	13,480	276,203	**2**
uPVC, double glazed windows	169,312	100,301	0	16,451	57,393	343,458	**3**

Cc = Construction costs, Rc = Replacement costs, PPMc = Planned preventive Maintenance costs, RMc = Reactive Maintenance costs, Oc = Operating (cleaning) costs,

Evaluate results for uncertainty and risks

A sensitivity analysis for discount rates (e.g. 3.5% and 6%), economic life (e.g. 25 and 30 years) and various physical life expectancies (e.g. from HAPM, BMI and industrial partners) was carried out. For example the changes in discount rate from 3.5% to 6% showed no sensitivity in selection of alternatives related to different types of windows. The variation between the lowest WLC option (e.g. £239 162 for softwood windows) and the most expensive WLC option (e.g. £343 458 for uPVC windows), is 30.3%, at

a 3.5% discount rate and 28.3% at a 6% rate. Figure 2. shows the cumulative WLC (NPV) at 3.5% for different alternatives.
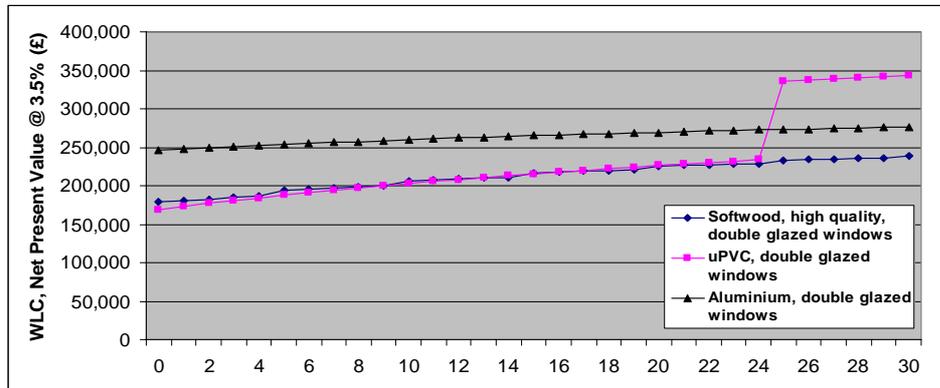

Figure 2. Whole life costs (discounted at 3.5%) for windows

WLC for the whole project was compiled in the form of NPV
Due to the unavailability of data related to costs which were not related to the building's physical elements (e.g. management and overheads costs, costs of utilities etc.), in this case study, only costs related to the building's physical elements were considered. The WLC of three selected significant elements (floor finishes, wall finishes and windows), based on lowest WLC (NPV) were added to the original WLC of other elements, in order to get a sum of all WLC elements, equal to £8 093 878. The total WLC (NPV) of the original design alternatives was £ 8 269 542. The total WLC (NPV) saving is 2.1%.

Findings were reported
The WLC analysis of different types of double glazed windows (Softwood high quality, Aluminum and uPVC) shows that the NPV at a discount rate of 3.5% for 30 years can vary between the lowest WLC option and the most expensive WLC option by about 30%. Variation in the discount rate from 3.5% to 6% showed no sensitivity to the selection of alternatives related to different types of windows. Figure 3. shows the contribution of costs in total WLC (NPV), for 30 years.
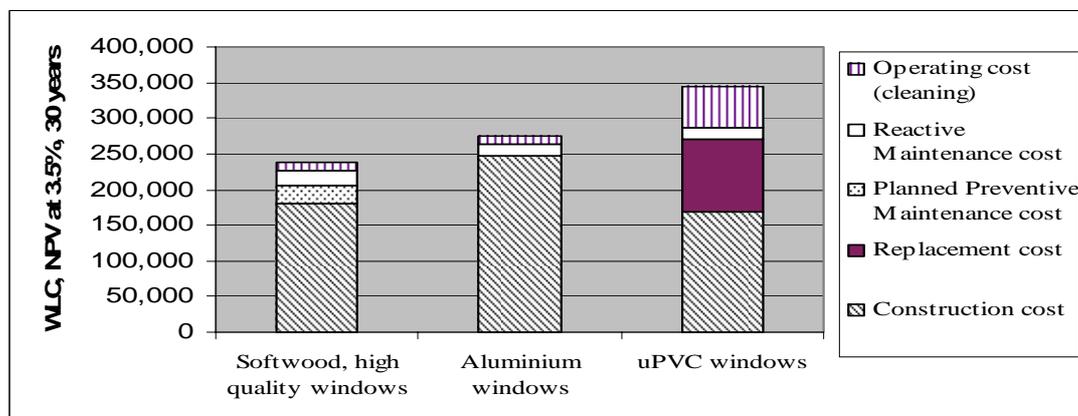

Figure 3: Contribution of costs in total WLC (NPV) at 3.5%, 30 years, for different alternative of windows.

CONCLUSION

The developed WLC toolkit has been applied to a practical example. The identification of WLC significant elements is based on "the theory of significance". This "theory" is a powerful tool for defining the WLC significant elements, for each building type. This will help to reduce the collection of data needed for detailed WLC analysis. For example, in high school used in this analysis, 38% of all elements contribute to 82.4% of total WLC.

The selection of planned preventive and reactive maintenance tasks were based on the application of FMEA and RCM. The WLC toolkit has been implemented on three selected WLC significant elements including windows, floor finishes and wall finishes, generating a saving at project level of 2.1%.

The WLC toolkit might integrate the use and sharing of data related to project design, construction, operation and maintenance costs and it might encourage closer working relationship between members of the construction industry supply chain to make the best decisions from the WLC point of view. The WLC toolkit could be used for analysis and reduction of WLC in early design stages (e.g. scheme design). Further analysis on different types of buildings will be carried out in order to check the consistency of occurrence of WLC significant elements. If such a consistency is found, the effort required to estimate WLC can be reduced by some 60%.

ACKNOWLEDGEMENTS

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Whole Life Costing in the Building Industry: A Case Study. Conference Paper. Oct 2006. Â The life cycle costing is a key economic analysis tool for sustainable construction. The design for sustainable billings must consider the long-term performance of projects. The lack of reliable historical data, especially for new building materials, is the main problem for life cycles estimate of building elements in PPP/PFI projects. The objective of this research is to develop a fuzzy expert system to estimate the life cycles of building elements at the strategic design stage. A case study was presented to demonstrate the fuzzy rule based system and its implication to estimate the life cycl Build your customer e-mail list and implement a referral program. A recommendation from a current customer is far more likely to result in a sale than traditional marketing. Network more, advertise less. Clients are more likely to hire a business with a face they recognize. Cut marketing costs by doing more in-house. Increase social media use and reduce traditional marketing. 5. Use efficient time strategies. Optimizing productivity effectively lowers your cost of doing business. Remember, wasted time equals wasted dollars. Â Quality sells whether in the form of products or services. Satisfied customers increase sales through referrals and repeat purchases. Higher quality and a solid reputation allows you to charge higher prices, which equals higher revenue and a healthier bottom line. Performance and whole life cost data for built assets are often widely dispersed, unstructured and ill-defined, making it impossible to compare or benchmark performance. This paper will describe the current UK industry-led approach to solving this problem. The project aims to identify and structure cost and performance data covering the service life of constructed assets. The aim is to improve investment performance and reduce whole life costs of constructed assets by providing standard methodologies and benchmark data on performance of constructed assets in support of business activities. Sav Whole Life Cost: An economic assessment of an item considering all significant costs of ownership over its life. x. List of abbreviations. Â This research and closing information that comes from it set out to assist people in the construction industry that purchase building services design, such as building owners, developers and main contractors, to make better informed decisions about the nature of the companies they are engaging, the form of the building services design they can expect, and the value of that design. 1.3 Research Framework. This research is categorised under the following chaptersâ€¦, Â· 1 Introduction: Provides the reason, aim and structure of this report.