

Whole life costing: application to water distribution network

M. Engelhardt*, D. Savic*, P. Skipworth**, A. Cashman**, A. Saul** and G. Walters*

* University of Exeter, Devon EX4 4QF, UK

(E-mail: m.o.engelhardt@ex.ac.uk; d.savic@ex.ac.uk; g.a.walters@ex.ac.uk)

** University of Sheffield, Sheffield, S1 3JD, UK

(E-mail: p.skipworth@ex.ac.uk; a.cashman@sheffield.ac.uk; a.j.saul@sheffield.ac.uk)

Abstract There is an increasing pressure from the economic regulator in England and Wales for water companies to ensure that their capital maintenance decisions reflect an understanding of the long-term impact on their operational costs and risks. This implies that decisions must not only reflect the costs borne now but the likely costs in the future, and how these might be optimised. It is noteworthy that within the construction and transport industries, asset management decisions which have been driven in this direction utilise a whole life costing (WLC) methodology. This paper addresses the implications of transferring the concept of WLC to service-based assets such as water systems.

A WLC approach to distribution network management aims to achieve the lowest network provision and operating cost when all costs are considered to achieve standards enforced by regulation. Cognisance is to be taken of all relevant costs – direct and indirect, private and societal – in order to balance the needs of the service supplier, the customer, society and the environment in a sustainable manner. A WLC analysis thus attempts to develop a cost profile over the life of the asset. Accounting for the costs over this period is achieved through a combination of activity based costing (ABC) and a life cycle assessment (LCA) used to identify potential social and environmental costs. This process means that each of these identified costs must be linked to some physical parameter that itself varies over time due to changing demands on the system, the different operational strategies available to the operator and natural deterioration of the fabric of the system. The links established between the cost and activities of the operator provide the basis for the development of a WLC decision tool (WiLCO) for application to water distribution network management.

Keywords Decision making; water distribution networks; whole life costing

Introduction

The water industry in England and Wales has been operated by private water companies since 1989. This privatised industry is economically regulated by the Office of Water Services (Ofwat). Ofwat has two prime duties: to ensure water companies' operations meet statutory requirements and that the companies remain commercially viable. Its secondary aims are to ensure that customers' interests are protected, provide incentives to reduce costs and pass savings on to customers, and to facilitate competition. Economic regulatory control is exerted via five yearly pricing reviews. At the beginning of each of these periods, negotiations take place between Ofwat, the other governmental regulators [Environment Agency (EA), Drinking Water Inspectorate (DWI)] and the companies to agree on the asset management programme (AMP) to be undertaken and to place caps on the prices that can be charged to customers in order to finance the AMP. To ensure the ongoing performance of the water industry's large "long-life" asset bases, appropriate levels of expenditure must be anticipated. Ofwat (2000) indicated that previous submissions were not entirely adequate and grounded in sound economic principles. Proper justification for pipe renewal is unlikely to be driven by a single operational consideration (for example, leakage), but more likely by an array of considerations including, for example, structural failure, water quality performance, and leakage performance which all affect levels of serviceability.

Serviceability is defined as “a measure of the ability of the company assets to provide the service required by customers” (Ofwat, 2001).

The requirements placed by the regulatory regime and the nature of the infrastructural assets underpins the development of the whole life costing (WLC) methodology. The methodology centres on an accounting scheme that links costs to their drivers, whether performance related or not. Performance aspects are identified by the actions that result from them and the costs associated with these actions. Thus, as performance or output changes as a result of an action or operation, so the accounting framework tracks the changes in cost. This allows for least-cost decisions to be identified which meet performance constraints, with all knock-on private and, where applicable, social costs accounted for. It is fundamental that the performance of the system is understood and is capable of prediction with a degree of certainty.

The methodology as presented is encapsulated within decision support software (WiLCO). This software integrates data from two separate databases, consolidating the input data so that the consequences of decisions across the spectrum of input costs and costs drivers can be visualised. The output generated by the software for a WLC analysis is subsequently demonstrated on a case study system.

Whole life costing

Whole life costing (WLC) as a term, has been around for nearly 20 years, e.g. Chenery (1984) with respect to buildings and the provision of infrastructure. WLC was born out of a recognition that initial capital costs only represent a minor portion of the overall costs incurred throughout the lifetime of a building or infrastructure. Solutions weighted towards minimising initial cost may be economically inappropriate in the longer term. Increasingly, the UK government is advocating the adoption of WLC approaches as a way of optimising investment decision making and to ensure the adoption of cost-effective solutions. Its application to buildings and structures has extended to inclusion within the BS ISO 15686 Part 1 (2000) “Building and constructed assets – service life planning”, with Parts 2 and 3 out in draft for public comment (BS ISO 15686). The Office of Government Commerce (2000) in Construction Procurement Guidance No. 7 Whole Life Costs has been prepared for projects related to the construction of facilities for government use. Adoption of WLC has extended beyond the construction industry. The Higher Education Funding Council for England has taken the lead in developing and promoting WLC within its overall procurement strategy (HEFCE, 1998). Since the late 1980s the Transport Research Laboratory (TRL) has been involved with developing a WLC approach for transport infrastructure, from scheme specific applications to the whole of the major road network (Highways Agency, 1999). The policy of the Highways Agency, since 1999, is that all works must be evaluated using a WLC approach in order to meet with government best-value policy requirements. The acceptance and appropriateness of WLC has received a boost from the emphasis on private finance initiatives and best-value approaches to procurement across a wide range of government services.

Application of WLC to water distribution networks

In respect of a service facility, WLC methodologies consider all the costs (private and social) that accrue for its initiation, provision, operation, maintenance, servicing and decommissioning, over its useful life (Skipworth *et al.*, 2002). The application of WLC to water distribution networks has been more recently discussed (Mukhopadhyay, 1994; Conroy and Hall, 1995). The Water Research Centre in the UK has been active in developing a WLC application to pipelines although not to whole distribution systems. In respect of the application to the distribution network, essentially a network of assets, the WLC methodology extends and takes the concept beyond previous work.

To make any WLC analysis tractable, especially in the case of distributed assets, boundaries need to be defined geographically, temporally and financially. For example, water distribution networks span large geographical areas through integrated systems. The work presented here places geographic boundaries from downstream of the service reservoir (tank), with the cut-off point at the point of first practicable use. However, distinct areas cannot be considered in isolation. How the distribution network is operated and performs affects systems both upstream (abstraction, treatment and transfer) and downstream (wastewater collection, treatment and disposal). Given that the cost of treated water provision is interdependent with the upstream system, the interconnected nature of costs should be explicitly included in the accounting framework.

The primary purpose of expenditure on water distribution networks is to maintain an appropriate level of performance (serviceability in England and Wales). An implication of this is that there is an indefinite “useful” life for a network. The “useful life” is constantly being altered by the way in which the operator operates and maintains a network, which consequently affects current and future performance. Period of analysis therefore takes over from the “useful” life, design life, depreciation period or accounting life span, in the WLC methodology as a more realistic and pragmatic approach. A period of analysis has to be determined that is long enough for the effects of expenditures on performance to be manifest through the system, but not so long as to trivialise them when discounted. It is for these reasons that a period of analysis of 50 years is proposed. For the purposes of the analysis undertaken here, the period of analysis is split into five-year time steps in line with the pricing period utilised by Ofwat. With respect to discounting, it is pointed out that this is often a matter of subjective judgment and that the most appropriate approach is to have some mid-range estimate accompanied by a sensitivity analysis.

Whole life cost framework

In presenting a framework for application of WLC to water distribution networks a distinction is made between the accounting and the definition and assessment of performance. The accounting recognises financial boundaries whilst the network performance module follows the geographical boundaries previously stated.

WLC accounting

The WLC accounting module provides a methodology whereby the costs arising from the operation, maintenance and management of a water distribution network can be identified, quantified and coupled to the performance of the network. Costs accounted for within the module are primarily private but can include the social as well. Private costs are those that accrue for the operator from being in the business of providing a service to customers. These costs include those that might conventionally be termed direct, indirect or overhead and general cost items. Social costs are those that accrue for society as a result of the operator being in business but that the operator, currently, does not have to account for. They are sometimes referred to as public costs, or more generally as externalities.

Identification of the private costs utilises Activity Based Costing (ABC; Innes and Mitchell, 1990). ABC provides a better understanding of the nature of indirect, overheads and general cost items and what drives them are seldom related to volume of production. A link is made between activities and products by assigning costs of activities to products based on the consumption of an individual product or demand for each activity.

Cost drivers relate activities to a product or products. Activities identified as potential cost drivers must provide an adequate explanation of cost outputs whilst at the same time being measurable and change sensitive. The social costs are identified through life cycle assessment (LCA; EPA, 1995). LCA evaluates the processes, material inputs and outputs

of a process to uncover the cost drivers and causes of the environmental burdens as well as accounting for the consequential costs. Its costing equivalent, life cycle costing (LCC), associates costs with the external environmental impacts of those operational activities hence internalising the externalities.

Network definition

Water distribution networks are supposed to provide an efficient service to customers and are required to meet a wide variety of disparate performance requirements. Much literature (Satcha, 1978; Deb *et al.*, 1998) has reported on those performance requirements that need to be addressed when making network management decisions (a summary of these is given by Engelhardt *et al.*, 2000). The serviceability assessment applied by Ofwat covers a wide range of performance assessments indicated in this literature. Figure 1 identifies all the sub-modules included in the “network definition” module for application in England and Wales. Each sub-module must be able to quantify current and future performance and the effect on performance of interventions, e.g. pipe replacements and changes in operational strategy, at given time horizons. Ultimately when considering performance all significant aspects that have an impact on costs must be considered holistically and quantified over the period of analysis in terms of cost drivers.

WLC decision support

WLC and LCC are sometimes looked upon as exercises in identifying, quantifying and tracking costs over the lifetime of an asset. In this way, WLC has been a decision support tool as a means to prioritise alternatives. However, the proposed methodology takes this one step further through providing links between the actions, their effect on the system and its subsequent impact on costs. This casual chain can be seen diagrammatically in Figure 2. Each action which can be undertaken within a network is characterised in terms of its resultant cost (as identified within the WLC accounting module) and its effect on performance (as defined within the network definition module). Such links enable each element to become a variable and its concomitant impact to be observed. The decision support provided by this framework moves beyond that of a prioritisation model, allowing the automation of the decision making process through the use of an optimisation or search technique. A resultant of the application of such techniques should be the identification of the least WLC solution.

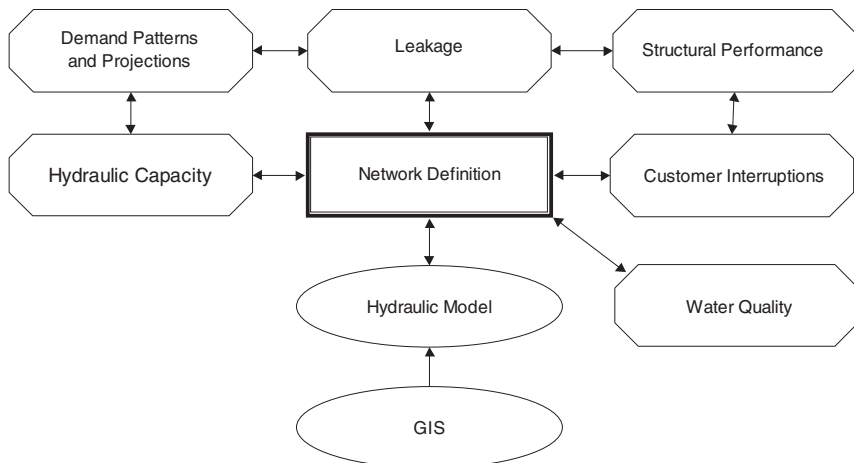


Figure 1 Network definition – performance sub-modules

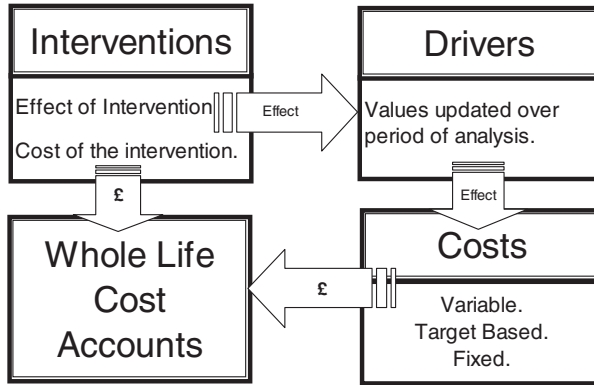


Figure 2 The linkage within the WLC methodology

The framework as presented in Figure 2 provides the basis for a WLC decision tool. It is the first of these elements, “Interventions” that represents the management decisions that can be investigated through the developed WLC decision tool. An “Intervention” represents any action that can be undertaken which will have an effect on the performance of the system, e.g. a pipe replacement or a change in leakage control strategy, or on an attribute which is identified as a driver for one of the input costs. WiLCO, a WLC decision tool has been designed around the framework of Figure 2 for application to water distribution networks.

WiLCO: whole life cost optimiser

WiLCO provides a single platform which integrates all of the data imported to allow the WLC of a network to be determined. To do this, it connects two databases. The first is a GIS/hydraulic package called Strumap (Geodesys, 1999), which represents the network and allows the hydraulic properties of the network to be evaluated. The second connection is with an MS-Access database which contains custom designed tables that allows all other required data to be imported. WiLCO has been provided with a user interface that allows for all elements within the WLC analysis to be manipulated. This then allows the investigation of different operating and maintenance scenarios and their effect on the network’s performance and WLC profile. WiLCO has also been integrated with a genetic algorithm which allows automation of the decision making process. This is the last step in the process, and requires each variable to be defined to the decision maker’s satisfaction before providing meaningful results.

As an example, a WLC analysis within WiLCO is undertaken for a case study network. The water distribution network consists of 25 km of mains, supplying 2,000 customers (population ca. 5,000). The results are summarised to provide the cost profile over the period of analysis. Figure 3 provides three separate cost profiles derived from the WiLCO software: the first presents the WLC profile if no maintenance occurs; the second utilises the user-defined functionality of WiLCO, replacing all cast iron mains for replacement in the first time step, whilst relaxing the leakage control strategy; the last profile utilises the GA to identify the least WLC operating profile.

Figure 4 presents cost profiles for the GA solution as is observed in the WiLCO software. Six profiles are provided:

- the total cost of operating the network;
- the private cost directly accruing to the operator;
- the social costs associated with the operation of the network;
- the operating costs of the networks;

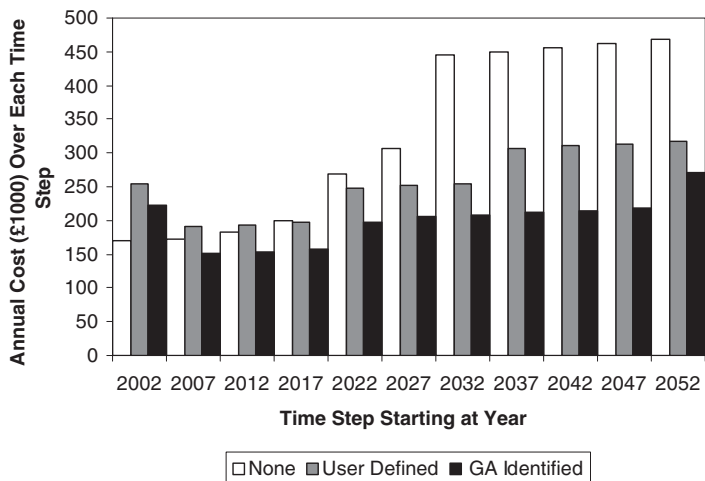


Figure 3 Cost profiles for a water distribution with maintenance profiles

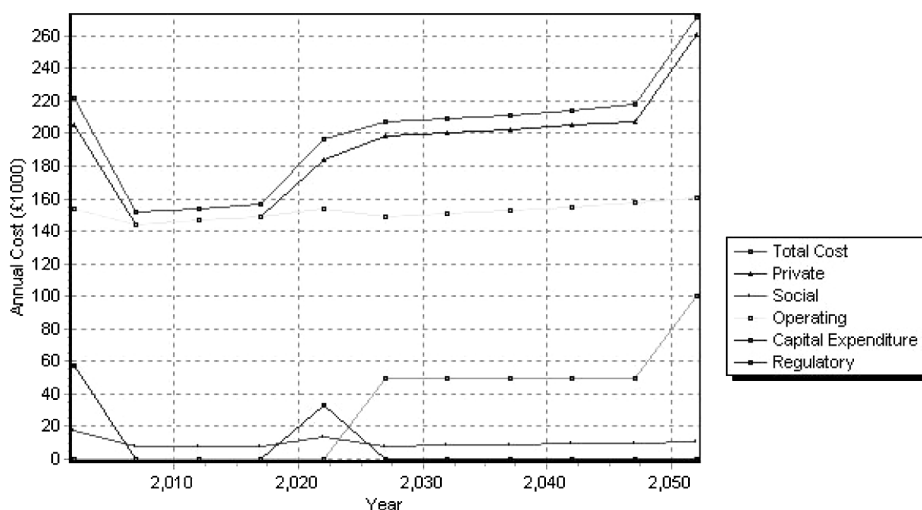


Figure 4 Various cost profiles for the least-cost operating/maintenance regime as provided by WILCO

- the capital expenditure associated with main replacements;
- the regulatory penalties associated with not meeting the required levels of performance.

Curves of this type indicates where the cost increases over the period of analysis. In Figure 4 the major cost increase is associated with the regulatory penalties. More detailed identification of these costs can be attained through observing curves for individual costs and drivers. WILCO also presents the user with the ability to observe the costs over the period of analysis as a series of accounts.

Conclusion

WLC as a methodology is increasingly being used within the UK across a number of sectors. This paper has presented a WLC methodology which has been derived specifically for application to service-based infrastructure, in particular water distribution networks. Underpinning the approach are the explicit links between the activities undertaken on the distribution network, their effect on the performance of the network and subsequent impact on the cost of the network to the operator and potentially to society. It thus provides a basis by which a decision tool can be derived which accounts for the various operating and

maintenance scenarios and their implications for the performance and cost of operating a network. The links established between the activities and their costs thus allow search techniques to be applied which identify the least operating or maintenance regime for a given scenario. The challenge remains one of populating the software with costs that are realistic and representative of the network being investigated, as well as the ability to adequately understand and predict the crucial aspects of network performance.

Acknowledgements

The authors thank the representatives of the collaborators of the work (Ewan Optimal, Geodesys, ONDEO, Thames Water Utilities, Untied Utilities, Yorkshire Water Services) for their input and support throughout the project. This work was supported by the UK Engineering and Physical Sciences Research Council, grant GR/M16115.

References

- BS/ISO 15686 (2000). *Building and constructed assets – Service Life Planning*. Part 1. Parts 2 and 3 in press.
- Chenery, C. (1984). Whole life cost of construction informal discussion – structural engineering group. *Proc. Instn. Civ. Engrs.*, Part 1, **76**, 822–825.
- Conroy, P.J. and Hall, M.J. (1995). Rehabilitation and leakage – a joint approach. *J. Water SRT – Aqua*, **44**(4).
- Engelhardt, M.O., Skipworth, P.J., Savic, D.A., Saul, A.J. and Walters, G.A. (2000). Rehabilitation strategies for water distribution networks. *J. Urban Water*, **2**(2).
- EPA (1995). *An Introduction to Environmental Accounting As A Business Management Tool: Key Concepts And Terms*. Office of Pollution Prevention and Toxics, Environmental Protection Agency, Washington D.C., USA.
- Geodesys (1999). *StruMap Users Guide*. Geodesys, Redditch, UK.
- HEFCE (1998). *Whole Life Costing: A Good Practice Guide for End Users and all Those Involved in the Procurement Process*. Higher Education Funding Council for England; <http://archive.uwcm.ac.uk/uwcm/pr/jppsg/handbook/toolkit/wlc>
- Highways Agency (1999). *Highways Agency “Next Step” Review*, October, London, UK.
- Innes, J. and Mitchell, F. (1990). *Activity Based Costing: a Review with Case Studies*. Chartered Institute of Management Accountants, London, UK.
- Mukhopadhyay, T.K. (1994). Rehabilitation of old water supply pipes. *20th WEDC Conference*, Colombo, Sri Lanka.
- Office of Government Commerce (2000). *Construction Procurement Guidance No 7 Whole Life Costs*. Her Majesty’s Stationery Office, London, UK.
- Ofwat (1992). *RAG 4.01: Guideline for the Analysis of Operating Costs and Assets*. Office of Water Services, Birmingham, UK.
- Ofwat (2000). *MD 161: Maintaining Serviceability to Customers*. Office of Water Services, UK; <http://ofwat.gov.uk/lettersmd/md161.htm>
- Ofwat (2001). *Levels of Service for the Water Industry in England and Wales*. Office of Water Services, UK; <http://www.ofwat.gov.uk/pdf/files/los2001.pdf>
- Satcha, J.H. (1978). Criteria for Pipeline Replacement. *AWWA Journal*, **70**(5), 256–259.
- Skipworth, P.J., Engelhardt, M.O., Cashman, A., Savic, D.A., Saul, A.J., Walters, G.A. and Lewis, L. (2002). *Whole Life Costing Approach for Water Distribution Network Management*. Thomas Telford Publishing, London, UK.

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.