Whole life costing of sewer systems

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Abstract

The UK water industry faces a need to manage sewer systems to meet and maintain required levels of service in a cost effective manner whilst minimising social and environmental impacts. Whole life costing approaches have been shown to provide an ideal platform for the evaluation of such a system by taking account of system behaviour, performance and regulation within a sensible economic and engineering framework. Combined with a decision support tool, the whole life costing approach has the potential to provide optimised solutions for sewer system management.

Introduction

The management of sewerage systems requires a balance between many, often opposing, objectives set out by different parties – consumers, shareholders, the Environment Agency, OFWAT etc. For these parties the main drivers of could be briefly summarised as level of service, cost, environmental impact and profit. In addition to current demands, the implementation of the Water Framework Directive (Kallis and Butler, 2001), shifting socio-economic trends and changing public perceptions (OFWAT, 2003a) increase the need for an intellectually robust, transparent and auditable methodology for the cost-efficient management of sewerage systems.

The term 'Whole Life Costing' (WLC) has been around for two decades (e.g. Chenery, 1984), being born out of the recognition that initial capital costs often represent a small portion of the lifetime costs of a building or piece of infrastructure. The government is increasingly encouraging the use of WLC approaches to optimise decision making and ensure cost effective solutions.

'Cost-S: A whole life costing approach to sewerage' is an ongoing EPSRC funded project, which is being undertaken by the Pennine Water Group and Centre for Water Systems in collaboration with the water industry. The two groups previously developed a WLC methodology for the management of water distribution networks (Skipworth *et al*, 2002; Engelhardt *et al*, 2002) and are extending this approach to the more complex situation of sewerage systems.

Cost-S Approach

The efficient and effective management of urban drainage systems should be based on a number of prerequisites. These include a proper and adequate knowledge of assets, an understanding of system performance, the level of service provided and required, the management intervention options available and their impact, the costs associated with system performance and interventions and, the consequences of service failure.

The research is developing models of hydraulic behaviour, collapse, blockage and pump station behaviour based on actual asset and performance data sets for use as predictive tools to reflect changes in assets, asset condition and performance over time. An important aspect of this work is the development of 'Key Performance Indicators' (KPIs) that are generated by the modelling and that are used to both evaluate performance and act as a mechanism to initiate intervention options (Ashley and Hopkinson, 2000).

The time span of the WLC approach is important as it must recognise the generally long life of the assets and allow the impacts of interventions to be fully realised such that a proper trade-off between the short- and long-term effects of capital and maintenance strategies can be made. The methodology is based on a horizon over which the WLCs will be calculated and this is split down into multiple timesteps, at which performance is assessed and interventions are applied as necessary.

The Cost-S approach to WLC utilises three distinct but interdependent modules – Network Definition, Whole Life Cost Accounting and Decision Support Tool, as illustrated in Figure 1.

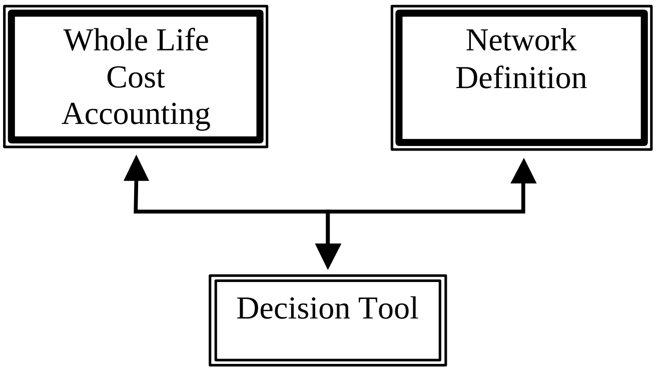

Figure 1: WLC Framework

Network Definition

Network definition includes the physical layout and characteristics of the sewer system (both in its current state and changes over time associated with deterioration, rehabilitation and upgrading applied at future timesteps throughout the period of analysis), the catchment input conditions i.e. dry weather flows and wet weather rainfall inputs, the performance of the system and the performance constraints imposed. This is shown graphically in Figure 2. The performance of the system is split into two related parts – hydraulic modelling and asset performance modelling, the hydraulic modelling being simulation based, whilst the asset performance modelling is derived from historical data. The results of this modelling are used to generate KPI values which can then be compared to target and/or trigger values.

The sewer asset data will be imported from existing water company databases into the Cost-S software. As part of the project a common data format is being developed which will include fields for all data required to enable hydraulic and asset performance modelling to take place. At each time step, age will be increased and deterioration models will be applied to the sewer assets to enable the temporal variation in system performance to be apparent. Deterioration modelling of sewer assets is at an early stage of development and is dependant on complete historical data, which is generally limited (Wirahadikusumah *et al*, 2001), thus as with all models in the Cost-S software, it will be possible to change the model coefficients or substitute the model for an improved version as techniques evolve.

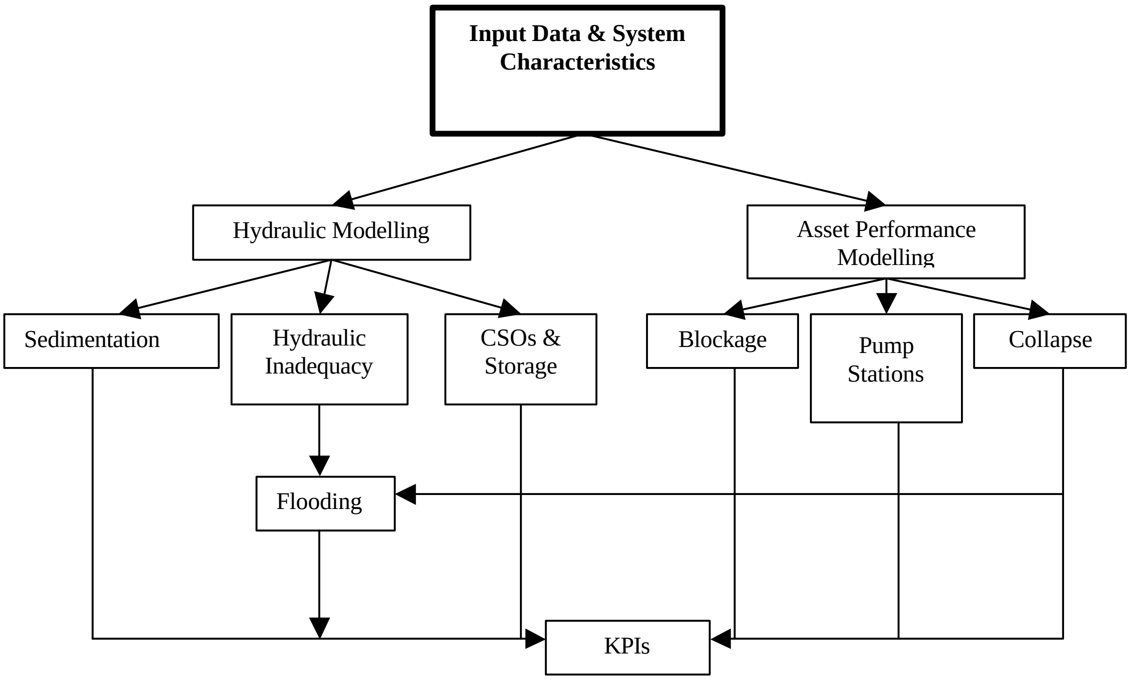

Figure 2: Network definition

Hydraulic modelling

Within Cost-S, hydraulic modelling will be undertaken using 3DNet software, this has been decided upon for a variety of reasons including IPR agreements as well as the functionality of the software which allows both kinematic wave and dynamic wave modelling to be used. It is intended to use the computationally more onerous, but more accurate dynamic wave model only to identify problems in the initial state and for verification of final solutions. The faster kinematic wave model will be used for optimisation of intervention options.

KPIs directly linked to the hydraulic modelling include Sewage Available to Transport (SATT), wet weather performance, sedimentation and CSOs. These KPIs will be calculated on an asset by asset basis, but will also be combined to produce system wide indications of performance on an areal basis.

SATT is a concept which has been developed within Cost-S to measure hydraulic inadequacy under dry weather conditions, it is calculated as the available volume in the sewer divided by the design volume and can thus be considered as a 'headroom' term. The KPI will measure the SATT at the peak DWF and if and for how long a set threshold value is exceeded.

Under wet weather conditions, a development of the performance assessment system described by Cardoso *et al* (2002) has been proposed, this would be expressed in terms of either water level or discharge, a diagrammatic representation for the performance function in terms of water level is shown in Figure 3. The hydraulic performance functions would be calculated for each of the WWF design events and for each asset a series of performance indicators produced. These would compare actual performance from the simulations against the requisite performance level for that particular asset. The performance functions would be further aggregated in the following steps:

- By integration over the duration of wet weather event (and normalising over unit time).
- By selecting critical values for each and every one of the different storm conditions.
- By averaging with respect to probability of occurrence, i.e. by summing values for each return period multiplied by its probability.
- By aggregating to the system level with weighting proportional to pipe length. This step could be done either for the entire system in the same manner, or within groups

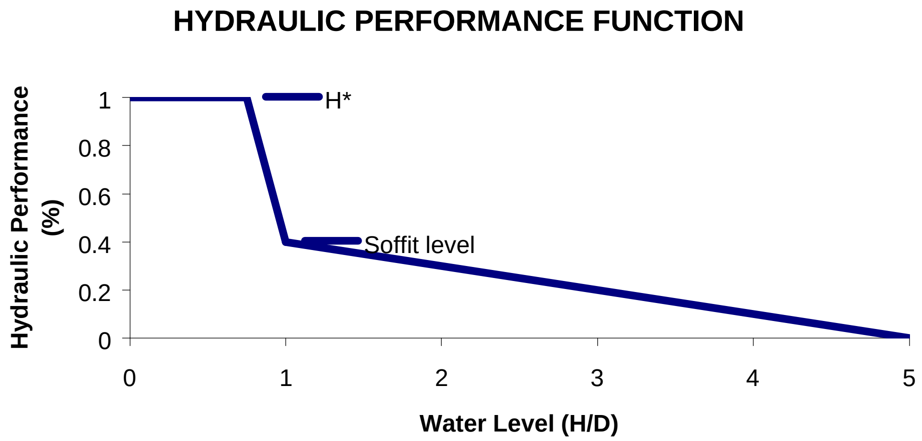

Figure 3: Wet weather performance

Sedimentation will have a similar performance function, based on the time aggregated velocities in the sewer in relation to the self cleansing velocity. Where possible the results from individual assets will be calibrated against actual sedimentation recorded and cleaning actions undertaken. This can then be used to specify a frequency of cleaning, which would be modified if changes to the sewer system result in changes to the velocity performance function for the asset.

For CSOs, the KPI will be based upon the consent conditions for the CSO in terms of number of spills. A second KPI may be used to predict screen performance to allow related maintenance costs to be built up.

Asset Performance Modelling

Asset performance modelling is split into three areas – blockage, collapse and pump station. However, blockage and collapse are related in that performance is generally related to physical characteristics such as age, material, diameter, structural condition and depth of cover.

Structural condition of the pipe is obviously the primary driver in many collapses, but it is also an important driver in blockages which are often a result of displaced joints, root intrusion or sedimentation. Although structural condition is an important driver, it will rarely be the sole cause of an incident – in the case of blockage, the composition of the sewage is important – e.g. large objects, rags, fats. In cases of collapse other important factors include loading – live or dead, levels and frequency of surcharging.

Predictive modelling for blockage and collapse is being developed from analysis of incident records and corresponding asset databases. The intention is to produce models which will predict the number of blockages and collapses on a system, given sufficient asset data. The accuracy of the model and application of the model will of course be dependant upon the quality of the input data.

Pump stations are more complex as there are numerous potential failure mechanisms which it is not practical to try and model individually. Instead analysis of operational data is taking place to identify the regularity of failures, linked to physical characteristics and maintenance regimes. Failure of a pumping station is defined as inability to pump the design flow of the station. The output of the performance modelling will be the number and duration of failures.

Interventions

The term interventions is used to describe all actions applied to the sewer system, these have been split into four levels which are briefly described below.

1) Inspection and Operational maintenance – any intervention which does not involve a physical change to the sewer structure, these will primarily be inspection and cleaning and may be regular operations, or only in reaction to an incident.
2) Repair – a physical improvement to the fabric of the sewer, but of a minor / local nature, thus no change to the structural performance grade.
3) Renovation – similar to repair in that it uses the existing structure, but on a larger scale – whole pipes rather than problem areas, thus there should be an improvement to the structural performance grade.
4) Replacement – anything that replaces the entire original structure, or adds a new structure to the sewerage system, this would reset the structural performance grade.

In each class of intervention only a limited number of options will be considered – for example those most commonly used by the water company. This keeps the problem tractable and reduces the likelihood of unsuitable interventions being chosen.

Whole life cost accounting

The accounting module brings together the costs arising from the operation, maintenance and management of the sewer system using an activity based costing approach (Innes and Mitchell, 1990) using a combination of RAG (OFWAT, 2003b) and the range of activities required to maintain the provision of the service. Costs are therefore broken down on an item by item basis, for example, the costs of a blockage incident will usually start with the fielding of one or more complaints, this will lead to the level 1 intervention of an operative being sent out, who may or may not be able to solve the problem, if not, a level two intervention of a contractor with jetting equipment will be sent out etc. In addition to the costs of actions carried out, costs are also attributed to impacts and consequences. Impacts considered are both those internal to the company (e.g. cleanup costs) and external (e.g. traffic disruption, costs to householders). Consequences are the costs which are borne as a longer term response to the incident, such as regulatory penalties, GSS payments, and pollution fines.

Decision support tool

The decision support tool (DST) is at the heart of the Cost-S software platform which links the three modules together. The purpose of the DST is to take the current performance of the sewer system, it's associated operational expenditures and projected deterioration, and apply different management strategies based on a range of constraints including performance targets, available interventions and finances, with a view to optimising the performance and cost efficiency of the sewer system over the WLC horizon. As the tool will work sequentially through discrete time steps, Markov decision processes provide the underlying theory behind this part of the software.

There will be several modes of operation of this tool available – firstly a manual version in which all decisions are taken by the user, thus the tool provides user with a set of options based on the performance of the system and other constraints, and then implements the user's decisions. Secondly a semi-automatic option will be able to take basic decisions based on a set of rules and requires some user input. The final option is a fully automated tool which would make use of an evolutionary algorithm to enable advanced decision making.

Conclusions

Cost-S is developing a package which will enable sewerage managers to investigate the effects of different intervention strategies over a time frame which enables the full effects of maintenance and capital works to become apparent. This will be done through the use of predictive modelling techniques and a comprehensive cost accounting module together with a sophisticated decision support tool.

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