NEW LIFE CYCLE COSTING AND RISK APPROACHES TO ASSET INVESTMENT AND PLANNING

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ABSTRACT

Understanding the lifetime costs of investing in and operating power distribution and transmission assets is of critical importance to maintaining and reinforcing existing networks and developing new ones, including those anticipated in future networks such as Smart Grids.

INTRODUCTION

A new integrated life cycle cost (LCC) and risk assessment methodology, which addresses whole life costs from original planning, to construction, operation and eventually the management of end-of-life of assets, has been developed. The approach was developed to support asset investment and policy to enable optimum solutions to be identified, taking into account economic, environmental, health and safety and social costs, with explicit account of hazards and risks, including those arising from asset failure.

METHODOLOGY

The LCC methodology is based on life cycle principles and reflects many of the concepts and constructs of conventional LCA and life cycle inventory (LCI) methods for environmental assessment, as reflected in the SETAC framework [1]. The method developed also makes use of Total Cost Assessment (TCA) elements [2] and is part of an ecometric set of techniques [3]. A key part of the LCC method is its ability to handle health and safety related aspects by incorporating asset and human stream analysis on a common basis, as shown in Figure 1.

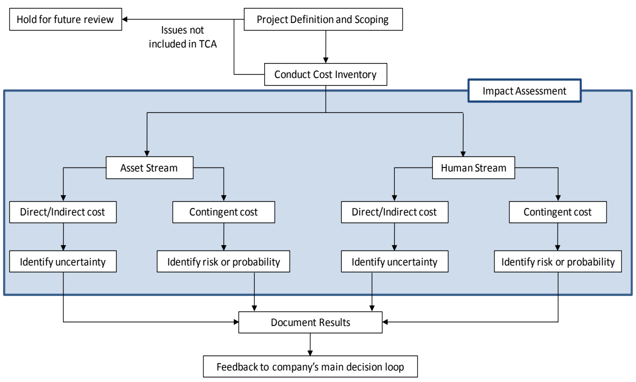

Figure 1. Overview of LCC methodology

Cost Categories

Since costs can come from a variety of sources, with a varying degree of accuracy and different methods of quantification; they are divided into five categories. These categories describe the general source and significance of the costs assigned. The categories are:

Type I – Direct costs e.g. capital investment, labour costs, raw materials and waste disposal

Type II – Hidden direct costs e.g. operational or site overhead costs not assigned to a single asset or project

Type III – Possible future costs and liabilities e.g. compliance costs, fines, compensation payouts or costs associated with industrial process risks

Type IV – Internal intangible costs such as impact on market share, staff morale and reputation as a result of the projects success or failure

Type V – External intangible costs e.g. impact on the environment both locally and globally, or the impact on society.

Cost Elements

In order to construct models and scenarios the cost elements to be used need to be considered and defined. These cost elements can encompass any relevant cost that needs to be taken into account. Some examples of cost elements, and the cost category these are assigned to are shown in Table 1.

Direct/Indirect costs

These are the costs where there is no uncertainty about their occurrence; they will definitely arise and will have a value associated with them, although this might be a range of values.

Contingent costs and risk

For contingent costs, the first level of uncertainty is whether the cost will occur or not. This uncertainty is associated with the risks associated with asset failure, which in turn may be linked to the asset's Asset Health Index. The first evaluation is whether any particular asset presents a hazard and what the corresponding risk is.
Risk is calculated using the following expression:

$$IR\ (Individual\ Risk) = Failure\ Probability\ \times Exposure \times Vulnerability$$

where,

$$Probability = Historic\ Failure\ Rate\ \times Weighting\ Factor$$

This method of quantifying risk can be applied to risk of fatality or injury to people and to risk of damage to assets from incidents occurring. Each of the factors in the functions, above, are described in brief below.

Historic failure rate:
This is used to calculate the probability of incidents and failures occurring. It is expressed in terms of failures per unit per year and reflects the historic experience of equipment of similar type, suffering destructive failure, or equipment removed from service with a defect. The historic failure rate needs to take into account the average age of the equipment in service, the number of units in service and the number of destructive failures so far recorded. The historic failure rate can then be calculated as:

$$Historic\ Failure\ Rate = \frac{Number\ of\ failures}{Number\ in\ service\ \times\ Number\ of\ years\ in\ service}$$

Ideally this should also be for a particular mode of failure. In the absence of historic failure rate data, it may be possible to estimate failure rate from the experience of other equipment operators. If this is also unavailable it may be possible to assume an upper limit failure rate based on past experience of similar technology.

Weighting Factor:
In the calculation of Probability the Historic Failure Rate is multiplied by a Weighting Factor. This allows the operator to convert the historic rates of failure into a projected failure rate by assessing the condition of the equipment using engineering judgement.
Weighting factors can be applied to the entire population of an equipment type, which may occur immediately following a failure where the condition leading to the failure is not fully understood. These particular weighting factors may be reviewed and refined as investigation into failures yields additional information. Weighting factors may also be applied to sub-populations identified as being at higher or lower risk based on knowledge of the condition of the equipment. In this case, a range of weighting factors may be applied to reflect the judged risk associated with different sub-populations.
Weighting factors can be assigned using engineering judgement and also through use of the asset health index (AHI) or similar asset condition metric.

Exposure and Hazard Zone:
The calculation of risk takes into account the amount of time an individual or asset spends in the Hazard Zone of the affected or examined equipment. Exposure is taken to be the fraction of a working year than an individual is present within the Hazard Zone. For assets, where they are fixed in place, exposure is constant – all of the time. Where the Risk Management Hazard Zone extends outside the site, a realistic judgement of public exposure based upon local site knowledge must be used.

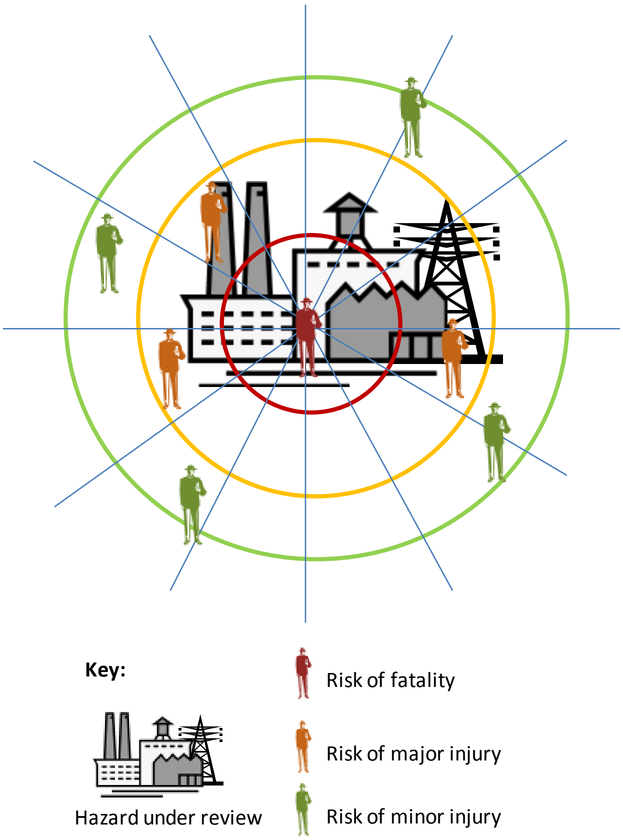

Figure 2. Example of Graduated Hazard Zone

In the figure there are three zones identified surrounding the hazard under review. In the inner zone the person is at risk of fatality and assets at risk of destruction or severe damage. The cost implications of this damage to assets may be in terms of replacing or repairing the asset, any costs associated with asset "down-time" and labour and transportation costs.

In the middle zone, there is risk of serious injury to people and damage to assets, which has similar cost implications. Repair of the asset rather than direct replacement may have additional impacts on the assets health index and its expected remaining lifetime.

In the outer zone, there is a risk to people of minor injury and a risk of slight damage to assets, which may be realised as an impact on the asset health index rather than requiring any immediate attention. This may then have implications with regard to expected lifetime of the asset and potential for suffering failures itself, which can be taken into account.

Vulnerability:
This final factor represents the estimated likelihood that an individual or asset will be affected, and the severity, if failure of equipment occurred. This factor has some uncertainty associated with it as it depends on engineering judgement to assess the severity of the potential failure mode and the vulnerability of surrounding assets and individuals.
This judgement takes into account the nature of the failure mode and any known debris patterns from previous failures, the level of protection given by surrounding equipment and structures and the percentage of the hazard zone which is accessible.
This factor makes it possible to allow for more robust assets weathering incidents better than delicate ones, and individuals protected by structures suffering less from being in the hazard zones.

Asset Health Index

The diagram below in Figure 3 shows the relationship between AHIs, the age of the asset and the probability at any point in time that the asset will require replacing. This also shows how AHIs can change over time due to either a fixed or varying deterioration rate and how this influences the probability of replacement.

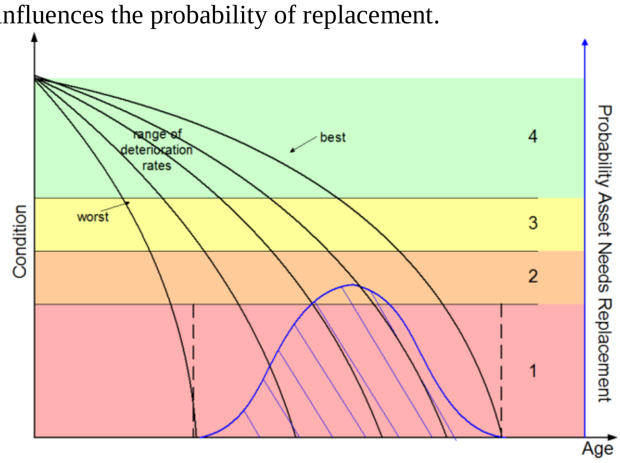

Figure 3. Asset deterioration rates

Handling Uncertainty

Since it is often not possible to specify a fixed value for many of the cost elements identified, the methodology and the software implementing it can handle uncertainty in cost values.

Uncertain Values:
In some cases uncertainty will be on the exact value for a cost element, be this a one off or recurring cost. This can be handled simply, by specifying a range within which the cost is anticipated to fall. A modal value (most likely value) can also be specified and the software tool can generate a value for this cost element, within the given bounds.

Nested Events:
In some cases, the occurrence of an event may lead to a number of other costs being incurred, either fixed or of an uncertain nature themselves. To handle this, uncertain cost elements can contain other, nested cost elements. These elements will only be included in the analysis if the parent elements event actually occurs, otherwise the nested elements cost contribution will be zero. Therefore, the actual probability of these events occurring is the probability of the parent element multiplied by the probability of the nested element.

Monte Carlo Analysis:
The diagram in Figure 4 shows a simple Monte Carlo analysis process based on three cost elements with varying probability distributions.

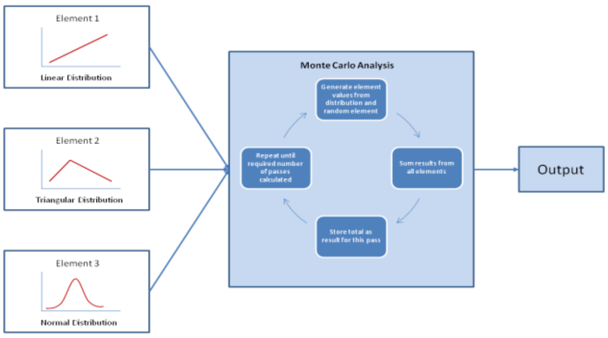

Figure 4. Monte Carlo Analysis

The basic process is to run the simulation multiple times, each time generating new values for any uncertain values from the assigned probability distributions. The results from each run can then either be averaged out to give a set of single cost values showing what should be the most likely total cost, or the distribution of total costs can be plotted to give a probability distribution for the total cost. This can also be rearranged to give a cumulative probability plot showing the cost at which there is an 80/50/20% likelihood of occurrence.

CASE STUDIES

To assess the newly developed methodology GnoSys worked with National Grid to examine a number of asset policy areas where economic, environmental and risk performance was important. The case studies examined were extensive and detailed and so the summaries below are confined to briefly reporting the background of just two studies and their essential findings.

Asset Policy Studies: Cable Tunnel Co-location

The goal of this case study was to carry out an LCC to help inform decision-making on the potential life time costs and the benefits and dis-benefits associated with co-location of 400kV and 132kV power cable assets in comparison with current, single owner/occupier tunnel systems for single cable types.

The functional unit adopted for the study was:
10 km of tunnel and cable system of 2 x 400kV circuits and 3 x 132kV circuits (1 cable per phase in both cases) over 60 years of operation, which also included all accessories such as cable joints.

It was found that there is a short-term capital investment and long-term total life cost saving, and significant environmental benefits, from the adoption of a 4m co-located cable tunnel facility rather than individual 3m cable tunnels for the DNO and TSO cable circuit requirements considered here.
The climate change benefit in greenhouse gas emission (GHG) terms is typically 194,000 tonne CO_2 eq. with no account of avoided carbon credits. This equates to a saving of around 25% of the GHG emissions for the combined 3m tunnels. There would also be a significant reduction in overall environmental impacts during construction. However, the likely impact on local people and organisations living and working close to a 4m tunnel construction will be higher than that of a similarly located single 3m tunnel.

The level of additional risk must however be carefully considered particularly in regard to operational cable circuit failures arising from potential cable joint failures and tunnel fires. International experience of XLPE cable joint failures suggests the TSO will experience a 1.5 times larger risk of cable circuit outage in a co-located tunnel compared to a single occupancy 400kV cable tunnel due to cable joint failure. In contrast, the DNO could experience a risk which is 3 times larger than the risk of cable outage in comparison with a single occupancy 132kV cable.

Assessment of Alternative Substation Switchgear Technologies

This study was carried out to assess the benefits and dis-benefits of utilising either AIS or GIS switchgear in new substations. There is some debate surrounding the choice of which switchgear is preferable both economically and environmentally. AIS is seen as the cheaper option, and GIS is typically reserved only for sites where AIS is not feasible. Examining the whole life costs of the two options will lead to clarification on whether previous assumptions are true and how the environmental costs may contribute to choice of switchgear.

The functional unit adopted for the study was:
A substation, as a new installation, consisting of 6 switchgear bays, 2 transformers and all ancillaries required in a functional facility operating over 40 years.

The LCC-Leets model constructed is a whole-life model including construction and operation cost impacts for two scenarios, but the 40year lifetime does not include a major refurbishment of the facility. Therefore there are no end of life costs considered, except those associated with assets which fail, and require disposal, prior to the end-of-life of the switchgear.

The switchgear LCC case study has shown how the multiple cost and green house gas environmental impact elements associated with construction and operation can be examined critically with account of site functional differences and different major modes of failure.

The type I costs dominate the 40 year lifetime of the scheme, for both scenarios. These include all the installation and materials costs as well as the costs of the assets. Relatively speaking, for normal operation in the absence of faults, the cost of operating the switchgear is small compared to the capital investment cost. On comparing the two technologies, GIS is more expensive over the lifetime than AIS in all stages of the lifetime, i.e. both construction and operation. However, the difference between the two scenarios is relatively small, 17% of the cost of the GIS facility.

On examination of the GWP impacts of the two technologies, SF6 leakage dominates both scenarios, with the power losses contributing relatively small amounts. This is particularly clear when examining the potential effect of future changes in the UK generation mix on the impact of system losses. In this case there is little effect seen on the yearly global warming impact for the two technologies as the CO2 emission reduces with the introduction of larger amounts of renewable generation.

Monte Carlo assessments examining total GWP of the scenarios instead of costs suggest that the GIS scheme has a consistently higher environmental impact then AIS, and this impact increases significantly when SF6 tank rupture events occur. While these events have a low probability, it is possible that such an event may happen once of even twice within the lifetime of a scheme.

REFERENCES

[1] SETAC, 1991, "A Technical Framework for Life Cycle Assessment"

[2] Daryl Ditz, Janet Ranganathan and R. Darryl Banks, "Green Ledgers: Case Studies in Corporate Environmental Accounting, An Introduction to Environmental Accounting as a Business Management Tool: Key Concepts and Terms", June 1995

[3] Ecometrics – see www.gnosys-ecometrics.com