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Integrated Life Cycle and Risk Management

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1. Introduction

Asset failures and their consequent costs are a routine and often unavoidable aspect of the operation of utility plant. Optimum planning requires the risk of failure to be taken into account over the life cycle of the assets. This achieves the right balance and timing between capital, preventive maintenance costs and the risk-weighted costs of failures. This constitutes risk-based asset management.

This paper overviews a methodology for determining life cycle costs of assets. It considers maintenance and replacement policy, with breakdown and other risks over an extended time. Benefits realised are:

- Justification of maintenance and replacement decisions either for business governance or regulatory compliance.
- Alignment of risk reporting and forecasting with asset management planning.
- Ad-hoc testing of different maintenance or replacement scenarios.
- Increasing business valuation through minimising asset life cycle costs.
- Improved basis for setting insurance excess costs.
- Ability to value risk controls such as the marginal value of an additional spare or improving asset protection systems.

Application to a specific example is described that is characteristic of the problem faced by an electricity distribution utility.

2. General Definition of Problem

Optimal planning requires knowledge of the costs of operation of assets. Some of these costs and the time of their occurrence are known and can be planned for. Others arise from unpredictable failures in assets and thus present a risk cost to the utility. Although the exact cost and time of occurrence of these events is unpredictable, information is often available, or estimable, as to the probability of their occurrence and the variation of this probability with time. Thus it is possible to calculate risk costs as a function of time. From this, an estimate of the asset's net present value may be obtained that can be used to guide replacement and maintenance policies.

The operation of an asset is affected by events internal to the asset itself and also from external sources. Failure events of a particular asset directly affect its operation. However, such events may not be the only ones that affect this asset. Utility companies usually own many assets that together contribute to their overall business. Failure events in one asset may affect the operation of others. It is, therefore, necessary to consider the group of assets together in order to determine the risk costs to the utility.

Risk cost profiles showing the probability for each type of failure for all the assets and the cost consequences of each of these failure types, over a forecast period, is required. From these cost profiles, a discounted present value may be calculated to represent and compare the value of a planned set of actions and their consequences.

3. Failure Modes and Consequences

An asset may fail in multiple ways as different components of the asset fail. Even a single component may fail in a number of ways. It may fail from corrosion, wear, or from damage due to an external event. These are referred to as failure modes and they usually have a number of consequences resulting in risk costs whose severity may vary due to the state of the system at the time of failure depending on, for instance, whether fire protection systems were installed and functioning correctly.

4. Forecasting the Probability of Failure

4.1. Hazard functions

The probability of failure for each failure mode (or “fmode” in the terminology of our methodology) is described by its hazard function. A hazard is the probability of a failure in the next interval of time (usually a year) give the asset is functioning at the beginning of the interval.

Relevant component and asset data may be known empirically from historic and manufacturer data. However a number of difficulties arise when using this data to determine hazard functions.

1. Appropriate data may be unavailable or is of dubious validity, particularly for new technologies.
2. The data only applies to an ensemble average; actual values for individual components may vary widely from this average.
3. The data only refers to the performance under some average operating condition that might not be the case for the actual situation.

If the internal physical processes that lead to the failure are known, a two step approach may be used. First, a condition score for the component at a given time is calculated and then a hazard function, whose argument is this condition, is used to calculate the failure rate at that time.

Where the condition can be measured through inspection procedures, this approach allows for condition monitoring to provide more reliable information on the actual assets and components, and accounts for variation due to different and changing operating conditions.

4.2. From present knowledge – constant state forecast

The current state of the system defines the present hazards associated with the failure modes and also the future values of these hazards insofar as the state of the system does not change. We refer to the use of hazards, calculated in this way, as using a constant state forecast. Scheduled state changes, such as result from planned refurbishment and replacement of assets, are taken into account by piecewise definition of the hazard functions.

However, unscheduled state changes, as result from failures, cannot be accounted for as only their probability of occurrence is known, not when (or if) they actually occur. Unscheduled state changes of an asset are forced by both internal and external events. Failure of the asset itself is such an internal event. External events, as may be caused by failures in other assets that affect state variables relevant to the asset in question through the sharing of common resources. One such resource is the supply of spares.

The hazard functions thus defined are only valid until an unscheduled change of state occurs. Thereafter, the deviation from the true hazard increases with time. Where groups of many interacting assets are considered, significant deviations from the true hazards may occur after a time very much shorter than the expected lifetimes of the assets. Nevertheless, a constant state forecast may be useful in a specific context, particularly as it may be computed quickly.

4.3. Modeling the system – dynamic state forecast

To properly account for the evolving state of the system, the hazard functions must be updated when the system changes state. We refer to this as using a dynamic state forecast.

This may be achieved through a computer simulation of a system model and the use of a Monte Carlo method to calculate expectation values of the risk cost profiles.

5. The “LCRM” Methodology

LCRM is a set of structural and computer methods Hyland McQueen have developed and apply that sets out a structure for the definition of specific client problems and enables forecasts of risk costs associated with a group of assets to be calculated. It is a simulation method using dynamic state forecasts. It takes account of:

- scheduled and unscheduled events,
- repair and maintenance policies,

- shared resources such as spare parts.
- risk controls such as electrical protection, fire fighting, etc.

The analysis provides expectation risk cost profiles over a group of assets.

5.1. Failure mode modeling

A number of age related failure and condition related failure models have been developed including deterioration of the degrees of polymerisation (DP) of transformer paper insulation and hazard forecasting off generator condition assessments.

5.2. Failure mode consequences

Failure mode consequences are represented as binary trees that are traversed when that failure mode occurs. The particular path traversed in the tree depends on the values of system state variables at the time of failure. Scripts, executed at each consequence, increment risk cost categories, implement appropriate replacement policies, consume or increment spares stocks, and effect other state changes in the group of assets.

5.3. Asset representation

The target of the analysis is a group of interacting assets which are grouped into a number of sites. Schedules and other data are attached at the group and asset levels.

5.4. Dynamic state forecast

The evolution of the whole system is modeled through a computer simulation. Such a simulation provides risk cost profiles through one possible scenario of the evolution of the system. A Monte Carlo method is used to provide expectation values for the risk costs by repetitively analysing many possible scenarios.

The simulation steps through the forecasting period, updating the system state. The size of the time step is chosen to ensure that no more than a single state changing event occurs in each step. Where many assets are analysed over a considerable period of time, this may lead to large computational problems. It is necessary for a simulation method to take advantage of special features of the problem, such as the slow varying nature of the hazard functions, to enable a solution to be produced in a practical length of time.

5.5. Presentation of results

Risk cost profiles are generated for each failure mode. These are accumulated by component, asset, site grouping, and the whole group. Net present values can be calculated by integrating these risk cost profiles taking account of expected depreciation rates, cost of capital etc..

6. Transformers Example

An example overview of the use of LCRM is provided for the case of a group of transformer assets.

6.1. Failure mode modeling

Two types of failure mode modeling for the components of the transformers are used in this example.

1) Age related failure.
This type of failure mode depends on the operational age of the component. Hazards for these, at each time during the scenario, are calculated from a Weibull distribution using parameters from historical and manufacturers' data.

2) Condition related failure.
For the core winding component, the degree of polymerisation (DP) of the paper insulation determines a condition score and from this a translation function is used to determine the hazard. The DP is assumed to deteriorate in accordance with an empirically derived function that considers age, temperature, moisture and acidity. This representation allows for scheduled events, such as transformer oil reclamation, to alter the future condition path and hence the future risks.

6.2. Failure mode consequences

An example of a failure mode consequence tree is shown in figure 1 which represents the possible outcomes resulting from failure of the core winding component of a transformer.

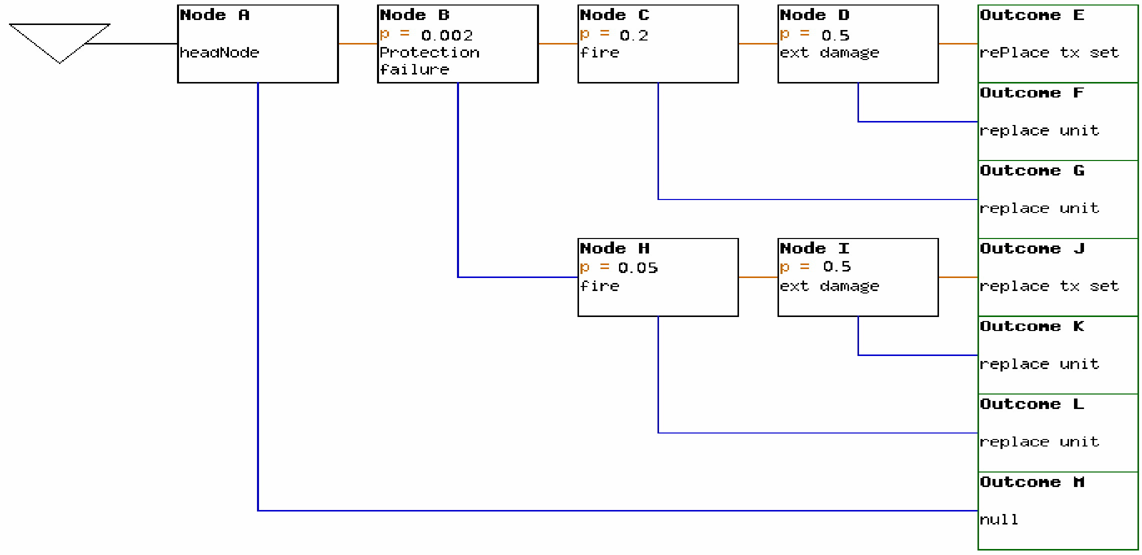

Figure 1. - representation of failure consequences.

6.3. Asset representation

Two types of transformer assets are represented in this example. Firstly, a transformer asset consisting of a single three-phase transformer and second, a transformer asset consisting of three single-phase transformers. Other asset types that have been analysed include: generators, exciters, and turbines.

A representation of the assets' structures, is shown in figure 2.

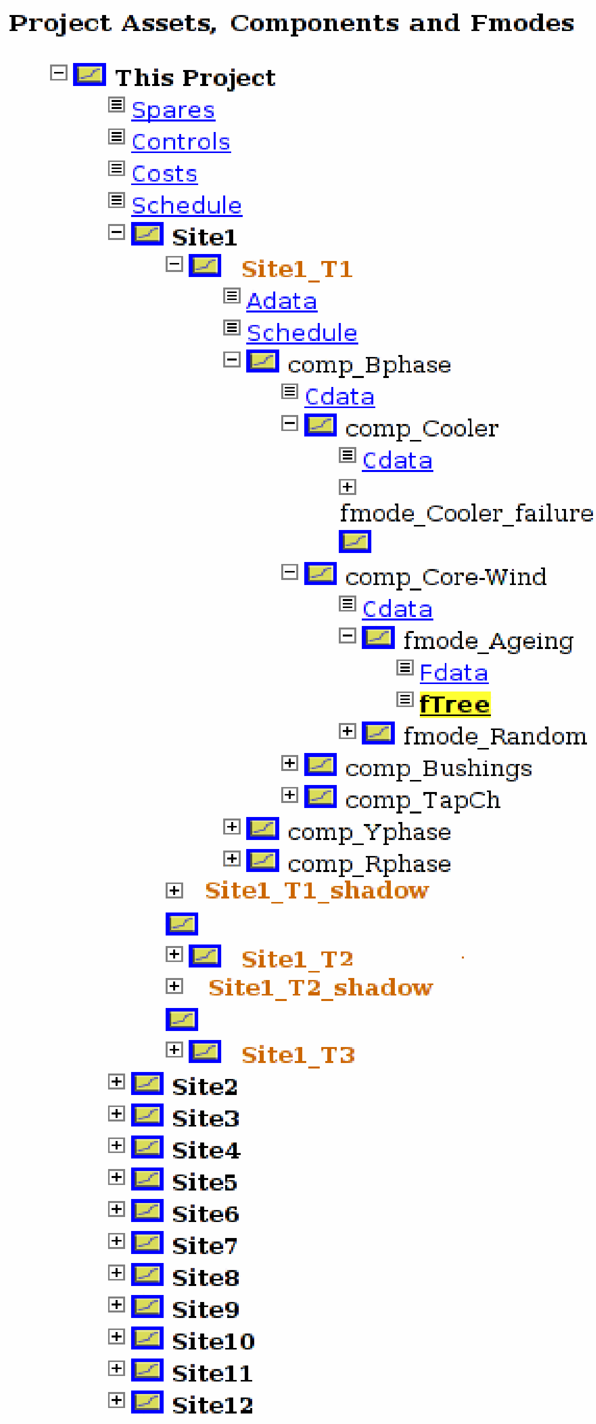

Figure 2 – representation of transformer asset group.

6.4. Dynamic State Forecast

For this example, the time period analysed was 50 years in 15,000 time steps with 10,000 Monte Carlo iterations. This gives acceptable accuracy in the risk cost profiles at the whole group, site grouping, and individual asset levels. At lower levels the failure rates at some components and may be too low for reliable risk cost profiles to be found. These must be considered as indicative only.

6.5. Results

The analysis was run over a forecasting period from 2007 to 2057. Risk costs for a number of categories for the whole group of assets is shown in figure 3. The two peaks correspond to the fact that the ages of the assets are not uniformly distributed. An older group of assets contribute to the peak at 2018 and a younger group to the peak at 2035.

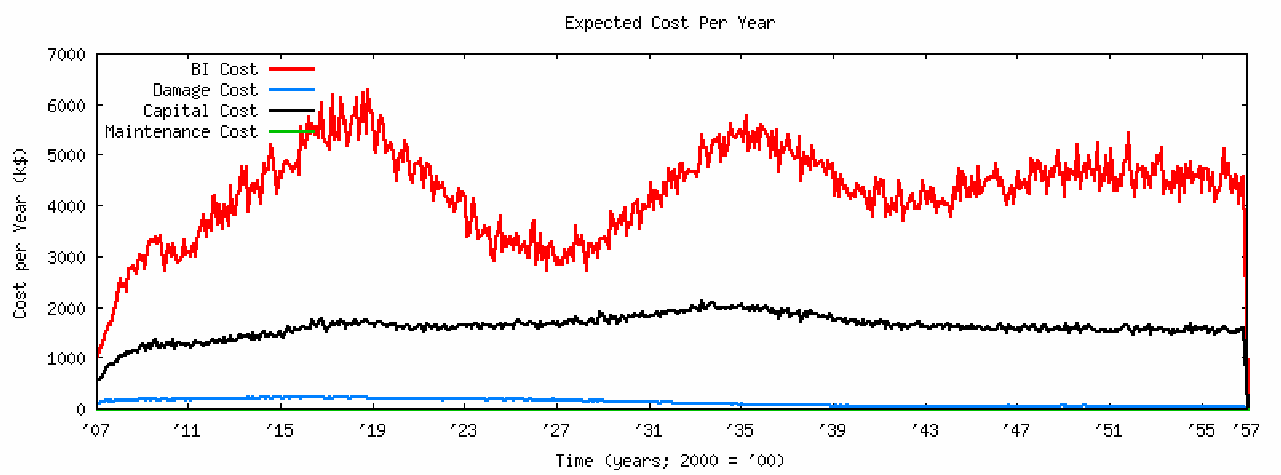

Figure 3 – Risk Costs calculated for the whole group of assets. (BI is business interruption cost)

The results for a single asset, "transformer T1 at Site1" is shown in figure 4. A scheduled replacement occurs at 2019 with a consequent drop in failure rates, then slowly rising to the peak at 2048 as the transformer ages.

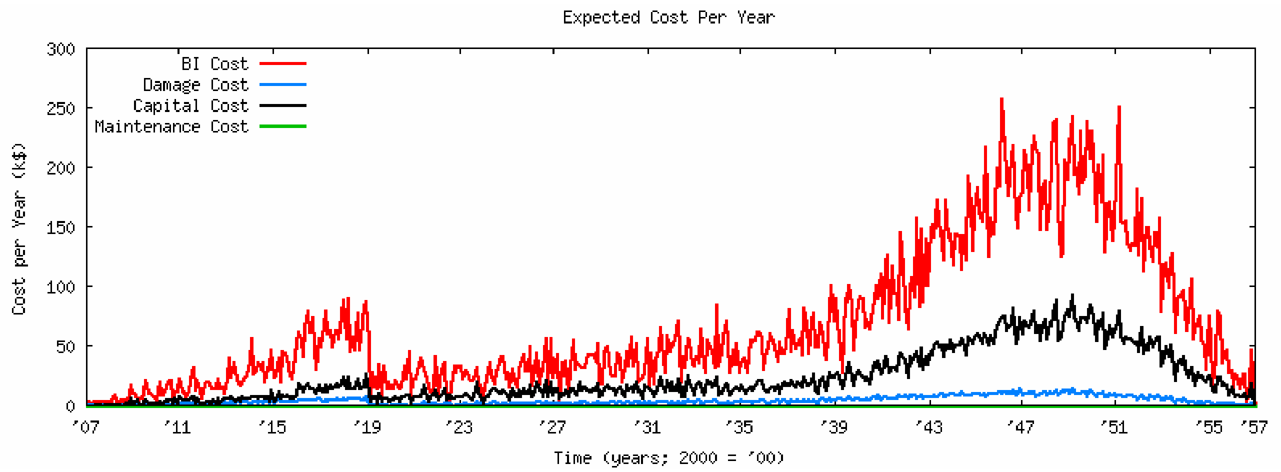

Figure 4 – Risk Costs calculated for transformer T1 at Site1. (BI is business interruption cost)

Specific analysis included a valuation of the risk reduction by appropriate timing of transformer winding dry-out on individual transformers, and viability and appropriate location of a second shared 3-phase transformer spare.

7. Conclusion

The LCRM methodology is an effective approach for undertaking asset life cycle cost forecasting under risk of failure. It provides a structured approach for assessing the balance and timing between capital and preventive maintenance costs and risk-weighted costs of failures. It enables better assessment of business value and provides a means to assess and compare different asset management strategies.

The LCRM methodology encompasses a generic problem structure and an associated set of computer methods for solving this type of problem. Note that the LCRM is not a computer application for sale – it is a set of methods and tools that Hyland McQueen apply to solve specific client problems.

Hyland McQueen welcome utility enquiries as to how this methodology may be applied to their circumstance. Contact info@hylandmcqueen.co.nz