# ANNEX 2A: CBRM PRINCIPLES

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# Condition-Based Risk Management of physical assets within the electrical power sector

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## Abstract

Condition-based risk management (CBRM) is a methodology that brings together asset information, engineering knowledge and practical experience of assets to define and quantify current and future asset condition, performance and risk. CBRM provides a means to express and communicate engineering information for large numbers of assets in a form that enables asset managers to define and justify future investment. The CBRM methodology was first created by EA Technology Limited (EATL) and Electricity North West Limited (ENWL) in 2002/3. Over the past 10 years, both parties have continued to update and develop the process, using the outputs to support ENWL's asset management activities. This paper documents this evolution.

## 1 Introduction

The CBRM methodology and its application have been developed by EATL in conjunction with electricity network operators over the past 10 years. CBRM projects have been carried out with over 50 companies in at least 12 countries. It is important to emphasise that CBRM is a flexible methodology and not a rigid, fixed process. CBRM models have been built for the main asset groups (transformers, switchgear, cables, overhead lines, etc.) many times, but every model is different, reflecting the specific information available, the specific operating context and the particular requirements of the client. Each application is therefore a learning experience and almost without exception each application has resulted in some development and extension of CBRM capabilities.

Thus, it is true to say that CBRM has continually evolved over its 10 year history and every one of the 50 plus companies have contributed in some way to this evolution. However, the contribution of some of these companies has been particularly significant. In that context EATL is delighted to document and acknowledge the role played by ENWL, by means of this paper.

## 2 CBRM development timeline

The development history of the CBRM process is described below, covering the period from 2002 to date.

**2002**

ENWL was facing the twin challenge of managing an ageing network with a large peak of assets approaching nominal 'end-of-life' and an increasingly demanding regulatory environment. They recognised the need to move from age based asset models to condition and/or risk based models in order to renew the network in a cost effective manner and maintain levels of reliability.

**2002/3**

In response to these challenges, ENWL and EATL created the first generation CBRM models for 20 major asset groups [1]. These models defined current asset condition by a numeric health index (HI) for each asset. The HI was explicitly linked to the probability of failure (POF) of the asset. Current HIs could be aged to estimate future HIs and POF, enabling estimation of future failure rates with specific levels of intervention.

**2004/5**

The CBRM models were used to define and justify replacement volumes in the fourth Distribution Price Control Review (DPCR4) submissions to the electricity regulator (OFGEM). The use of the models resulted in reduced replacement volumes to maintain the current failure rates when compared with traditional age-based models. The results were positively received by OFGEM.

**2005/6**

Learning from the experience of building and populating the first-generation CBRM models, ENWL reviewed and modified the information gathered during inspection and maintenance processes to improve the reliability and discrimination of the HIs [2]. EATL, in conjunction with other electricity companies in the UK and overseas, further developed and improved the CBRM methodology.

**2006/7**

ENWL and EATL created and populated second-generation CBRM models. These included improved methodology and asset information, leading to improved HIs that enabled interventions to be applied with more confidence for individual assets.

During the development of these models with ENWL, the process was extended to include consequences of failure and asset criticality, enabling current and future 'asset risk' to be quantified for individual assets [3].

**2009/2010**

During the fifth Distribution Price Control Review (DPCR5), OFGEM adopted the concept of HIs as a reporting measure for distribution network operators [4]. At this time, OFGEM also adopted load indices to support load-related investment.

OFGEM also identified a future requirement for an output measure that reflected both probability of failure and asset criticality.

The ENWL capital expenditure requirements for asset replacement in their DPCR5 submission were supported by output from their improved CBRM models and were again well received by OFGEM, resulting in virtually all proposed replacement volumes being accepted.

**Post-DPCR5, working towards RIIO**

OFGEM is currently working to define more detailed reporting requirements under the new regulatory regime (RIIO: Revenue = Incentives + Innovation + Outputs). These outputs are being developed and implemented during DPCR5 and will include both HI and criticality index (CI). It is OFGEMs explicit intention to use these to demonstrate and quantify risk reduction for future investment plans [5].

In addition to being able to generate the required CIs, the risk process within CBRM provides the means to explicitly quantify the change in risk (expressed financially) for any investment package and enables investment to be targeted at assets with the optimum cost-benefit. With CBRM models it becomes possible to move to a genuine risk-based asset replacement strategy.

In addition to this, ENWL and EATL (in conjunction with other UK network operators) have undertaken work that builds on the concept of load indices and quantifies load-related risk. Significantly, this will enable the building of a risk methodology that combines load and condition risk, enabling the cost benefit of investment proposals across both streams to be directly compared.

This paper reflects ENWL's experience of CBRM but it is also important to note that during the period of CBRM development and application with ENWL, EATL has worked with many other electricity companies, as well as with gas network operators and operators of private networks. CBRM models have been built with over 50 companies in more than 12 countries, often to assist with development and support of investment plans for regulatory submissions. It is important to recognise that the all these projects and all the companies involved have contributed to the overall development and the capability of the CBRM process. However, as this paper highlights, ENWL's involvement in the development of CBRM has been crucial. The first CBRM models were created with ENWL and a number of subsequent key developments have been undertaken with them. Their original challenge to produce an analytical process based on asset condition, their hard work and persistence in moulding the outputs to meet their requirements and their involvement in ongoing improvement of the process has made a major contribution to its overall development and application worldwide.

# 3 CBRM outputs

The fundamental outputs for each asset are as follows:

- The health index (HI)
- Probability of failure (POF)
- Risk - expressed in monetary terms (£s, $s or €s)

For each group of assets, the following are also produced:

- Health index profiles – overall distribution of health indices
- Overall failure rates
- Total risk

Crucially, the model enables the current health index to be 'aged' so that future, condition, performance (failures or failure rates) and risk can be estimated with and without interventions. The process is highly granular and it is possible to factor in any combination of interventions.

**Quantifying risk**

The risk calculation is based on combining the POF value obtained from the health index with the consequences of failure. The consequences of failure are defined in several categories, typically network performance, safety, financial and environmental.

In each category the average consequences are estimated (based where possible on recent failures). In each of the categories the consequences have their own specific units (e.g. customer-minutes lost and customer interruptions for network performance, fatalities and injuries for safety, £s, $s or €s for financial and litres of oil, kg of $SF_6$, etc. for environmental).

Each of these consequences is given a monetary value. The overall risk is therefore calculated in financial terms. The relative importance of individual assets can be accounted for by defining the 'criticality' of the asset separately in each of the categories.

**The significance of risk in investment planning**

The significance of risk in asset management decision making terms is twofold. Firstly, it provides the opportunity to consider the criticality of individual assets. The asset in worst condition, with the highest POF, may not be the asset which poses the largest risk; that may be a more critical asset in better condition. Secondly, and more importantly, quantifying risk enables comparisons to be made across asset groups.

Because the measure of risk is the same for all assets, the benefit (the reduction in risk) for any intervention involving any combination of different assets can be compared.

Therefore risk quantification potentially offers asset managers an invaluable planning tool, the ability to be able to rank all investment projects on the basis of cost/benefit and perhaps the ultimate ability to define the financially optimum risk profile and future investment plan. The potential power of this is illustrated further in the following section and case study.

**Financial optimisation**

By quantifying risk in financial terms, CBRM provides the possibility of financial optimisation of investment [6].

Using a simple Net Present Value (NPV) model, the cost of investment which in present-value terms decreases if the investment is delayed, can be balanced against the increasing risk if an asset in poor condition, with an increasing POF and risk, is left on the network. The determination of the optimum i.e. 'least-cost' point to invest is illustrated in Figure 1.

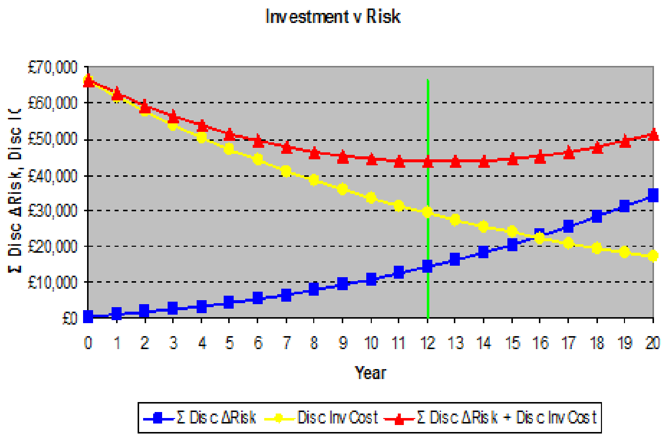


Figure 1: The NPV/risk curves for an individual asset, defining the optimum replacement year

For any asset the optimum replacement time (the time at which the sum of the investment cost and risk is at a minimum) can be calculated, and this can be used to generate an optimal 'least-cost' investment programme, as illustrated in Figure 2.

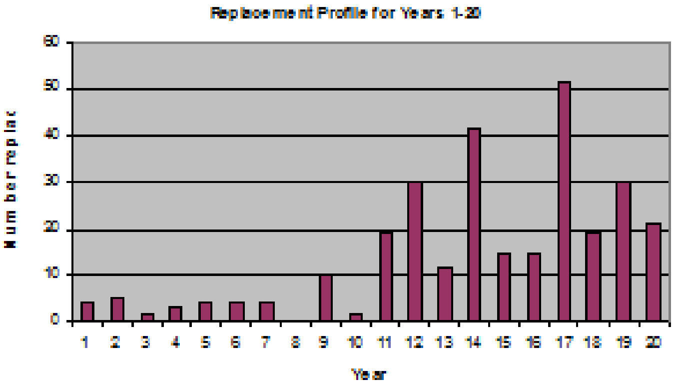


Figure 2: The optimum replacement profile for an asset group, derived from NPV/risk curves for individual assets

This process provides a means to efficiently define the optimum replacement programme (i.e. the most cost-effective programme) across all asset groups.

## 4 Implementation platform considerations

Initially, CBRM models were built as standalone spreadsheets. The flexibility and transparency of spreadsheets proved ideal for collating data from lots of disparate sources and building bespoke models via a series of interactive workshops. With the aid of the EATL software team, we were able to construct complex models with a high degree of functionality that were successfully deployed with many companies.

The models then progressed from one-off snapshots - produced to deliver outputs for a specific purpose, usually a price review submission - to ongoing asset management tools that required periodic updating. It then became apparent that spreadsheets were not the ideal vehicle for future delivery.

Consequently, EATL developed a software-driven database tool (CBRM 2.0) to deliver CBRM models. This has become the favoured delivery vehicle (although for trial applications or applications with smaller companies, spreadsheet models remain an appropriate solution). The concern when moving to the new system was that we would lose the flexibility and transparency that is such an important element of CBRM. The EATL software team have succeeded in creating a system that retains a high level of flexibility and transparency, and so maintains the essential character of the process.
CBRM 2.0 is sometimes described as an integrated solution, meaning that it is integrated with the IT systems of the client company so that the models can be automatically refreshed/updated directly from the client IT systems. While this level of integration has been achieved in at least one case, in reality most applications to date would better be described as partially integrated. In most cases, the client companies do not have all the necessary input information in systems that can be interfaced in this way. In the majority of cases it is necessary to create an intermediate data repository to which information from a variety of sources can be transferred, audited and then uploaded.

This flexibility in gathering source data has proved to be an important feature of successful implementation and is an effective means of establishing a system that can be refreshed periodically in a reliable and efficient manner. CBRM 2.0 has therefore been demonstrated to be an effective and robust asset management system suitable for providing output to support decision making in an ongoing, routine manner.

## 5 Why CBRM works for ENWL

ENWL have identified a number of reasons why the CBRM methodology is particularly appropriate for their investment planning:

1. CBRM is a process that is based on capturing, utilising and reflecting asset information, engineering knowledge and practical experience of the assets to influence and justify investment plans. Specific engineering knowledge and experience of the assets must be a better basis for making asset management decisions than high level models that do not reflect specific knowledge of the assets.
2. CBRM is a transparent process. It is straight forward to relate an output (a HI or risk value for a specific asset) to the information that gave rise to it. It brings together all relevant engineering information for each asset and thus provides clarity of reasons for replacement or other intervention.
3. The data is cost-effective to collect and maintain. This minimises operational expenditure while enabling ENWL to meet their statutory requirements.
4. CBRM is a tool to provide asset managers with information to assist with decision making; it is not a process that tells you what or how to intervene on an asset.
5. It provides a view of the future performance (failure rates or risk) for different investment scenarios and thus assists ENWL in working collaboratively with OFGEM.
6. It provides a means of testing the cost effectiveness of different investment plans by comparing cost with outcomes.
7. For high volume asset groups (distribution) it provides a structured methodology to define asset replacement volumes linked to measurable outputs.
8. For lower volume (higher value assets) it provides a structured process, for assessing the benefit and cost effectiveness of specific interventions (replacement or different levels of refurbishment) for individual assets.
9. The CBRM models have been instrumental in achieving satisfactory outcomes from the two most recent price reviews
10. The output from CBRM models provides an excellent basis for meeting the current and future reporting requirements of OFGEM.

## 6 Summary of CBRM in 2012

The CBRM methodology has undergone considerable development and evolution in the last ten years. Nevertheless, some aspects of the process have emerged as essential to ensuring a successful deployment. These are described below, and in the authors' view should be seen as the key 'success factors' when considering the deployment of similar investment planning processes.

**CBRM is a bottom-up, asset-specific process.** It collates information for individual assets and uses this to define condition, performance and risk of individual assets currently and with any future investment programme. This means that interventions can be applied - and the effects assessed - at the asset level. Detailed asset-specific interventions can then be evaluated.

Its primary purpose is to bring together, summarise and communicate all available and relevant asset information, engineering knowledge and practical experience of the assets to enable this information, knowledge and experience to be accessible to influence investment planning.

**It is a flexible methodology, not a rigid prescriptive process.** From the outset it was realised (i) that to be relevant it was necessary to be able to use whatever information was available (not to define a specific set of information points for a particular asset) and (ii), to produce results that were credible we had to capture, apply and reflect the engineering knowledge and experience of the local engineers and asset managers.

CBRM was originally created in response to specific requests from network operators and development has continued to follow this approach. Most developments have been undertaken while working with network operators. Consequently, the methodology, its application and outputs have been carefully tailored to the particular needs of network operators.

**CBRM models are transparent.** They are not 'black boxes'. On completion of a project engineers and asset managers should have a complete understanding of the input information and how it is combined to arrive at a particular result. They should understand the calibration mechanisms built into model and know how to adjust them to reflect their knowledge and experience. It is easy to trace back from a result (a HI or risk value for a particular asset) to the information that has given rise to it.

**Creating and populating CBRM models is an inclusive process**. We seek to involve a good cross section of engineers and asset managers with practical knowledge of the assets in the process. Our aim is for them to take ownership of the models and overall process.

**The process provides genuine analytical capability.** The definition of condition by deriving a numeric HI is by itself a descriptive outcome. However, by linking the HI to POF and then combining the POF value with consequence and criticality information that ultimately results in a risk value expressed in monetary terms, it becomes possible to produce output in the form of failure rates and/or changes in risk expressed in monetary terms for different future investment programmes.

**CBRM is a process that promotes and benefits from continuous improvement.** Initial models are built for and populated with available information, producing the best definitions of condition etc. with that information. This initial experience then provides a platform for improving the asset information so that subsequent iterations of the models can utilise better information and incorporate developments to the methodology.

One of the primary uses of CBRM models is to assist network operators prepare and justify reports and price review submissions to regulators. In general regulators have reacted positively to the methodology and the outputs produced. In some cases it is apparent that the application of CBRM has made a significant and positive contribution to the direction of regulation and expectation of regulators.

## 7 Conclusions

The condition and risk based methodologies developed as part of CBRM have demonstrated the potential for asset based risk models that utilise available asset data and the extensive engineering knowledge and practical experience that exists within electricity companies.

The asset information, the extensive engineering knowledge and the practical experience relating to the performance of these assets represent a very significant resource for network operators. Use and communication of this should be a vital component in achieving cost effective investment programmes to maintain acceptable levels of reliability.

The approach embodied in CBRM, combined with the ability to produced measured outputs for different investment strategies, is generally positively received by regulators. Hence CBRM models are playing an increasingly significant role in presenting and justifying future plans for many companies in several countries.

The industry continues to face up to the increasingly demanding challenges of renewing ageing networks, maintaining or improving levels of reliability, introducing smart grids and low carbon networks while demonstrating efficiency and effectiveness to satisfy regulators and operating in a business environment where access to capital can be difficult. It is therefore believed that such models will become increasingly important.

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