Paper Title: Asset criticality modelling in electricity distribution networks

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Abstract

The Commerce Commission published an open letter to industry in November 2017 highlighting our short-term and current work priorities. One focus area we highlighted in the letter is to improve our understanding of EDB performance and asset management practices; particularly the extent to which EDBs recognise the most critical assets affecting network operation from both a reliability and safety perspective, taking into account the probability and consequence to customers, of asset failure.

EDB asset management practices can have a significant impact on customers and we believe that these practices should be underpinned by robust asset management systems for collecting, managing and analysing asset-related data. Our view is that systematised EDB asset management practices are necessary to fully understand the linkages between asset health, asset outage costs and asset criticality, in order that network expenditure is targeted and provides the best value for customers.

Asset Management Plans reveal a range of practices in the understanding and use of asset criticality. Some EDBs have quite well developed asset criticality frameworks underpinning their network investment programs, while others do not discuss it. The Commission is keen to explore this topic further with industry as we believe that an analysis based asset criticality understanding would benefit investment decision making and inform relative quality outcomes.

To begin industry discussion on this topic and to improve our understanding of asset criticality, the Commission developed a simple generic network model. The network model illustrates how assets can be compared and prioritised using a variety of measures; including outage probability weighted asset health, asset MW outage impact, asset outage duration, and customer outage costs based on lost load cost estimates. The model also illustrates how asset outage SAIDI/SAIFI impact can be estimated probabilistically, linking asset investment to relative quality outcomes.

Introduction

The way an EDB manages its network assets will have a significant impact on the costs customers incur and level of reliability they experience. To maximise the best outcomes for customers, we consider the asset management practices of EDBs should be underpinned by robust asset management systems for collecting, managing and analysing asset-related data.

In particular, our view is that systematised and analytical asset management practices are necessary to fully understand the linkages between asset health and outage implications from the customer perspective. In this regard we believe that a systematic asset criticality framework would be useful in testing different network expenditure strategies, and to provide the best value for customers[1].

Our on-going quality assessment of EDB asset management plans, and experience with Customised Price Paths (CPPs), where detailed information about EDB policies and processes are revealed, have indicated a range of practices in the understanding and use of asset criticality. Some EDBs have quite well developed asset criticality frameworks underpinning their network investment programs, while others do not discuss it.

This paper is intended to be a starting point for discussions with industry about the technical and commercial issues that may need to be overcome in developing a fully systematic and analytical asset criticality framework.

With reference to our recent open letter to industry [1], this paper firstly discusses our focus on asset management practices, and asset criticality informed decision making and why we see this as valuable.

The difference between reliability and resilience is also discussed and how we see both concepts feeding the understanding of asset criticality, both from a single asset perspective, and for groupings of assets.

We then discuss development of a test asset criticality framework. We have used a small network model to improve our understanding and prompt industry discussion. This network model is used to inform us about how assets can be compared and prioritised using a variety of measures; including asset health, customer outage costs based on the Value of Lost Load (VoLL) estimates, and SAIDI.

Finally, we summarise what we have learned, some observations and our likely next steps in this topic area.

The 9 November 2017 open letter to industry

We published an open letter on 9 November 2017 to set out our short-term and current priorities in the EDB sector. One key priority we identified was that we wanted to better understand EDB network performance and how this links to EDB asset management practices.

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[1] Asset criticality frameworks are also consistent with the ISO 55000 Asset Management Standard and with the accepted asset management practices of Total Asset Lifecycle Management (TALC), Reliability Centred Maintenance (RCM) and Condition Based Risk Management (CBRM)

Improving understanding about electricity distributors' performance is an important first step in moving towards a sector in which electricity customers have confidence that their local lines business is delivering the services they demand at appropriate price levels.

While there are a range of performance areas we are charged with incentivising, at this point we consider that better understanding the risks associated with over- and under-investment, and impacts on service quality, will provide the greatest benefit to customers over the long term.

As EDBs' asset management practices continue to mature, we would expect them to be increasingly focusing on the health and criticality of their assets; investment 'sufficiency' (the extent to which they are re-investing in assets at a prudent level); particularly appropriate levels of network resilience (the ability to maintain and restore supply following high-impact, low probability events).

Asset criticality

In our work we make decisions on CPP proposals where detailed information such as expenditure business cases, and policies and procedures that underpin EDB business practices are assessed to a greater level of scrutiny than Default Price Path (DPP) assessments.

Reflecting on a recent CPP process [2] we considered that had an asset criticality framework been in place it would have informed a more granular understanding of investment/quality linkages and provided better information on where to target investment.

In our ongoing EDB AMP review work we have identified some EDBs with partial or full asset criticality frameworks in place but this is inconsistently applied. One EDB, in their 2016 AMP, discusses how an analytical asset criticality framework has been applied at an asset class level, to rank the priority assets for maintenance or replacement. This framework contains considerations of load type (e.g. CBD, industrial, residential), number of customers served by the asset, network configuration and backfeed capability, and is useful at an asset class level to rank priority assets for maintenance or replacement.

We have also observed some examples of EDBs having a comprehensive asset criticality tool in place or aspects of it. For example, one EDB states in their 2016 AMP that they use a commercial software package for this purpose. This software is used extensively in the UK by the Distribution Network Operators (DNOs) to comply with regulatory requirements; such as understanding key asset outage risk cost effects and an ability to rank critical assets. Annual quality estimates can also be made, and for this purpose different asset failure rate estimates are required. A key observation made in this paper is the importance of estimating failure rates for different assets used to produce annual quality estimates.

We know that asset criticality is an aspect of many well-known advanced asset management processes such as ISO 55000 and the Condition Based Risk Management (CBRM) framework, but we have observed that these techniques are inconsistently applied in industry.

We were keen to understand how difficult it might be to implement a systematic[2] criticality framework for an EDB network; whether any additional information would be required by

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[2] By systematic we mean an analytical system or process that is repeatable and doesn't necessarily rely on particular staff in an organisation.

EDBs, and whether it yielded useful information that would inform expenditure decision making.

In the context of this work we refer to asset criticality as the understanding of the relative effect that individual assets have on the customer experience. This criticality understanding could be an awareness of relative SAIDI and SAIFI outcomes, or outage costs for larger customers that may not necessarily be reflected in quality measures at present.

Ideally we consider that an asset criticality framework should be able to provide the following information:

- relative SAIDI and SAIFI impact of an asset outage – ideally each key asset will have an asset health measure which will affect the asset outage probability with the outcome that SAIDI and SAIFI can be expressed probabilistically;
- relative kWh or MWh impact of an asset outage – which means that some understanding of the kW or MW outage magnitude and return to service durations are needed for each of the critical assets; and
- relative asset outage cost – which includes the consumer outage cost using VoLL, and can include the potential repair, refurbishment or replacement cost of the asset.

Understanding the potential asset outage cost from a customer perspective could assist EDBs to judge asset prioritisation, not just within each asset class, but across the asset fleet on a normalised basis.

Resilience vs reliability within a criticality framework

We understand there is delineation between reliability and resilience considerations within the context of electricity network analysis, investment decision making and asset criticality[3]. It is understood that asset reliability is concerned with expected asset outage events (usually single event single asset) and that resilience is concerned with unexpected events (single event multi-asset[4]).

Some may view asset criticality as only being applicable to multi-asset network resilience type events, where a major event occurs, affects multiple network assets, and there is an outage for an indeterminate period. However network resilience and asset reliability are two distinct areas of study. Asset reliability analysis is based on asset outage probabilities, estimated using large historical asset outage data sets that include aspects of asset outage frequency and duration for specific asset types. This historical data set is used to provide some idea of asset outage likelihood into the future.

Major events that test network resilience are usually non-uniform in their impact (they can affect multiple assets over a wide ranging area), and are caused by issues such as earthquake, flood or storm events. These events are so infrequent, that they have probabilities expressed as return periods (which can be in the range of hundreds or thousands of years). It is up to the asset operator or owner to estimate some credible scenario of outage impact and return to service durations, to rank outage exposures and identify economic mitigations.

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[3] Resilience analysis is sometimes referred to as HILP event analysis (HILP - High Impact Low Probability)

[4] Another area we haven’t explored in this work is safety, and how safety exposures for staff and the public, may be identified, ranked and mitigated, as these are affected by network design and operation.

While an asset criticality framework could be applied to resilience type events, in order that they can be ranked, and mitigations identified and economically tested (e.g. such as building earthquake strengthening, and substation flood mitigations), that is not the focus of this paper. In this paper we are focussing on asset criticality as it is applied to single network asset outage events.

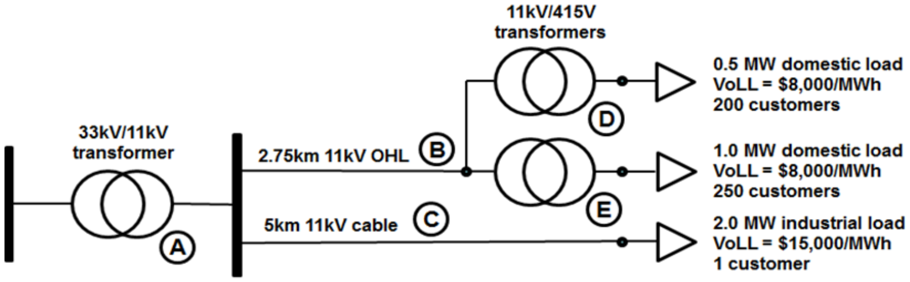
Asset criticality modelling

As discussed previously we are aware that there are commercially available software tools to provide EDBs with an asset criticality framework. Also we understand that some EDBs have been developing bespoke asset criticality frameworks to inform their asset management practices.

To better understand the topic of asset criticality, we started by constructing a small generic network model to underpin the asset criticality framework. We took this hands-on modelling approach for a number of reasons. Firstly, we wanted to better understand the technical challenges of this type of modelling, and what additional data may be needed. Secondly, we wanted to understand whether an asset criticality framework using measures such as SAIDI and customer Expected Unserved Energy (EUE) costs, with asset health estimates incorporated, was useful, and whether it could assist in the understanding of asset investment/quality trade-offs and prioritisation.

The network model we developed is shown in Figure 1 and is not based on any actual network or specific problem. We have attempted to make this model as realistic as possible in terms of likely connected load magnitudes, customer numbers, cable and overhead line length etc.

Figure 1: Example network model for asset criticality analysis



The assets we are interested in are denoted as A through E. There are three loads; two residential and one industrial connected by an overhead line and cable respectively. The small network is supplied via a 33/11kV transformer. We have assumed this small network is part of a larger network with 25,000 consumer connections (to enable the SAIDI calculation to be made).

It was clear that, for this purpose, some assumptions regarding asset outage rates and durations needed to be made. Asset outage rate estimates were difficult to find, but for the purpose of demonstration we based our analysis calculations on distribution asset outage rate data from a 2015 CIRED[5] paper [3].

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[5] CIRED – Congrès international des réseaux électriques de distribution (International Conference on Electricity Distribution)

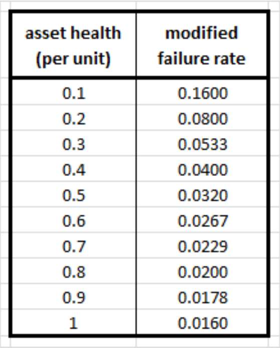
Asset health modifying asset outage rates

To model the effect of declining asset health on expected asset failure rates (similar to the “bathtub” or Weibull distribution failure curve effect) we applied a simple *1/x* function, using the per unit value of asset health, *x*, to modify the expected asset failure rate value (see Figure 2). This approach was taken as a demonstration only and is not proposed as a solution to modelling declining asset health effects.

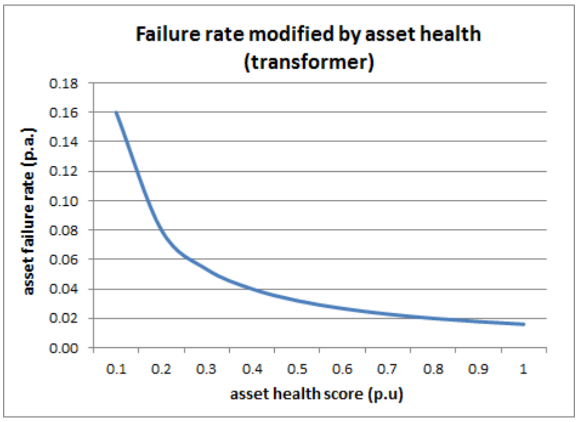
As an example of how this is applied, for asset A (the 33/11kV transformer), we used the CIRED paper asset outage rate of 1.6 faults per 100 installed units per annum, resulting in an expected asset failure rate of 0.016 failures per annum. We assumed that this was the expected failure rate of a transformer **unaffected** by a decline in asset health. This failure rate is denoted as $FR_{asset\ A\ exp}$. If the 33/11kV transformer is assumed to have an asset health indicator of 30% for example, then the failure rate ($FR_{asset\ A\ @30\%}$) was calculated as 0.0533.

Figure 2 illustrates the asset failure rate changing for a range of asset health estimates (in per unit) using the simplified *1/x* function approach we took.

Figure 2: Modelling of failure rate modified by asset health



asset health (per unit)	modified failure rate
0.1	0.1600
0.2	0.0800
0.3	0.0533
0.4	0.0400
0.5	0.0320
0.6	0.0267
0.7	0.0229
0.8	0.0200
0.9	0.0178
1	0.0160



Probabilistic SAIDI

SAIDI is a measure of the average outage duration for each customer served in the network and is commonly expressed in minutes. The general SAIDI formula is expressed as:

$$SAIDI = \sum_{i=1}^{n} \frac{U_i\, N_i}{N_T}$$

For a specific location *i*, U_i is the outage time (in minutes) and N_i is the number of customers affected for a particular outage. Over the year the outage incidents are all summed together and divided by the total number of customers N_T to produce a total network SAIDI minutes result.

To estimate probabilistic SAIDI, for each asset per annum, the expected outage rate was modified by its asset health score, and multiplied by the estimate of the asset average outage duration. This was then further multiplied by the ratio of the number of customers affected by that asset outage, and the total customer numbers.

In the example where transformer asset A is assumed to have a health score of 30%, the probabilistic SAIDI minutes per annum $SAIDI_{asset\ A}$ can be expressed as:

$$SAIDI_{asset\ A} = 60 * FR_{asset\ A\ @\ 30\%} * OD_{asset\ A} * \left(\frac{N_{asset\ A}}{N_{network\ total}}\right)$$

where $FR_{asset\ A@30\%}$ is the failure rate of asset A at 30% asset health (0.0533), $OD_{asset\ A}$ is the assumed asset A outage duration based on the CIRED paper data (14.4 hours), $N_{asset\ A}$ is the number of customers affected by an outage of asset A (451), and $N_{network\ total}$ is the total network customers (25,000).

Converted to minutes, and for the assumptions made, the probabilistic SAIDI per annum for asset A at 30% asset health was calculated as **0.831 SAIDI minutes**.

Probabilistic customer expected unserved energy cost

Probabilistic customer expected unserved energy (EUE) cost estimates, linked to specific assets, were calculated in a similar fashion to the probabilistic SAIDI calculation.

To calculate the EUE cost for the 33/11kV transformer, $EUE_{asset\ A}$, first the affected load (MW) and outage duration estimate (h) are used to calculate an unserved energy estimate in MWh for a **single outage**. This is then multiplied by the affected customer Value of Lost Load[6] and the asset health modified outage rate. For asset A at 30% asset health the formula used is:

$$EUE_{cost\ asset\ A} = EUE_{asset\ A} * VoLL_{asset\ A} * FR_{asset\ A@30\%}$$

Where $EUE_{asset\ A}$ was the expected unserved energy for a single outage of asset A (50.4MWh), $VoLL_{asset\ A}$ is the average value of lost load for an outage of asset A (\$12,000/MWh), and $FR_{asset\ A@30\%}$ is the failure rate of asset A at the 30% health estimate (0.0533).

Based on these assumptions, the probabilistic expected unserved energy cost of a transformer A outage was calculated to be **\$32,256 per annum**[7].

Further analysis results

EUE outage costs and SAIDI effects were tested by varying the asset health scores of 30% to 90% for two of the model assets, namely the 33/11kV transformer (asset A) and the overhead line (asset B).

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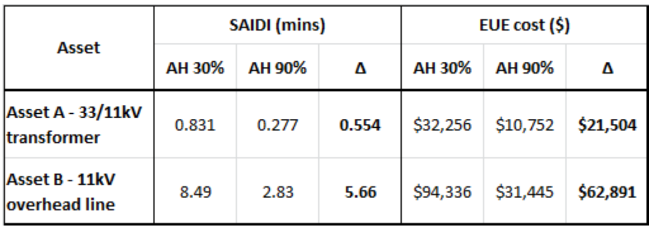
[6] The VoLL value assigned to transformer A is just a ratio of the two VoLL values used in the model depending on the load at the time of the outage.

[7] It must be noted that because we simplified the load to a single MW value over the year, we were able to use the annual outage rate figures in the calculation. For greater accuracy using demand duration curves to model load, probabilities at a more granular level (say hourly) would need to be estimated and hourly SAIDI and EUE cost figures summed over that year.

Table 1 Probabilistic SAIDI and EUE costs p.a. for 2 Asset Health (AH) indicators



Asset	SAIDI (mins)			EUE cost ($)		
	AH 30%	AH 90%	Δ	AH 30%	AH 90%	Δ
Asset A - 33/11kV transformer	0.831	0.277	**0.554**	$32,256	$10,752	**$21,504**
Asset B - 11kV overhead line	8.49	2.83	**5.66**	$94,336	$31,445	**$62,891**

The two scenario results for these different asset health indicators are summarised in Table 1 (Tables 2 and 3, and Figures 3 and 4 in the Appendix show the full model results in tabular form and graphically for the above asset health change scenarios).

The results indicate that a modelling approach like this can generate a lot of useful information for EDB and Commerce Commission decision makers, such as what asset health improvements will likely provide the best quality outcomes, and if outage risk was monetised, how this risk may be traded off against any expenditure to mitigate that risk in any cost-benefit analysis. The value of such a framework is that these understandings can be made across the asset fleet and critical assets identified using a variety of calculated measures.

If a framework like this was applied to the asset fleet, then it is possible that different asset investment strategies and their likely quality outcomes could be tested at a more granular level with decision makers within an organisation, and importantly, with customers.

However, we also understand that an analytical and systematic asset criticality framework should be a tool that informs decisions within an organisation, rather than one that simply makes those decisions in isolation. Other factors need to be considered regarding investment decisions and their timing, such as resource availability and third-party planning.

Conclusions

The objective of this work was to understand what information an asset criticality framework may provide and what the technical implementation barriers may be.

We have discussed the asset criticality framework as it applies to EDBs, and better understand how to develop one, the results it might provide, and an indication of the additional information that may be needed (such as asset outage rate and outage duration estimates).

The modelling process and analysis results have demonstrated to us that a systematic and analytical approach to asset criticality has potential, and will provide very useful information to EDB and Commerce Commission decision makers (and customers). It can improve understanding of investment/quality linkages, outage costs from a customer perspective, and how to prioritise asset expenditure across an asset fleet on a normalised basis.

Following this paper we plan to discuss this topic further with industry, and are interested to hear from businesses about their experience in this area. We plan to further discuss these ideas in an appropriate forum, such as the EEA Asset Management Group who can provide further insight in this topic area, and assist us with the next steps.

Reference

[1] Open letter on our priorities for the electricity sector for 2017/18 and beyond – Commerce Commission 9 November 2017 available at http://www.comcom.govt.nz/dmsdocument/15863

[2] Final decision on Powerco's 2018-2023 customised price-quality path – 28 March 2018 available at http://www.comcom.govt.nz/dmsdocument/16180

[3] G. Kjϕlle, H. Vefsnmo and J. Heggset, "Reliability data management by means of the standardised FASIT system for data collection and reporting". - 23rd International Conference on Electricity Distribution, Lyon 15-18 June 2015.

Appendix – Full results of asset health scenario tests

Table 2: Results scenario 1 (asset A and B – 30% asset health score)

Asset	Customers	Load (MW)	Outage duration (h)	Unserved Energy (MWh)	Average VoLL cost ($/MWh)	Asset health (AH)	Asset failure rate at start of life (FR)	Asset failure rate weighted by asset health (FR)	Expected EUE cost pa ($s)	Expected SAIDI minutes (pa)
Transformer - A	451	3.5	14.4	50.4	$12,000	30%	0.01600	0.05333	$32,256	0.831
Overhead Line - B	450	1.5	12.8	19.2	$8,000	30%	0.18425	0.61417	$94,336	8.490
Cable - C	1	2	9.4	18.8	$15,000	70%	0.11000	0.15714	$44,314	0.004
Transformer - D	200	0.5	14.4	7.2	$8,000	60%	0.01600	0.02667	$1,536	0.184
Transformer - E	250	1	14.4	14.4	$8,000	40%	0.01600	0.04000	$4,608	0.346

Figure 3: Unserved energy cost ($) and expected SAIDI minutes for Scenario 1

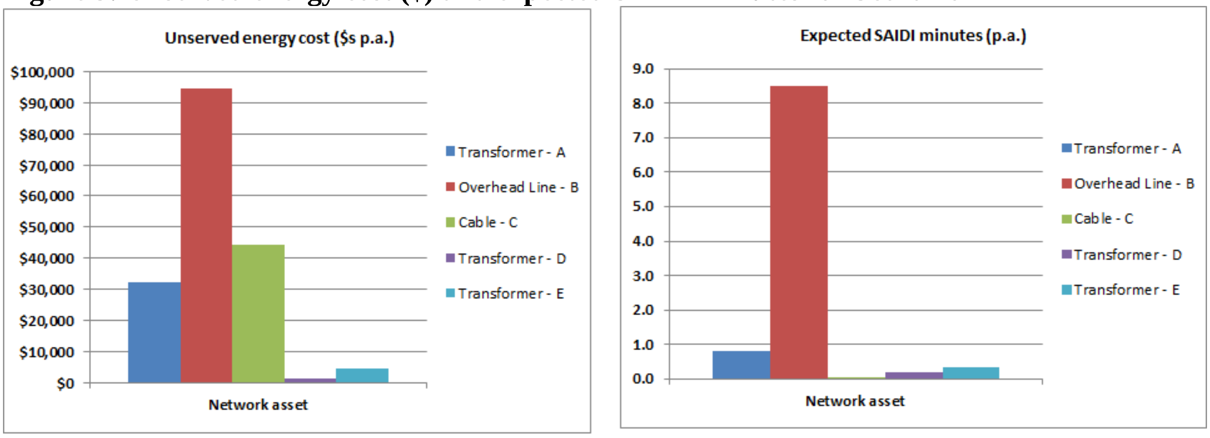


Table 2: Results scenario 2 (asset A and B – 90% asset health score)

Asset	Customers	Load (MW)	Outage duration (h)	Unserved Energy (MWh)	Average VoLL cost ($/MWh)	Asset health (AH)	Asset failure rate at start of life (FR)	Asset failure rate weighted by asset health (FR)	Expected EUE cost pa ($s)	Expected SAIDI minutes (pa)
Transformer - A	451	3.5	14.4	50.4	$12,000	90%	0.01600	0.01778	$10,752	0.277
Overhead Line - B	450	1.5	12.8	19.2	$8,000	90%	0.18425	0.20472	$31,445	2.830
Cable - C	1	2	9.4	18.8	$15,000	70%	0.11000	0.15714	$44,314	0.004
Transformer - D	200	0.5	14.4	7.2	$8,000	60%	0.01600	0.02667	$1,536	0.184
Transformer - E	250	1	14.4	14.4	$8,000	40%	0.01600	0.04000	$4,608	0.346

Figure 4: Unserved energy cost ($) and expected SAIDI minutes for Scenario 2