Asset Risk Quantification Guide

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1. Purpose

The purpose of this document is to provide Network Asset Management employees a reference guide of analytical methods and data to:

- Understand and assess asset failure modes and their consequences;
- Determine appropriate probabilities of failure for network assets;
- Quantify varying types of asset risk;
- Support risk assessment processes and;
- Assist in determining the least-cost approach to manage assets.

This document shall be reviewed regularly and amended as required in order to reflect changes in design and construction standards, the application of new technologies or changes to network operations and field experience.

2. Document Scope

This document applies to network assets managed by Network Asset Management, primarily zone substation primary assets (including buildings and grounds).

It does not apply to:

- Corporate risks
- People-related risks
- Depots and office buildings
- IT Assets
- Communication assets

3. Objective

This document aims to ensure a consistent approach to the assessment of different management options across different asset types, with a view to providing a consistent input for risk analysis purposes, as well as means of providing relevant asset-related measures which could be used by the wider business.

4. Asset Management Definitions

4.1 General Definitions

The following series of definitions are recommended to be understood and referenced within Asset Management. All definitions are based on relevant standards. Where a source is not quoted, the definition will have been reworded from the relevant standard but is consistent with the principle and relevant mathematical expression for the term.

It is acknowledged that the terms below may be defined elsewhere, both within and outside of the organisation. These definitions are generally in alignment, however can be subtly different such that when applying the term in a literal sense, the outcomes may vary.

AS ISO 55000.1	Asset	An item, thing or entity that has potential or actual value to an organisation
	Item	An individual article or unit
	System	A set of Items working together as parts
IEC 60050	(Required) Function	function considered necessary to fulfil a given requirement
	Reliability	The ability of an item to perform a required function under given conditions for a given time interval
	Maintainability	The ability of an item, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its required function(s)
	Availability	The probability that a system is available for use at a given time
ISO 31000	Risk	Effect of uncertainty on objectives
AS IEC 60300.3.3	Life Cycle	The time interval between a product's conception and disposal
	Defect	An observed condition that has not resulted in a failure, but will eventually result in failure
IEC 60050	Failure (of an item)	Loss of ability to perform the required function(s).
AS IEC 60300.3.3	(constant) Failure Rate	The rate at which failures occur
AS/NZS IEC 62740	Cause	Circumstance or set of circumstances that leads to failure or success
AS/NZS IEC 62740	Human error	Discrepancy between the human action taken or omitted, and that intended or required
	MTBF	Mean Time Between Failures

Table 1: General Definitions

Numerous industry groups may have subtle variations of the above definitions that generally reflect the interest or purpose of that body. The definitions in Table 1 serve as the most abstract, high-level definition that shall be used within Asset Management, and are derived from relevant standards and engineering literature.

For network asset functional and failure definitions, UE-ST-2100.2 may serve as a useful reference.

5. Risk Quantification

This section is intended to serve as a guide to asset managers on the quantification of risks associated with assets in a structured manner.

The focus of risk in this document is on uncertain events relating to an asset in a given period (typically one year)1. Each identified risk (there can be many risks associated with one asset) has a likelihood and a consequence.

Classifications of risk are included in three (3) groups to align assessment with asset failure modes and effects as per Reliability-Centred Maintenance. This is demonstrated below in Figure 1 .

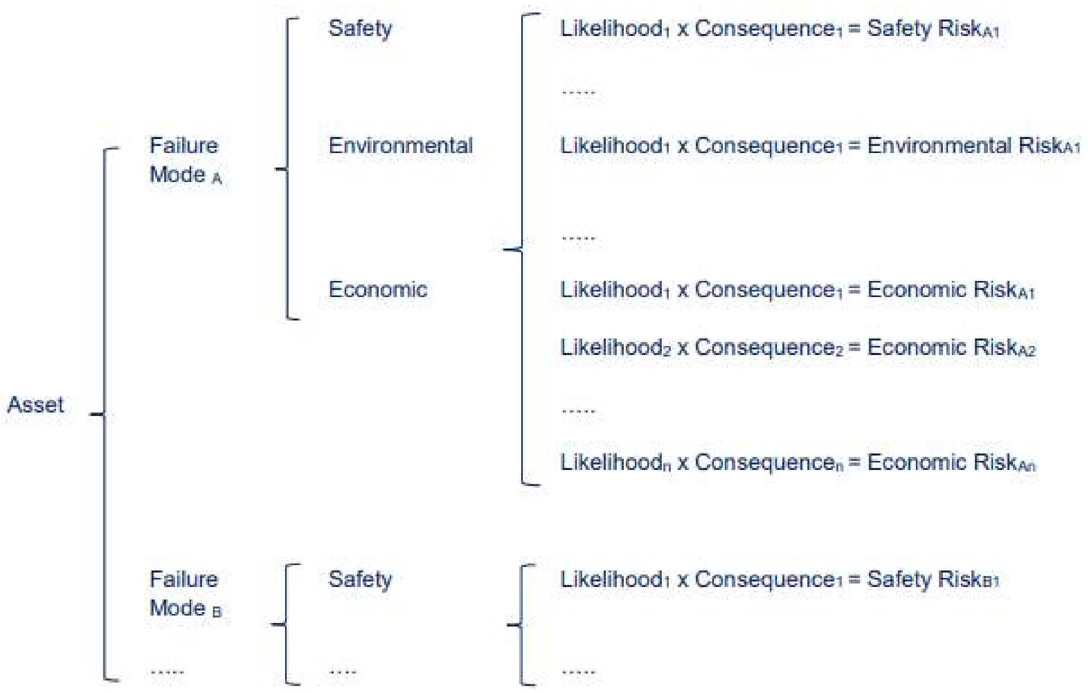

Figure 1: Failure Mode Tree

For each asset, different failure modes may exist, each with different consequences and likelihoods. Different failure modes and consequences can assist in the development of a total listing of asset risks. Failure modes are generally linked to the equipment's physical attributes and construction. Each failure mode has a likelihood, however depending on circumstances at the time, that failure mode may result in a variety of consequences.

For information on types of risks to be considered, refer to Table 2

Mathematically, the total risk can then be quantified as the sum of risks for a given time period. This can be expressed as:

$$\sum_{n=1}^{n} h_n(t).PoC_n.CoF_n$$

[1] It is important to note the time over which the risk is assessed.

Where:

- n = number of failure modes
- t = time period under analysis (typically a given year)
- $h(t)$ = hazard function, or probability of a failure (or failure mode if more than one failure type is under analysis) in time period under analysis (t)
- PoC_n = conditional probability of a specific consequence occurring for a given failure mode.
- CoF_n = Consequence Cost for a given failure mode.

For risk modelling, the following five (5) risk elements shall be considered in a risk model as a minimum. Note that for some assets, the risk element may not eventuate, so should be set to zero.

5.1 Multiple Consequences

In many cases, the consequence associated with failure is uncertain; for example, a distribution transformer failure may or may not result in an oil spill or a fire. The range of possible consequences associated with an asset should be considered. This can be modelled as a set of matrices, assuming a known probability of occurrence of each consequence, this is shown in the equation below.

$$Risk(t) = \sum_{n=1}^{n} h_n(t).\begin{bmatrix} LoC_1 & \cdots & LoC_m \\ \vdots & \ddots & \vdots \\ LoC_n & \cdots & LoC_{mn} \end{bmatrix}.\begin{bmatrix} CoC_1 & \cdots & CoC_n \\ \vdots & \ddots & \vdots \\ CoC_m & \cdots & CoC_{nm} \end{bmatrix}$$

	Minor	**Significant**	**Major**
Asset Failure	A functional failure that can be readily repaired with minimal effort	A failure that results in a significant level of repair works to the asset to restore condition	A failure that requires the whole asset to be replaced (repair is not practicable)
Reliability	A momentary interruption	A sustained outage of less than 3000 customers	A sustained outage of more than 3000 customers
Fire	A fire limited to the asset that does not reach the ground	A ground fire	A ground fire where damage to a network or third-party assets occurs
Safety	A safety incident with limited consequence e.g., shock on tap.	Lost Time Injury (LTI)	One or more fatalities
Environment	TBA	TBA	TBA

Table 2: Risk types

5.2 Assets and systems

In the Integrated Network Management System (INMS), Asset Management Plans (AMP) typically cover a single class of plant, such as a transformer or pole. However, these items on their own are not inherently useful; only when they operate in conjunction with other items do the assets generate value.

The collection of items into aggregates are generally studied as a ‘system’. Systems are generally covered under ‘non-asset class strategies’, however for some redundant assets (e.g. zone substation assets), system analysis can be included in an Asset class plan.

An example of major asset classifications is included below.

Term	Classification
Transformer	Item
Pole	Item
Feeder	System
Substation	System

Table 3: Asset classifications

Example: A pole is defined as an asset within the organisation. The failure rate attributed to a pole is comprised only of failure modes related to poles. A distribution feeder in its’ simplest form is a collection of poles, conductors cross-arms and transformers; its failure rate is comprised of failure modes relating to all items within the system. These items are generally connected in series, such that the failure rates are additive.

Example: A transformer is defined as an asset within the organisation. A substation comprises a collection of transformers, buswork, switchgear and electronic monitoring systems; its failure rate is comprised of failure modes relating to all items within the substation (system). These items are connected in both series and parallel.

6. Risk Quantification – Likelihood of an Event

The following table demonstrates which method should be applied to different asset types. The methods start off for the simplest approach and increase in complexity.

Assessment type	Complexity	When applied
Failure rate	Low	High-volume assets (or for single assets where a time-based failure curve is not possible)
Probability of Failure function	Medium	Single high-value or critical assets
Joint Probability	Medium	For substation assets with redundancy (e.g. two-transformer zone substation)
Conditional probability	High	For substation assets with redundancy where common cause failure(s) has been observed for the particular asset type

Table 4: Selection of likelihood assessment

6.1 Failure Rate

The discussion around asset failures and failure rates is the inverse to reliability; where an asset is 100% reliable, no failures will occur. Where an asset has a level of reliability less than 100%, the failure rate represents the difference between actual performance, and full reliability.

Failure rate defines the quantity of asset failures over a given unit of measure (usually time, but sometimes there is another measure e.g. kilometres). For asset management purposes, in most cases given unit measures shall be per annum.

The failure rate shall be denoted using the Greek letter λ.

It is important to note that the failure rate of the asset population will change over time as the age profile of the asset base alters. As such, it is appropriate to perform an analysis of the expected number of failures for a given time t for the asset, this will result in a predicted change in the value of λ over time. It may prove useful to add a subscript e.g. λ_{2018} denotes the failure rate expected in 2018.

The failure rate can also change when the management techniques applied change.

Note that λ does not give the probability of failure of a specific asset, only the expected number of failures over a given time period for a group of assets. For the probability of failure of an individual asset, refer to the Hazard function.

Example 3: A network has 1,500 RM6 switches in service and experience an average of one in-service failure per annum – a failure rate of 0.00067 per year. Because failure rates on a per-asset basis are often very low, failure rates should be expressed as a higher number, typically per-thousand assets, or per-hundred kilometres.

$$\lambda_{RMU} = 1 / 1500 \times 1000 = 0.67 \text{ failures / 1000 switches / year}$$

If the number of RMUs installed increases to 3,000 the number of failures can be expected to increase to 2 per annum, where λ remains constant.

If there is no data or evidence relating to the change in probability of failure of an asset over time, then the failure rate shall be assumed to be constant. In this case, the probability of failure of an asset shall can be given as:

$$PoF = \lambda \text{ / failure rate units}$$

This is simply the conversion of a failure rate per quantity of assets, into the failure rate for a single asset.

Example: A network has 1,500 RM6 switches in service, with a failure rate λ = 0.67 /1000 switches/year. The PoF of a single switch = 0.67 / 1000 = 0.0007 per annum.

In many cases, prudent risk management techniques applied to assets have prevented failures from occurring, thus preventing the determination of failure rates (likelihoods) from being quantified. In such cases, expert judgement should be applied, considering learnings and experience from other asset operators.

6.2 Multiple Failure Modes

For a given asset, a single failure rate may be sufficient for simplistic asset analysis purposes. However, for assets with a number of failure modes, it is better to define the failure rate as a result of each failure mode. Different condition assessment techniques or engineering changes only affect specific failure modes, so it is prudent to understand the effect on the overall failure rate.

This method should only be applied if there is reasonable data to quantify the likelihood of different failure modes, for example, categorisation of internal failure data by cause type or by component. If this is not available, relevant industry data can be used.

Example: A network has a total of 365,000 services, with an average of 1,900 failures per annum. Of these failures, 400 failures are attributed to vegetation-related causes, 20 vehicle impacts, and the remainder are electrical or mechanical failure. The overall asset failure rate can be expressed as:

$$\lambda_{total} = 1900 / 365{,}000 \times 1000 = 5.2 \text{ failures / 1000 services / year}$$

Failure rates by failure mode can be determined by:

$$\lambda_{vegetation} = 400 / 365{,}000 \times 1000 = 1.1 \text{ failures / 1000 services / year}$$
$$\lambda_{vehicle} = 20 / 365{,}000 \times 1000 = 0.05 \text{ failures / 1000 services / year}$$
$$\lambda_{(elec/mech)} = 1480 / 365{,}000 \times 1000 = 4.05 \text{ failures / 1000 services / year}$$

Logically, the sum of all failure modes is the overall asset failure rate:

$$1.1 + 0.05 + 4.05 = 5.2 \text{ failures / 1000 assets / year.}$$

Breaking down asset failures into failure modes is useful to refine the overall asset risk cost, as different failure modes have different levels of consequence. This can also be used to better target interventions that would improve asset reliability.

6.3 Probability of Failure

6.3.1 Weibull Analysis

When modelling the behaviour of a specific asset over time, Weibull analysis may be used to determine the change in failure risk over time (if a change exists).

Weibull analysis should be conducted based on the principles of IEC 61649. A two-parameter Weibull function is generally sufficient for asset risk analysis.

Where there are a number of assets still in service beyond the average failure age, or the asset replacements are driven by a mixture of asset replacements and failures, asset replacements should be treated as a suspension. Refer to IEC 61649 7.2.3.

Caution should be exercised when performing an analysis on the need to asset replacement which forecasts the average time to reach the asset reaching condition thresholds requiring preventative replacement. If the condition thresholds change, then a revised analysis will be required, as the time until the new condition threshold is met may be different.

It is recommended that where comprehensive asset data is available, the log-rank method produces reasonably accurate results. Where only partial data is available (e.g. for a certain time period), a non-parametric method (e.g. Kaplan-Meier) could be used, as it may produce results that better match experience.

When using the Kaplan-Meier graphical approach, consideration should be given to fitting a number of different distributions to the plot to determine if a Weibull distribution matches the observation plot, or another distribution (e.g. log-linear) provides a better fit.

6.3.2 Hazard Function

The hazard function refers to the probability of failure of an individual asset at a given point in time and is calculated from the Weibull distribution.

It is defined as:

$$h(t) = \frac{f(t)}{1 - F(t)}$$

Where f(t) is the probability density function for the asset, and F(t) is the cumulative density function.

The hazard function shall be used where a Weibull distribution is able to be derived for an asset class or failure mode. This can be determined via:

- Calculation i.e. using log-rank method
- Calculation using other methods i.e. using a Mean-life Estimator such as Kaplan Meier
- Estimation i.e. deriving task effectiveness

The calculation of the Weibull function should be performed in accordance with IEC 61649. Assets still in service and assets that have been replaced should be considered as censored data when deriving the hazard function for functional failures unless there is clear evidence that a failure was imminent.

The outputs of any calculation or estimation should be checked for validity by comparing the number of failures expected by the hazard function (by multiplying the function with the asset age profile) to the actual observed failure rate for the asset (if available). Data quality issues may impact the quality of the result.

6.3.3 Hazard Function Modifiers

The hazard function represents the baseline, or average failure function for a group of assets. Within the group, there may be some assets which are known to have an above-average (or below-average) risk of failure.

Where a condition or other parameter is known and the effect on failure risk understood, the hazard function may be modified to take this into account.

It is recommended that any adjustment to the hazard function is made where there is evidence to support the adjustment (which may be qualitative, based on engineering judgement).

It is preferred that any hazard function modifiers are derived using a quantitative approach e.g. Cox PHM.

6.4 Joint probability

For key electrical assets which have a significant (widespread) impact in the event of a failure, redundancy measures are often employed. For example, key protection and monitoring systems are often duplicated; substation transformers often have a level of redundancy or capacity margin during normal operating loads.

For these assets in the event of a single failure, it is unlikely that supply is lost for extended periods. However, multiple asset failures or increases in load beyond the redundant rating will result in widespread outages and customer impact.

For two plant in parallel, A and B, the probability of failure of either A or B = Pr(A) + Pr(B).

Where multiple failures are independent events, Pr (AB) = Pr (A).Pr (B)

Because of the variable nature in electrical load, the level of redundancy necessary to operate varies with time; for example, during winter, a three-transformer substation may be able to operate with only a single transformer online; as the load increases, two transformers may be necessary to supply load; during peak periods, the total station load may require all transformers in service, meaning for that period, there is no system redundancy.

As probabilities of failure are typically quoted on an annual basis, but restoration time typically occurs within one year (ranging from weeks to months for larger assets), care should be taken when analysing joint probability risk as the failures will need to overlap within the repair period for some failure consequences (e.g. supply risk of a substation operating below N-1 levels). This can be done by reducing the failure rate by a factor proportionate to the restoration time of the asset.

6.5 Conditional probability

In redundant systems, multiple plant failures may occur, rendering desired redundancy ineffective as a result of a shared cause or issue, rather than two separate events.

Where dependent or conditional events exist, Pr (AB) > Pr (A).Pr (B).

There is a large number of engineering references that indicate despite best practices, some level of dependency exists; that is, a conditional failure may occur. This may be caused by common elements to both assets, including similarities of:

- Design & construction practices
- Maintenance practices
- Operating duty
- Age/Condition
- Geography

The likelihood of a conditional failure depends on the engineering practices employed and experience. In order to comprehensively assess risk, it is recommended these risks are evaluated.

For the purposes of this section, the terminology 'common-cause failure' shall be used, where two or more component faults occur at the same time or within a short time period, with the same underlying cause.

6.5.1 Preferred methods

The beta-factor model is an extension of the joint probability assessment (outlined in 6.4), applicable to two-asset systems (such as a two-transformer zone substation).

The Multiple Greek Letter (MGL) method is the extension of the beta-factor model for 3+ asset systems.

The preferred methods to assess the likelihood of a common-cause failures is the Multiple Greek Letter model. This is one of the most used Common-cause failure (CCF) models (the model simplifies to the β-factor model in the 2-asset case).

The general case for the MGL is shown below. For further information, refer to NUREG/CR-5485.

$$Q_k^{(m)} = \frac{1}{\binom{m-1}{k-1}} \left(\prod_{i=1}^{k} \rho_t \right) (1 - \rho_{k+1}) Q_t$$

Where $\rho_1 = 1$, $\rho_2 = \beta$, $\rho_3 = Y$, $\rho_4 = \delta$, $\rho_5 = \varepsilon, \ldots, \rho_{m+1} = 0$

6.5.2 Conditional probability of failure expressions

The following expressions shall be used to determine the probability of event for different substation parallel arrangements.

Substation Layout	Scenario	MooN State	Expression
Two-asset substation; all units operating in parallel	One out of two fails	1oo2	$2Q_1 + Q_2$
	Two out of two fail	0oo2	$Q_1^2 + Q_2$
Three-asset substation; all units operating in parallel	One out of three fails	2oo3	$3Q_1+3Q_2+Q_3$
	Two out of three fail	1oo3	$3Q_1^2+3Q_2+Q_3$
	Three out of three fail	0oo3	$Q_1^3+3Q_1Q_2+Q_3$
Four-asset substation; all units operating in parallel	One out of four fails	3oo4	$4Q_1+6Q_2+4Q_3+Q_4$
	Two out of four fail	2oo4	$6Q_1^2+6Q_2+4Q_3+Q_4$
	Three out of four fail	1oo4	$4Q_1^3+12Q_1Q_2+3Q_2^2+4Q_3+Q_4$
	Four out of four fail;	0oo4	$Q_1^4+3Q_2^2+4Q_1Q_3+Q_4+6Q_1^2Q_2$

Table 5: Failure expressions for parallel systems (NUREG/CR-5485)

Term	2-Path	3-Path	4-Path
Q_1	$(1-\beta)\lambda$	$(1-\beta)\lambda$	$(1-\beta)\lambda$
Q_2	$\beta\lambda$	$0.5\beta(1-\Upsilon)\lambda$	$0.33\beta(1-\Upsilon)\lambda$
Q_3	N/A	$\beta\Upsilon\lambda$	$0.33\beta\Upsilon(1-\delta)\lambda$
Q_4	N/A	N/A	$\beta\Upsilon\delta\lambda$

Table 6: Q-values

Where a hazard function is available, it can be substituted for λ when analysing the probability of failure of an asset at a given point in time (e.g. when analysing power transformer failure risk over time).

7. Risk Quantification – Consequence of Event

This chapter outlines the main categories of consequence associated assets in the event of functional failure. Depending on the asset, some or all the consequence categories are applicable for asset risk quantification.

Some risks require additional weighting factors to be applied (e.g. for safety risks, a disproportionate factor is applied. For weighting factors, refer to PR-2914, Appendix B.

7.1 Energy at risk

The key element of asset functional risk is "energy at risk", which is an estimate of the amount of energy that would not be supplied if an asset was out of service, such that the 'system' would not be able to perform its' primary function (the transportation of electricity from one location to another).

This statistic provides an indication of magnitude of loss of load that would arise in the unlikely event of an asset failure.

The energy at risk shall be determined with a weighting of the 10th and 50th percentile Maximum Demand (MD) forecasts in alignment with AEMO and the other Victorian Distribution Business. The following risk weightings are used:

Demand forecast	Risk Weighting
10th percentile	30%
50th percentile	70%

Table 7: Demand forecast weightings.

7.2 Interpreting energy at risk

As noted above, "energy at risk" is an estimate of the amount of energy that would not be supplied if one asset (e.g. a transformer or sub-transmission line) was out of service during the critical loading period(s).

For example, the capability of a zone substation with one transformer out of service is referred to as its "N minus 1" rating. The capability of the station with all transformers in service is referred to as its "N" rating. The relationship between the N and N-1 ratings of a station and the energy at risk is depicted in Figure 7.1 below.

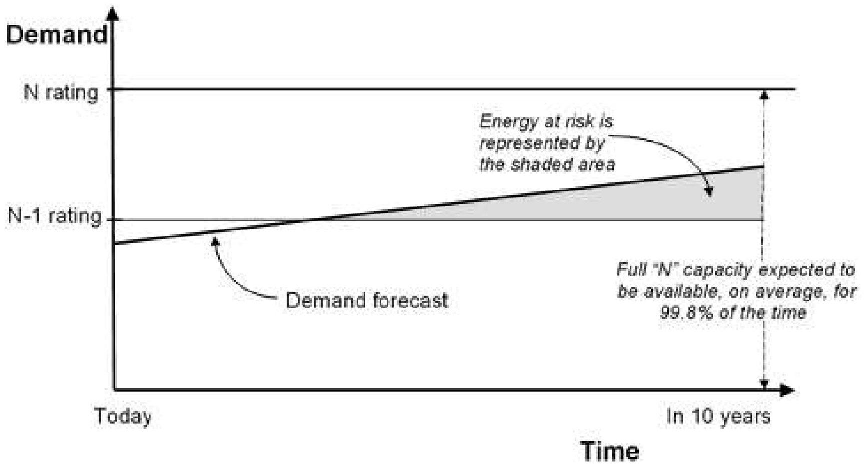

Figure 2: Energy at risk

Note that:

- under normal operating conditions, there will typically be more than adequate zone substation capacity to supply all demand; and
- the risk of prolonged outages of a zone substation transformer leading to load interruption is typically very low.
- The capability of a sub-transmission line network with one line out of service is referred to as the (N-1) condition for that sub-transmission network.
- under normal operating conditions, there will typically be more than adequate line capacity to supply all demand; and
- the risk of prolonged outages of a sub-transmission line leading to load interruption is typically very low and is dependent upon the length of line exposed and the environment in which the line operates.

7.3 Value of customer reliability (VCR)

To determine the economically optimal level and configuration of distribution capacity (and hence the supply reliability that will be delivered to customers), it is necessary to place a value on supply reliability from the customer's perspective.

Estimating the marginal value to customers of reliability is inherently difficult, and ultimately requires the application of some judgement. Nonetheless, there is information available (principally, surveys designed to estimate the costs faced by consumers as a result of electricity supply interruptions) that provides a guide as to the likely value.

These values are determined via surveys undertaken by the Australian Energy Market Operator (AEMO) to establish the Value of Customer Reliability (VCR). AEMO published the Victorian VCR values routinely in reports available on their website.

Sector	VCR ($/kWh)
Residential	$26.80
Commercial	$48.41
Agricultural	$51.60
Industrial	$47.70
CBD locations	2.7 times the ZSS VCR

Table 8: VCR values ($2023)

These values are multiplied by the relative weighting of each sector at the zone substation or for the sub-transmission line, and a composite single value of customer reliability is estimated.

These figures should be used to calculate the economic benefit of performing some form of intervention to reduce unserved energy risk.

For zone substations within the CBD (BQ, LQ, FR, WA, WP, JA, VM and MP), a VCR multiplier of 2.7 times the VCR value to reflect the increased GRP per MWh that applies to the Central Business District (CBD) of Melbourne. This modifier is required to reflect the increased risk in the area and ensure the risk valuation is reflective of the increased redundancy requirements in the CBD in Victoria.

7.4 Value of expected energy at risk

The financial value of expected energy at risk is calculated by multiplying the "energy at risk", as a function of the load-duration curve, the forecast MD, the "value of customer reliability", and the "plant unavailability".

7.5 Zone substation failures

For zone substation plant failures, the energy at risk is calculated based on the projected load profile, assessed hourly, for a calendar year, compared against the available capacity in the event of asset failures. The load use of load transfers should also be assessed which has the impact of lowering the load on the effected zone substation in the event of an outage. From the load profile, calculate;

- The total MWh in the year where the residual load profile exceeds the station's capacity in the event of a plant failure;
- The total MWh in the year where the residual load profile exceeds the station's capacity in the event of two plant failures (two and three transformer stations only);
- The total MWh in the year where the residual load profile exceeds the station's capacity in the event of three plant failures (three transformer stations only);

7.5.1 Distribution network feeders

The following utilization ratios should be used to determine average energy levels for distribution feeders in the case where a detailed analysis is not practical.

Ratio	Average Utilisation
Peak Demand / Feeder Capacity	50%
Average Demand / Peak Demand	50%
Average Demand / Feeder Capacity	25%

Table 9: Failure expressions for parallel systems

The Peak demand cited above refers to the historic maximum demand (MD) for a particular circuit or asset being assessed.

7.6 Safety Consequence

7.6.1 Likelihood of consequence

The likelihood of a safety consequence occurring because of an asset failure is very low; as a result, there is limited data available to determine a likelihood of this consequence occurring. In the absence of relevant safety consequence figures, figures from Ofgem [2] may be used unless a specific asset circumstance gives rise to the need of a different figure.

7.6.2 Cost of consequence

For further information, refer to Appendix C.3

7.7 Fire Consequence

Evaluation of the consequence of a fire start should be assessed on a case-by-case basis:

The likelihood of a fire event should be estimated using the PBSP Risk Reduction Model, calibrated to historic fault and fire data.

[2] Table 224, "DNO Common Network Asset Indices Methodology", OFGEM, 2021. https://www.ofgem.gov.uk/sites/default/files/docs/2021/04/dno_common_network_asset_indices_methodology_v2.1_final_01-04-2021.pdf

Fire impact should include agricultural losses, property damage, damage to infrastructure, tourism impact and life loss.

8. Option analysis

Where a risk is identified, several means may be practically available to reduce the risk to acceptable levels (or if possible, eliminate the risk); each possibility is known as an 'Option'.

The risk(s) identified may focus on;

- An individual element of the system – an 'asset' risk;
- The system e.g. zone substation energy at risk.

The whole of life cost for an option to manage an asset comprises three elements:

- Capital Expenditure (Capex)
- Operating and Maintenance Expenditure (Opex)
- Risk (refer Chapter 5).

The three elements are linked; an understanding of the relationship between them is essential to quantifying the outcomes of possible options, and the trade-offs that are expected when increasing or decreasing one or more of the three elements.

Example: For a fleet of 100 switches, the failure rate is a function of the level of routine maintenance, and number of proactive replacements implemented each year. If the routine maintenance is decreased, it can be expected that the number of failures will increase; conversely, if the number of failures is required to be reduced, then the amount of capital and/or operational expenditure will need to increase.

Examples of typical options are included below.

8.1 Typical Standalone Asset Options

8.1.1 Status Quo

This option refers to the existing operational case; continuing to operate the asset according to current policies.

Sometimes, this is referred to as the 'do nothing' option; this can be interpreted as literally 'do nothing'. However, for many assets, some activities are performed to manage the risk. This should be interpreted as 'do nothing different'.

Example: A ZSS transformer may have routine oil testing and OLTC and Bushing tests. In evaluating the economic case for asset replacement, the 'Do nothing' option does not indicate 'do nothing to maintain the asset, therefore the OLTC or bushings are likely to fail; rather, continue to perform routine maintenance as per current business policies'.

8.1.2 Changing the existing Assets

This involves performing work that replaces or modifies the asset (or operation of) in some way. Some examples include;

- Replacing an asset with a modern equivalent
- Replacing a component of an asset
- Modifying the operation of the asset in some way (e.g. protection setting change or operational restriction)

8.1.3 Non-network Options

This relates to other parties providing non network options to provide a solution to solve or defer the need for investment on the network. For example, paying a customer to reduce demand on the system to reduce the level of risk to an acceptable level rather than replacing an asset does not require any work on an asset or a system, however the risk is managed.

8.1.4 System - related Options

The following options are available to modify the behaviour of the overall system;

- Augmentation – for example additional parallel paths may be created, generally adding supply capacity to the distribution system.
- Performance **–** where the behaviour of a system generally comprised of series components is modified by changing the characteristic of a component, or inserting a new component in series. Note that this may also apply to Asset-related options e.g. fitment of possum-proofing to a substation.

When assessing option analysis, consideration should be given to understanding and quantifying the outcomes of modifying system by changing or adding assets. Where systems are modified in some way, there are typically positive and negative effects associated with all system changes; these should be understood and quantified so that assessing the option includes the upsides and downsides of system changes.

Note: for simplicity, these examples assume a constant failure rate.

Example: an additional ZSS transformer is proposed to be installed within a substation, in parallel with two existing transformers. Whilst the additional item improves the overall electricity reliability of the substation through the addition of a redundant path, the additional item will have increased operating costs by 50%, as well as the failure rate of the substation (as there are now three items that have to be maintained, and may fail, instead of two).

Example: In order to reduce the effective span length of a bay of 22kV conductor, a HV spreader (comprising 2 insulators) is installed mid-span to reduce the likelihood of conductor clashing whilst energized. However, from an item perspective, an additional 2 insulators has increased the number of insulators from 6 to 8 (assuming 3 insulators at the pole at each end of the span), as well as increasing the number of work points on conductors from 6 to 9. These actions will increase the number of insulator or conductor failures.

8.2 Risk Reduction

It is rare that risk can be practically eliminated; for option analysis, different options may reduce the level of risk by differing amounts. The risk analysis outlined in Section 5 primarily discusses quantification of risk; the risk analysis should be repeated as many times as necessary, as different options may address some, but not all failure modes.

9. Referenced Documents

Table 10: Referenced Documents

Title	Document No.
AFAP Risk Mitigation Investment Assessment Procedure	PR-2914

10. External References

10.1 Standards

Table 11: Standards

Standard	Title
AS IEC 60050	International Electrotechnical Vocabulary.
AS 61508.7	Functional safety of electrical/electronic/programmable electronic safety-related systems Part 7: Overview of techniques and measures
IEC 61649	Weibull Analysis.
IEC 61703	Mathematical expressions for reliability, availability, maintainability and maintenance support items.
NAVAIR-00-25-403	Guidelines for the Naval Aviation Reliability-Centred Maintenance Process.
NUREG/CR-5485	Common Cause Failures in Probabilistic Risk Analysis
AS ISO 55000	Asset management - Overview, principles and terminology
AS ISO 55001	Asset management - Management systems - Requirements
AS IEC 60300.3.3	Dependability management Application guide - Life cycle costing
AS/NZS IEC 62740	Root cause analysis (RCA)

Appendix A: Likelihood of Failure Values

The following values should be used to assess the likelihood of a failure of an asset per year (or for a specific age) of an asset.

Asset	Value	Comment
Zone Substation Transformer	0.5% (Constant Rate) Or Weibull function: α = 2.7, β = 118 for both Significant and Major failure modes	Likelihood of failure to be split 20% (Major) / 80% Significant
Zone Substation Circuit Breaker (6.6 to 66kV)	0.5% / CB or Panel / Year (asset more than 30 years of age) 0.05% / CB or Panel / Year (new asset)	No general time-varying function available Likelihood of failure to be split 50% (Major) / 50% Significant
Outdoor HV bus infrastructure	0.5% per bus per year	
ZSS Buildings	Weibull function: α = 8, β = 72	As buildings are generally repairable, this function applies to significant risk only.
Control wiring systems (external)	5% per year for sites beyond their design life	
Protection relays	α = 6, β = 75 (Electromechanical) α = 4, β = 56 (Analogue electronic) α = 3, β = 46 (Digital)	United Energy assets only

Table 12: Asset failure rates and function parameters

Appendix B: Conditional Probability Data

The following values can be used to assess general common-cause failure risk in systems.

Scenario	CCF
Two identical assets operating in parallel; spare not available – 12 month procurement time (e.g. ZSS Transformer)	0.25
Two identical assets operating in parallel; spare not available – 4 month procurement time (e.g. ZSS Switchboard repair)	0.20
Two identical assets operating in parallel; spare readily available, 1 month turnaround time	0.15
Two identical assets operating in parallel; spare readily available, 1 week turnaround time	0.08
Two different assets operating in parallel in the same geographical location	0.05
Two different assets operating in parallel in the same geographical location with additional specific controls to reduce CCF	<0.05
Three assets operating in parallel; two are identical (β), the third is different	β = as per above
Four assets operating in parallel; two are identical, assets three and four are different to the two identical units and each other	ϒ = 0.05

Table 13: CCF values

For ZSS transformers, there are a range of asset or installation criteria that affect the likelihood of a CCF. The following site-specific factors can be used to approximate a site-specific risk for multiple power transformer failures.

	Reduce CCF by
Physically separated	10%
Staggered maintenance	10%
Different plant manufacturer or design	50%
Different plant rating	5%

Table 14: CCF adjustment factors

Appendix C: Consequence Data

C.1 VCR values

The following tables shall be used to value energy at risk for CitiPower, Powercor or United Energy zone substations.

ZSS	VCR	ZSS	VCR	ZSS	VCR	ZSS	VCR
AP	$42.91	E	$57.70	NC	$35.89	TK	$41.82
AR	$35.60	F	$39.04	NR	$46.45	VM	$141.23
B	$54.16	FB	$55.38	PM	$48.57	WA	$139.20
BC	$41.68	FR	$140.08	Q	$36.83	WB	$41.58
BK	$43.00	JA	$143.60	R	$50.11	WG	$52.12
BQ	$135.88	L	$35.36	RD	$34.34	WP	$139.82
CL	$45.19	LQ	$145.56	SB	$52.58		
CW	$47.48	MG	$48.28	SK	$46.64		
DA	$52.37	MP	$135.90	SO	$49.22		

Table 15: Citipower ZSS VCR values ($/kWh, $2023)

ZSS	VCR	ZSS	VCR	ZSS	VCR	ZSS	VCR
ART	$43.70	DDL	$36.24	LVN	$54.51	SSE	$45.57
BAN	$44.75	DLF	$56.49	MBN	$42.13	STL	$47.32
BAS	$37.24	ECA	$47.52	MDA	$44.60	STN	$50.37
BBD	$52.62	EHK	$45.72	MLN	$37.90	SU	$47.67
BGO	$42.74	FNS	$47.16	MNA	$48.58	TNA	$49.77
BMH	$38.09	GB	$52.23	MRO	$40.99	TRG	$45.91
CDN	$45.43	GCY	$45.33	NHL	$44.49	WBE	$39.32
CHA	$48.01	GL	$37.04	NKA	$52.40	WBL	$45.09
CHM	$43.92	GLE	$43.19	OYN	$42.82	WIN	$36.39
CLC	$44.91	GSB	$30.76	PLD	$42.18	WMN	$61.33
CME	$46.88	HSM	$41.63	RVL	$49.46	WND	$34.10
CMN	$38.42	HTN	$38.28	SA	$35.43	WPD	$40.24
COB	$52.12	KRT	$47.05	SHL	$44.86		
CRO	$53.30	KYM	$47.80	SHN	$47.13		
CTN	$45.20	LV	$39.30	SHP	$50.19		

Table 16 - Powercor ZSS VCR values ($/kWh, $2023)

ZSS	VCR	ZSS	VCR	ZSS	VCR	ZSS	VCR
BH	53.30	**DSH**	64.05	**KBH**	43.35	**OAK**	40.45
BR	31.74	**DVY**	54.55	**LD**	42.11	**OE**	42.88
BT	34.51	**EB**	39.12	**LWN**	34.06	**OR**	33.24
BU	33.36	**EL**	28.82	**M**	36.73	**RBD**	35.93
BW	42.32	**EM**	35.73	**MC**	49.33	**SH**	31.79
CDA	42.15	**EW**	32.34	**MGE**	47.02	**SR**	35.82
CFD	30.47	**FSH**	38.01	**MR**	36.57	**SS**	43.70
CM	51.45	**FTN**	39.18	**MTN**	37.41	**STO**	31.70
CRM	47.10	**GW**	42.02	**NB**	34.94	**SV**	48.78
DC	35.90	**HGS**	41.16	**NO**	50.37	**SVW**	51.94
DMA	32.75	**HT**	50.88	**NP**	38.79	**WD**	30.74
DN	46.64	**K**	39.22	**NW**	37.34		

Table 17: United Energy ZSS VCR values ($/kWh, $2023)

C.2 Unplanned event information

The table below lists the average costs to return the asset to service, and duration of an unplanned event.

The unplanned event durations in Table 18 are also intended to be used with the VCR values as well as station load data to determine loss of supply consequence values.

Event	CP	PAL	UE
ZSS Transformer – Major Failure	Cost of planned replacement x 1.2 365 days		
ZSS Transformer – Significant Failure	$166,900 25 days	$164,000 25 days	$169,800 25 days
ZSS Circuit Breaker – Major Failure	Cost of planned replacement x 1.2 120 days		
ZSS Circuit Breaker – Significant Failure	$101,600 24 days	$118,600 24 days	$118,600 24 days
ZSS Building – Significant Failure	$88,000 5% probability of a 2-hour station outage		
Outdoor Switchyard failure (excl. CBs)	2-hour bus outage Negligible repair cost		
Station control wiring	2-hour bus outage Negligible repair cost		
Protection relay fault - Electromechanical (United Energy)	37% probability of failing to operate (trip) 16% probability of unnecessary operation (trip)		
Protection relay fault – Analogue electronic (United Energy)	32% probability of failing to operate (trip) 16% probability of unnecessary operation (trip)		
Protection relay fault - Digital (United Energy)	35% probability of failing to operate(trip) 13% probability of unnecessary operation (trip)		

Table 18: Unplanned event information ($2023)

C.3 Safety consequence values

The following references can be used as a basis for evaluating harm consequences:

- For VSL / VSLY:
  'Value of statistical life', Department of the Prime Minister and Cabinet, Office of Impact Analysis
  https://oia.pmc.gov.au/sites/default/files/2024-11/value-statistical-life-guidance-note.pdf
- For disability weights applicable for injury events:
- "The health of nations: The value of a statistical life" Australian Safety and Compensation Council
  https://www.safeworkaustralia.gov.au/system/files/documents/1702/thehealthofnations_value_statisticallife_2008_pdf.pdf - refer Appendix B
- For disproportionate factors applicable to specific scenarios, refer to PR-2914.

Appendix D: Environmental Risk inputs

The tables in this section support the evaluation of risk against possible controls when assessing environment-related impacts.

D.1 Ground Pollution

The following values should be used for the valuation of all types of oil (mineral, natural ester or synthetic ester).
The table includes:

- The base value of 1 litre of oil discharged to the environment.
- Additional multiplication factors (where applicable) to the base value.

Factors are cumulative, e.g., PCB-containing oil that is located 50m from a waterway is evaluated as:

$117.50 x 5 x 1.5 = $881.25.

Metric	Value
1 litre of oil	1/2000th of a VSLY Approx. $117.50 ($2023)
Level of oil source containment	0.1x - Fully contained, within a concrete bund or equivalent 1x – horizontal containment only (e.g., brick wall over gravel surface) 2x – no containment (vertical or horizontal)
Oil source is located in close proximity to a water catchment	2.5x - Within 40m 1.5x – 41-80m 1.2x – 81 to 120m
Groundwater level is within 5m of surface	3 x
Oil contains PCBs	5 x

Table 19: Oil consequence factors

D.2 Noise Pollution

Noise pollution/impact shall be assessed the same way as physical injuries, using the value of a statistical life-year (VSLY) as the basis. The following values should be used in conjunction with this to assess the noise impact to persons above regulatory requirements.

Metric	Value
Disproportionate Factor	3
Disability Weight	0.001 up to 6dB 0.005 above 6dB

Table 20: Noise consequence factors

For a residential property, an average of 2.5 occupants per premise may be used.