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REPEX Program CBA Modelling Methodology

January 2018

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Justification for replacement programs during the 2019 – 2024 Regulatory Period

Contents

1 Introduction

Ausgrid have developed a series of models to support risk based decision making and inform replacement program requirements and prioritisation. The models have two main objectives:

1. The establishment of a Health Index for the Ausgrid asset base to monitor asset risks and support risk based decision making; and
2. Support funding requirements as part of the 2019 – 2024 Regulatory Submission.

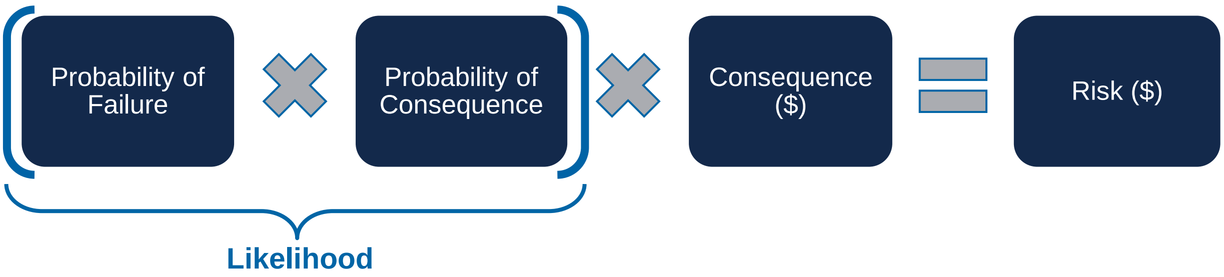
The models have been built either for each asset class or for a sub-class (replacement program). There are a number of key outputs that were developed in order to undertake this analysis. These include:

- Development of a Health Index;
- Development of a Risk Index; and
- Evaluation of investment options.

Key Output	Description
Health Index	A Health Index is represented as the likelihood of an asset failure. The Health Index is therefore a grouping of assets based on their probability of failure.
Risk Index	A Risk Index is represented by an assets total annual risk. Assets are grouped based on the individual risk cost.
Investment Evaluation	The investment evaluation supports the demonstration of value in undertaking an investment by comparing the benefits (or risks) to investment cost through a Cost Benefit Analysis (CBA).

The method for determining and evaluating risk is based on the principles of *ISO31000: Risk Management* which considers risk in terms of likelihood and consequence. The risk management inputs which underlie the model are shown below:

Figure 1 - Risk Index Inputs



While a single approach to the determination of risk is applied, there are variations in the modelling method based on the available information and the appropriateness of the approach for the asset class being reviewed.

The analysis undertaken is based on data sourced from a number of key areas:

- Ausgrid's enterprise systems;
- Industry benchmark information; and
- Subject matter expertise and feedback.

In establishing a Health Index, Ausgrid first considers the key factors (including age and condition information) which affect an assets probability of failure. The probability of failure is then determined by establishing the relationship between historical failures and age or an alternative key factor using data correlation and industry accepted modelling methods. The probability of failure is further refined by adjusting for individual assets within an asset class based on the other key factors and by applying a statistical adjustment method.

The Health Index is then derived by allocating assets within the range of probability of failures to an index from one (1) to ten (10) with one representing an expected life of one (1) year and ten representing the asset technical life or older. A more detailed explanation of the development of the Health Index is described in Section 2.

In establishing a Risk Index, the consequences of asset failures are assessed in monetary terms to determine the value of each consequence. The probability of consequence is determined and adjusted for individual assets using a similar statistical method as that applied to the probability of failure.

Once the probability of failure, consequence ($) and the probability of consequence are determined, the monetised risk of an individual asset is then derived using the equation shown in Figure 1. A detailed explanation of the development of the Risk Index is provided in Section 3.

Finally to determine investment requirements, the risks (or benefits where appropriate) are evaluated against the investment cost using Cost Benefit Analysis (CBA). The proposed investment is typically based on the replacement of an asset with a new modern equivalent. The investment is considered to add value where the risk mitigated (or benefit) exceed the investment cost over an appropriate evaluation period. Ausgrid considers a number of evaluation options before selecting the appropriate investment outcome.

The following sections detail how each component of the analysis was developed.

2 Health Index

2.1 Key Factor Analysis

In establishing a health index for each asset class, a number of key factors that affect the probability of failure were identified. These broadly include:

Key Factors	
Asset Age*	Environmental condition
Asset configuration	Constructed technology
Test results	Existing defects
Location Information	Asset utilisation

* Where asset age is applied in the regression to determine the probability of failure, it is excluded from the key factors. Refer to section 2.2 for more detail on the application of age in determining the probability of failure.

At most, the top five (5) factors of each asset class were analysed and combined to determine the overall "Health Factor Scores" through the following steps:

1. Each factor was scored from one (1) to five (5) based on available engineering and industry information and knowledge on how each factor affects the condition of the asset class;
2. A weighting was applied to each factor based on Ausgrid's understanding of how each affected the probability of failure;
3. All possible combinations of scores were brought together to form a "Health Factor Scores" table; and

Note: The total combination of possible factor scores is driven by the total number of factors considered. Ausgrid considered the top five (5) factors which affect the probability of failure. The total possible number of combinations is represented by:

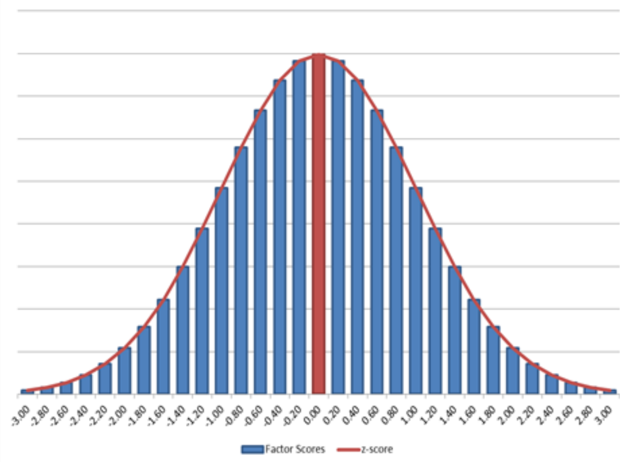
- Probability of Failure: 5^5 = 3,125 possible combinations

Appendix A shows how the individual factors are combined to determine the overall "Health Factor Scores". More detail on the application of consequence factors is detailed in Section 3.10.

4. Once all possible combinations were determined, a statistical analysis was undertaken to determine a health step change for each combination of scores.

Ausgrid has used a normal distribution and applied the statistical z-score method to determine the size of each step based on all possible combinations.

Figure 2 – Factor Scores to z-scores relationship



Ausgrid builds a normal distribution as shown to adjust the probability of failure of individual assets around the mean for the asset class.

A normal distribution was considered appropriate as it allows scores to be evenly divided on either side of the mean. This becomes important when it is used to adjust the mean probability of failure.

Relating factor scores to z-scores allows for statistical adjustments to be made to the initial (mean) probability of failure.

The figure above shows a normal distribution curve with the z-score adjustments based on the Factor Scores.

2.2 Initial Probability of Failure

One of the key inputs in the analysis of asset risk is the probability of asset failure. In many cases the realisation of asset risk is as a result of the asset failing. While many assets carry inherent risks, these are predominately only at risk of being realised when the asset itself has failed. Due to the nature of most assets, the probability of failure within an asset class is expected to increase with time as the asset degrades. However, external factors can impact the rate of degradation.

Where age is considered the key factor through the key factor analysis, Ausgrid has determined the initial probability of failure by correlating failure history with asset age. The following inputs are used to determine the probability of failure:

Key Input	
Failure history (failures at each age)	Failure modes (required for analysis)
Asset population	Asset age profile

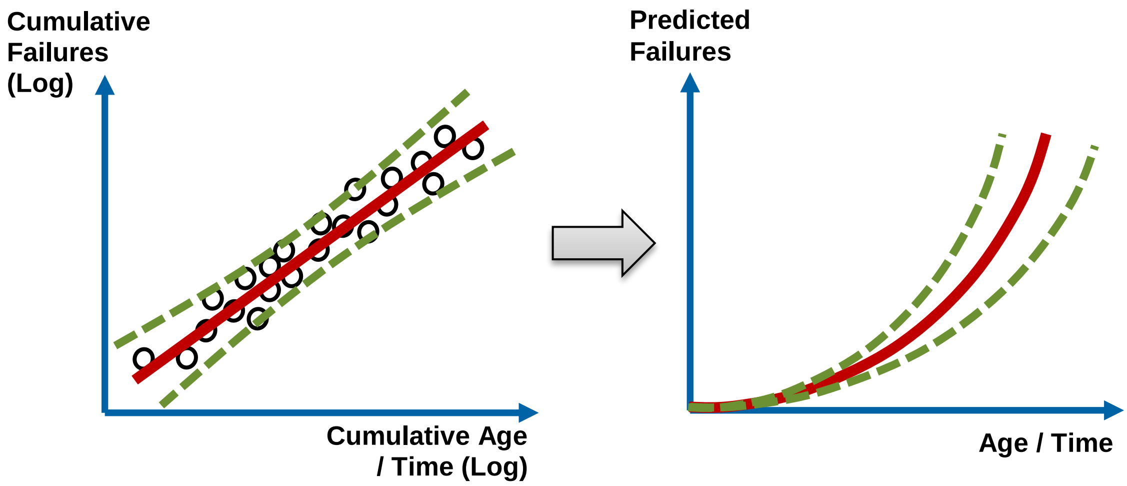
Ausgrid has applied one of the two correlation analysis methods[1]:

- Weibull analysis for discrete assets[2] (such as poles, switches), and
- A modified CROW-AMSA analysis for linear assets (such as overhead mains and underground cables), consistent with modern methods[3].

[1] Ebeling, C.E. 1997, An Introduction to Reliability and Maintainability Engineering
[2] Abernethy, R. 1996, The New Weibull Handbook Second Edition.
[3] Gill, Y. 2011, ‘Development of an electrical cable replacement simulation model to aid with the management of aging underground electric cables.’, IEEE Electrical Insulation Magazine, vol. 27, January-February, no. 1, pp. 31-37.

Ausgrid has also applied the “classical CROW-AMSA” method where time is used to correlate failures rather than age. In these examples asset age may be considered as an adjustment factor.

Figure 3 – Failure data correlation



The failure rate curve shown in Figure 3 represents the initial probability of failure for the asset class i.e. the other factors that affect the probability of failure have not been incorporated.

2.3 Adjusted Probability of Failure

With the determination of the health factor scores and initial probability of failure, an adjusted probability of failure can be calculated for each asset within an asset class. This approach allows Ausgrid to assign a probability of failure to each asset within an asset class based on its initial probability of failure adjusted by its z-score. There are a number of key assumptions used to apply this approach:

- The mean adjusted probability of failure is equal to the initial probability of failure
- The z-scores spread the probability of failure within the 95% confidence of the initial probability of failure (as explained further below)
- The adjusted probability of failure is based on the z-score step change from the initial probability of failure

The z-scores are normalised within the confidence interval boundaries so that the lowest z-score seen represents the lowest possible probability of failure and the highest z-score seen represents the highest possible probability of failure within the 95% confidence interval. This can be seen in the figure below.

Figure 4 – Z-scores and confidence interval

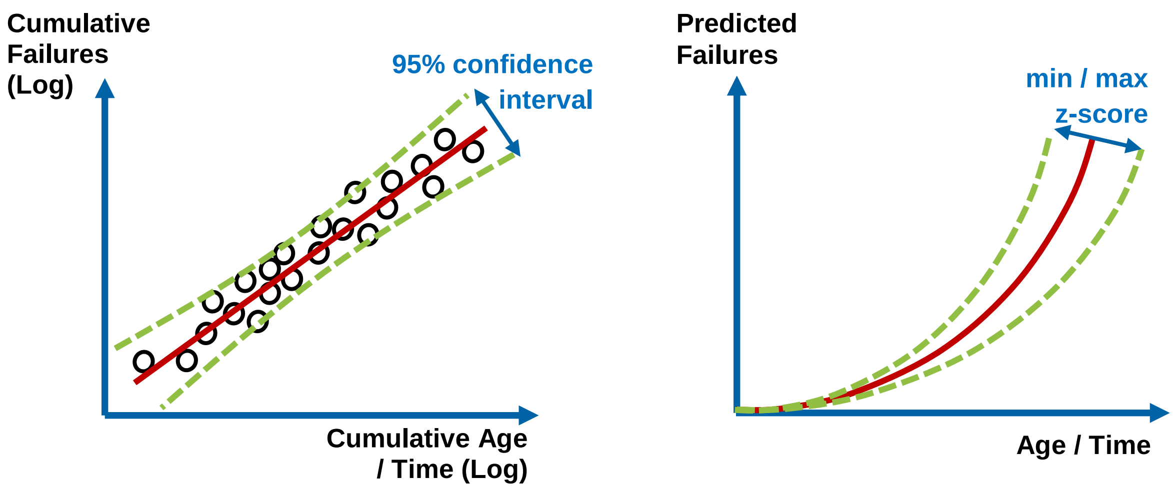
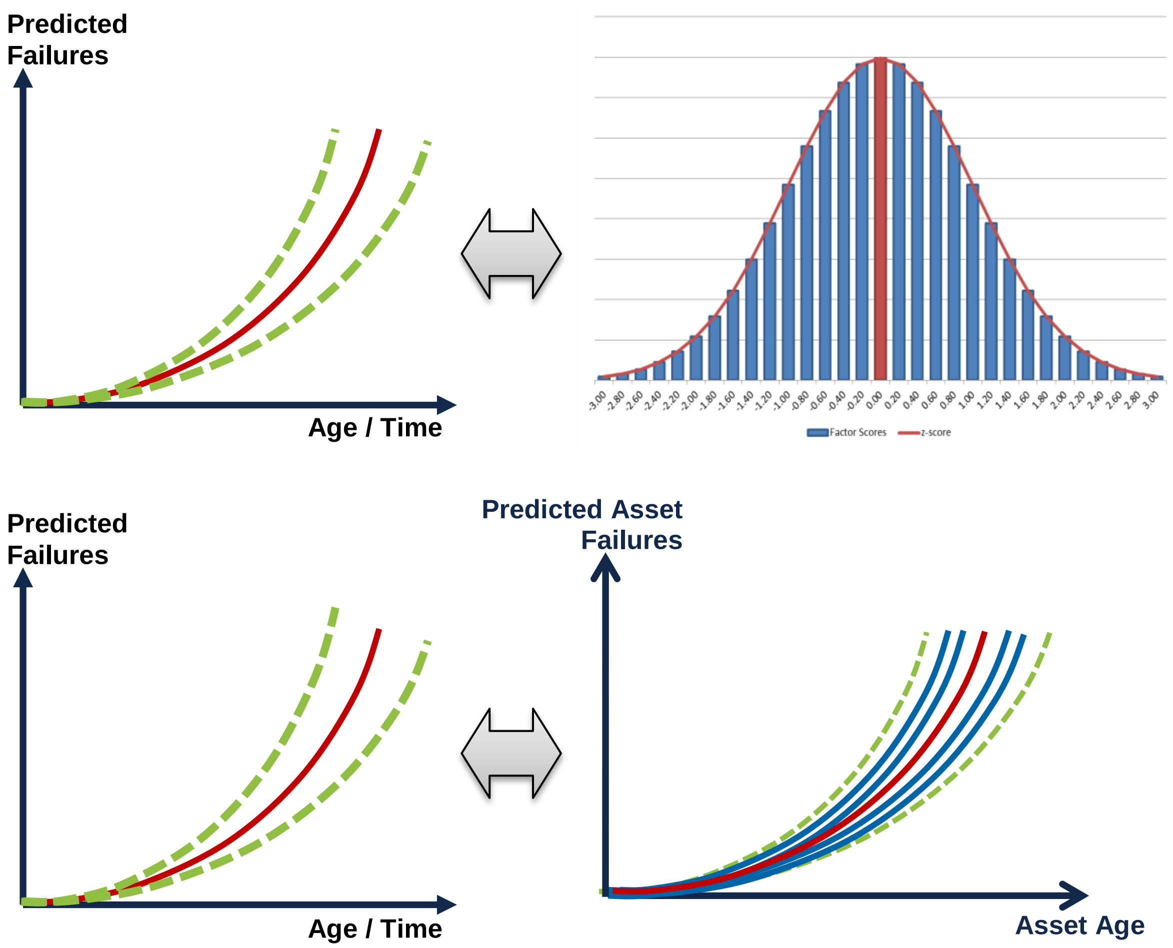


Figure 5 shows the initial probability of failure and how when combining with the adjustment z-score produces new probability of failure curves, specific to each asset. Since the age based failure probability and confidence intervals are derived from Ausgrid's own data, the adjustments applied remain statistically accurate (within 95%) to the actual asset performance.

Figure 5 – Adjusted Probability of Failure

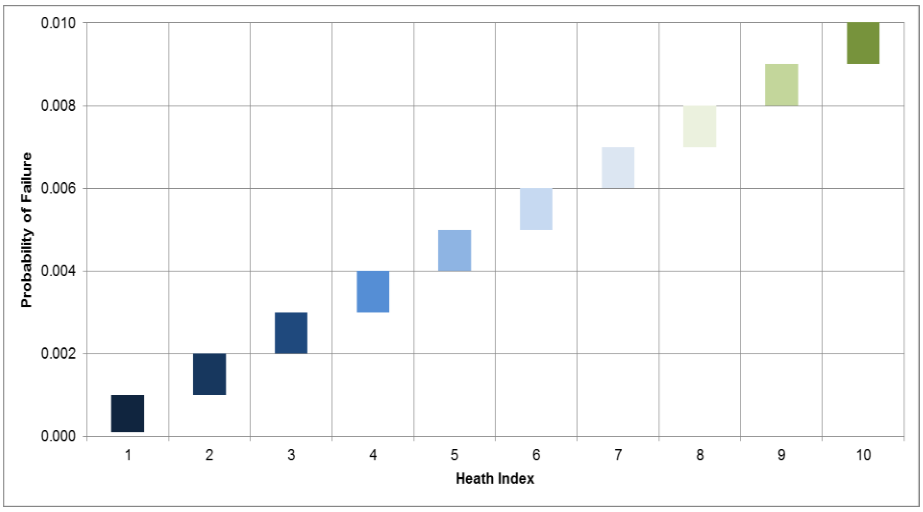


While all possible combinations are normally distributed, the resultant shape when applied to Ausgrid's own asset data may not appear normal. This is because actual asset health factors are not uniformly spread. Once Ausgrid's own data is applied, the scores are rebalanced so that the mean probability of failure remains the same.

2.4 Health index

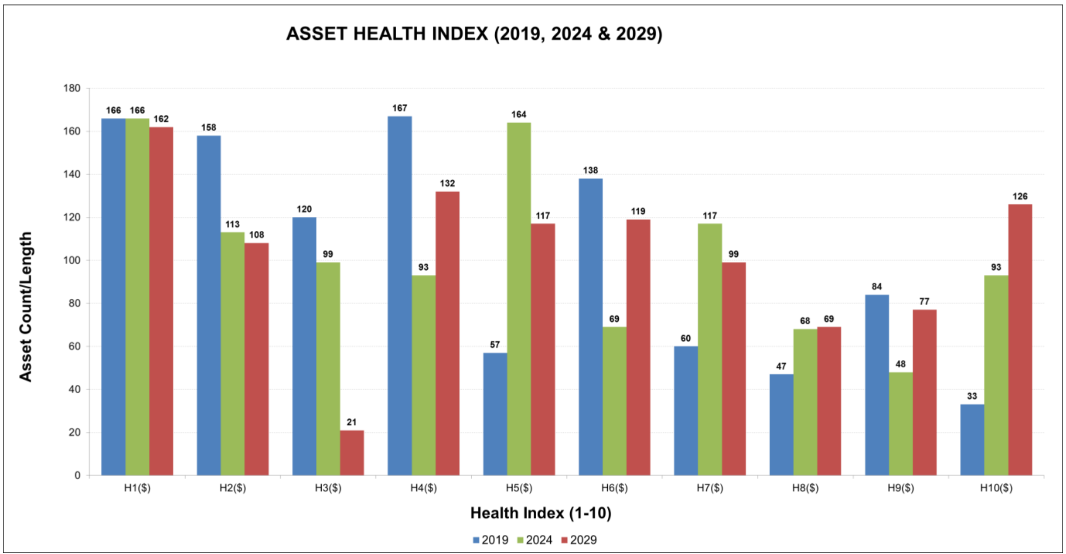
Once an adjusted probability of failure has been determined for each asset, the Health Index can be built. Each health index category from one (1) to ten (10) is based on a range of failure probabilities with one representing the lowest probability of failure and ten representing the highest. The Health Index range is derived by building a linear relationship between the index value and the probabilities of failure as shown in Figure 6 below.

Figure 6 – Example of relationship between HI and PoF



The Health Index is then derived as shown in Figure 7. The Health Index provides a visual representation of the probability of failure but is not used in the calculation of risk or the evaluation of investment.

Figure 7 – Example Health Index



The figure above shows the inherent health at end of 2019, 2024 and 2029. The change in health in each of these years reflects the change in the probability of failure over time. As the assets age, the probability of failure increases and is therefore reflected in how the volume of assets within each index category changes over time.

3 Risk Index

3.1 Consequences

While the Health Index provides an indication of asset risk based on asset failure, it does not consider the potential consequences and likelihood of consequences and therefore does not provide a full picture of risk. In order to undertake an economic risk evaluation, Ausgrid has monetised risk by monetising all consequences as shown in Figure 1.

Broadly Ausgrid has considered the following consequence categories:

Key consequence	Included
Safety	Public Safety (excluding from fire)
	Customer Safety (excluding from fire)
	Worker Safety (excluding from fire)
Environment	Environmental Fines
	Environmental Clean-up
Fire	Fire related Safety
	Fire related Environmental impacts
	Fire related property damage
Loss of Supply	Value of Customer Reliability
Financial	Replacement Cost – CAPEX
	Maintenance Cost – OPEX
	Property Damage

The approach for determining the value of consequences may be different for each consequence category. Once quantified the total consequence ($) for a single asset can be determined by the addition of the value of consequences for all consequence categories:

$$Total\ Consequence = Safety + Environment + Fire + Loss\ of\ Supply + Financial$$

3.2 Consequence Severity

For safety, environment and fire consequences, Ausgrid has applied a monetised value to each consequence severity. The severity covers the range of potential outcomes within each consequence category from insignificant consequence, through to severe. The definition of each severity classification is detailed within Ausgrid's Risk Management Framework.

The severity values generally increase on a logarithmic scale to reflect orders of magnitude changes in potential consequence risk.

3.3 Safety

Safety consequences are comprised of public, customer and worker safety. Ausgrid applies the same monetised value to each of these groups. A single value has been taken for each consequence severity.

Severity	Insignificant	Minor	Moderate	Major	Severe
Monetised Value	$447	$4,469	$44,693	$446,929	$4,469,292

The values selected are based on the value of a statistical life (VOSL) developed by the Office of Best Practice Regulation[4] in 2014[5].

3.4 Environment

Ausgrid has also developed a range of severity values to manage its environmental exposure. These values are based on the cost to undertake environmental clean-up and the potential fines.

Severity	Insignificant	Minor	Moderate	Major	Severe
Monetised Value	$10,193	$101,931	$1,019,312	$4,558,501	$10,193,119

3.5 Fire

Fire can lead to a combination of consequence outcomes including safety, environment and financial impacts from property losses and has therefore been captured separately. These consequences as they relate to fire are excluded from the other consequence categories. The values used for fire consequences are based on work undertaken by CulterMerz in reviewing appropriate values for catastrophic fire events in NSW and underpinned by analysis following the 2009 Victorian fires.

Severity	Insignificant	Minor	Moderate	Major	Severe
Monetised Value (2017)	$6,600	$66,000	$660,000	$6,600,000	$66,000,000

3.6 Loss of Supply

Ausgrid has determined the potential loss of supply on each asset within an asset class. The following key inputs were taken to determine the potential loss of supply:

- Average load lost per event (based on actual usage for each asset)
- Average restoration time

[4] Department of the Prime Minister and Cabinet 2014, Best Practice Regulation Guidance Note Value of statistical life, Office of Best Practice Regulation, Council of Australian Governments, Canberra.
[5] Using CPI data (Australian Bureau of Statistics, Consumer Price Index, cat. no 6401.0) to express the 2014 estimates in 2018 dollars gives a VOSL of $4.47 million.

- Value of Customer Reliability (VCR)

The average unserved energy is determined from the average load lost and the average restoration time.

$$Average\ Unserved\ Energy\ per\ Event\ =\ Average\ load\ lost\ \times\ Average\ restoration\ time$$

Where the asset configuration, network design or the failure type provides a significant variation in restoration time and impacted customers, the loss of supply calculation has been applied separately in the model with failure events apportioned to each impact type.

Ausgrid then applies the following VCR according to the AEMO Value of Customer Reliability Review Final Report[6]:

Feeder location	CBD*	Urban	Short rural	Long rural
Monetised Value ($/MWh)[7]	$47,494	$40,729	$40,729	$40,729

* different to the value used for a widespread event in the CBD

The loss of supply risk is calculated as the value of unserved energy by:

$$Value\ of\ Unserved\ Energy\ (\$)\ =\ Average\ Unserved\ Energy\ per\ Event\ \times\ VCR(\$)$$

3.7 Financial

Financial risk (or benefit) is split into both capital expenditure and operational expenditure avoided.

Since the probability of failure calculated previously is generally based on an end of life outcome, in replacing assets in a planned manner, the capital expenditure avoided is the cost of replacement plus any additional costs associated with the unplanned (reactive) replacement. Due to the following factors, Ausgrid generally incurs a higher cost when investment is not undertaken in a planned manner:

- After hour call-outs
- Mobilisation of replacement parts
- Mobilisation of specialised plant to access / undertake replacement
- Cancellation of other works
- Incident response

For these reasons, an additional reactive cost has been applied for reactive asset investment.

Operational costs avoided are determined as the difference between the current annual maintenance expenditure and the proposed annual maintenance expenditure for a given

[6] AEMO 2014, Value of Customer Reliability Review Final Report, Melbourne, 28 November.
[7] VCR values based on the AEMO 2014 VCR report recommendations, escalated to the October 2018 dollar value as recommended in the DRAFT DECISION Ausgrid Distribution determination 2019 to 2024 Attachment 10 Service target performance incentive scheme, November 2018.

investment solution. The impacts of changes in maintenance are built into Ausgrid's maintenance planning cycle.

3.8 Grossly Disproportionate

In accordance with the Electricity Supply (Safety and Network Management) Regulation 2014[8,9], Ausgrid eliminates safety risks so far as is reasonably practicable (SFAIRP) and where it is not reasonably practicable, to reduce to as low as reasonably practicable (ALARP). Common with industry, Ausgrid considers that a risk is not reasonably practicable when the cost is grossly disproportionate to the risk mitigated.

Ausgrid applies a grossly disproportionate factor to any safety benefit gained from its investment. UK Health and Safety[10] have suggested that a reasonable range for disproportionate factors is between two (2) and ten (10) where the higher values may be applied where extensive harm is possible. There is no specific reference available from within Australia that we are currently aware of. The use of values supported from UK HSE are also referenced in the AER's industry practice application note and is a common point of reference for Australian NSPs.

Interpreting the UK HSE definition, a range was applied to Ausgrid's safety risks utilising our risk management framework severity classifications:

Severity	Insignificant	Minor	Moderate	Major	Severe
Disproportionate Factor	x2	x4	x6	x8	x10

The approach supports the use of a higher disproportionate factor for the most severe consequences and a lower factor for the lower severity consequences.

3.9 Probability of Consequence

For safety, fire and environmental risks, the probability of consequence is determined by two factors:

1. Incident conversion rate, and
2. Probability of severity

1. Incident conversion rate

The incident conversion rate is taken as the ratio of incidents to failures, so that, for a given number of failures, a number of incidents are expected:

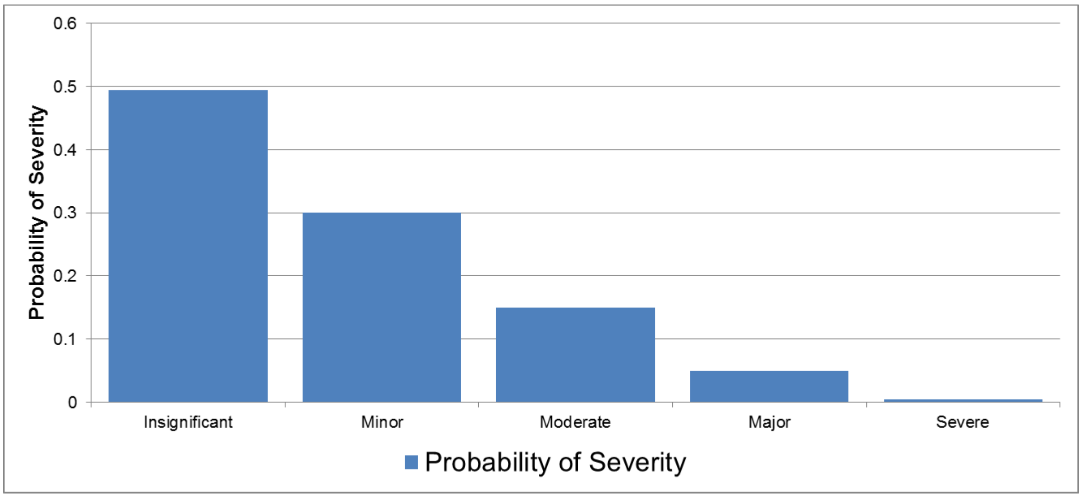
$$incident\ conversion\ rate = \frac{incidents}{failures}$$

8 *Electricity Supply (Safety and Network Management) Regulation 2015* under the *Electricity Supply Act 1995*
9 AS5577-2013, *Electricity network safety management systems*
10 Cost Benefit Analysis (CBA) checklist, Health and Safety Executive, United Kingdom, viewed on 7 December 2018 <http://www.hse.gov.uk/risk/theory/alarpcheck.htm>

2. Probability of severity

For each severity category a probability is applied based on the potential that, for a given incident, the severity realised is of a particular category. The figure and table below explain this concept.

Figure 8 – Probability of Severity Example



Severity*	Insignificant	Minor	Moderate	Major	Severe
Safety	0.45	0.3	0.2	0.01	0.04
Fire	0.5	0.3	0.15	0.045	0.005
Environment	0.3	0.4	0.2	0.05	0.05

*The values shown in the table are indicative only.

Within each consequence category, the addition of the severity probabilities must be equal to one (1).

The probability of consequence for each severity and each consequence category is calculated by:

$$PoC = incident\ conversion\ rate\ \times probability\ of\ severity$$

For loss of supply and financial consequences, two additional parameters are used:

- *% of failures resulting in unserved energy*
- *% of failures requiring replacement*

Ausgrid acknowledges that not all failures result in an outage. The "*% of failures resulting in unserved energy*" is used to moderate failure conversion into the realisation of unserved energy.

As previously mentioned, financial consequences are split into operational (repairs and planned maintenance) and capital expenditure. The "*% of failures requiring replacement*" is applied to split predicted failures between a repair solution and a replace solution. For the failures predicted in the analysis, the "*% of failures requiring replacement*" is used to determine the predicted number of reactive replacements.

3.10 Adjusted probability of consequence

The same approach which was used to develop a normal distribution to adjust the probability of failure has been used to adjust the probability of consequence. The z-score adjustments increase or decrease the probability of failure based on the step change from the mean.

In applying adjustments to the probability of consequence, each factor is also considered against each consequence and only applied to the consequences that it is expected to impact.

For example, an adjustment which considers the proximity of assets to major public infrastructure such as a school may have an increased public safety risk, however, has no impact on environmental or loss of supply risk. Therefore the adjustment is only applied to safety.

3.11 Risk Index

With all the inputs determined, the risk benefit is determined as per Figure 1. The calculation is shown below:

$$Risk(\$) = PoF \times PoC \times C(\$)$$

The actual risk avoided by a planned investment is determined by the risk calculated above and the risk of a new asset.

$$\Delta Risk(\$) = Risk_{old}(\$) - Risk_{new}(\$)$$

The change in total risk is therefore represented by the addition of the change in all risks and benefits:

$$\Delta Total\ Risk(\$) = \sum \Delta Risks(\$) + Benefits(\$)$$

The Risk Index is then formed by applying a similar approach to that used to develop the Health Index, however, rather that this being informed by the probability of failure, the Risk Index is informed by the monetised change in total risk. The relationship is shown in the figure below.

Figure 9 – Risk Cost to Risk Index Example

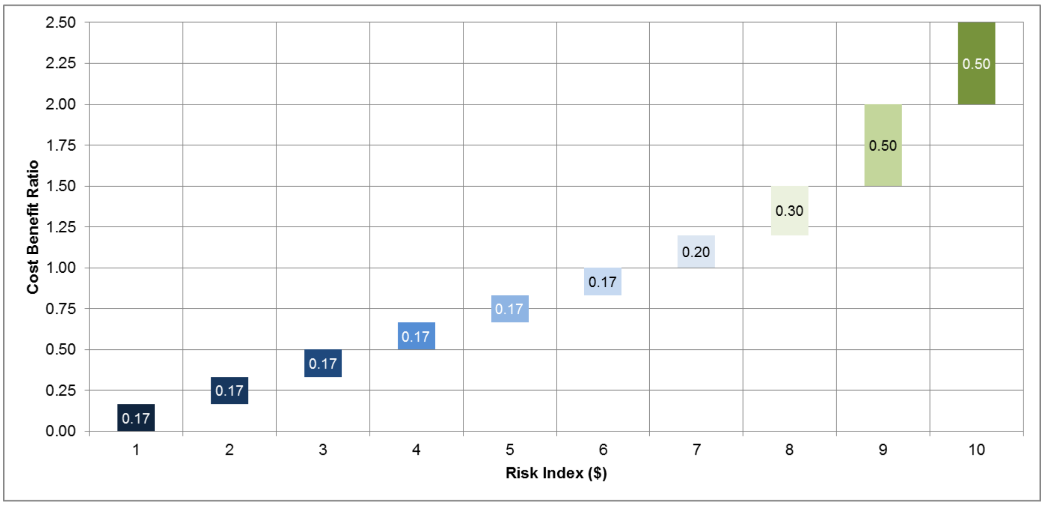
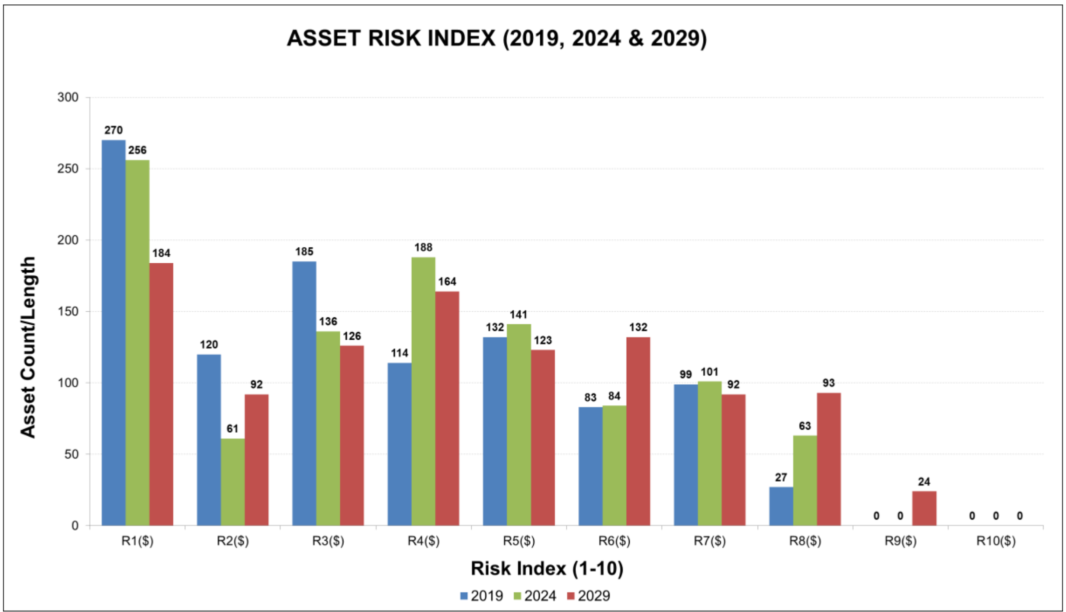


Figure 10 shows the output of a typical Risk Index after all assets have been given a risk cost and mapped to an index.

Figure 10 – Risk Index Example

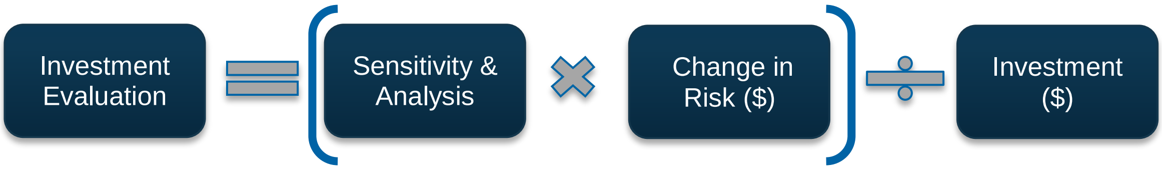


4 Investment Evaluation

4.1 Cost Benefit Analysis (CBA)

The final stage in the analysis process is to undertake cost benefit assessment with sensitivity analysis undertaken for key parameters.

Figure 11 – Cost Benefit Analysis method



The “investment” shown in the figure above is calculated by the Annual Deferral Benefit (ADB) realised for every year the investment is deferred. A one year deferral benefit is calculated on the basis of following principle.

$$One\ year\ deferral\ benfit\ = p - \frac{p}{(1+r)}$$

where, $p = investment\ (\$)$ and $r = discount\ rate\ (\%)$

For this analysis Ausgrid has applied a discount rate of 3.9%, however this figure will be reviewed for alignment to the most appropriate value relevant to the investment and adjusted as appropriate.

Ausgrid has adopted an approach whereby in order for an investment to proceed, the risk mitigated must exceed the investment i.e. where the benefit of the risk mitigated and any other benefits exceeds the annual deferral benefit. The risk mitigated is therefore determined by change in risk between the asset being replaced to a new asset.

Given the risk index has monetised risk and benefits for each asset within an asset class, all assets in a given year with a risk index greater than the annual deferral benefit are identified to be replaced. This analysis is undertaken in each year and as risk changes from year to year.

The range of monetised risk within each risk score has been normalised for each asset class so that any asset with a risk score equal to or greater than seven (7) has a risk greater than the annual deferral benefit and is therefore cost benefit positive. Therefore the values and relationship between risk cost and the risk index shown in Figure 9 is specific to each asset category and dependant on the annual deferral benefit of each asset class.

Figure 12 – Normalised Risk Index Example

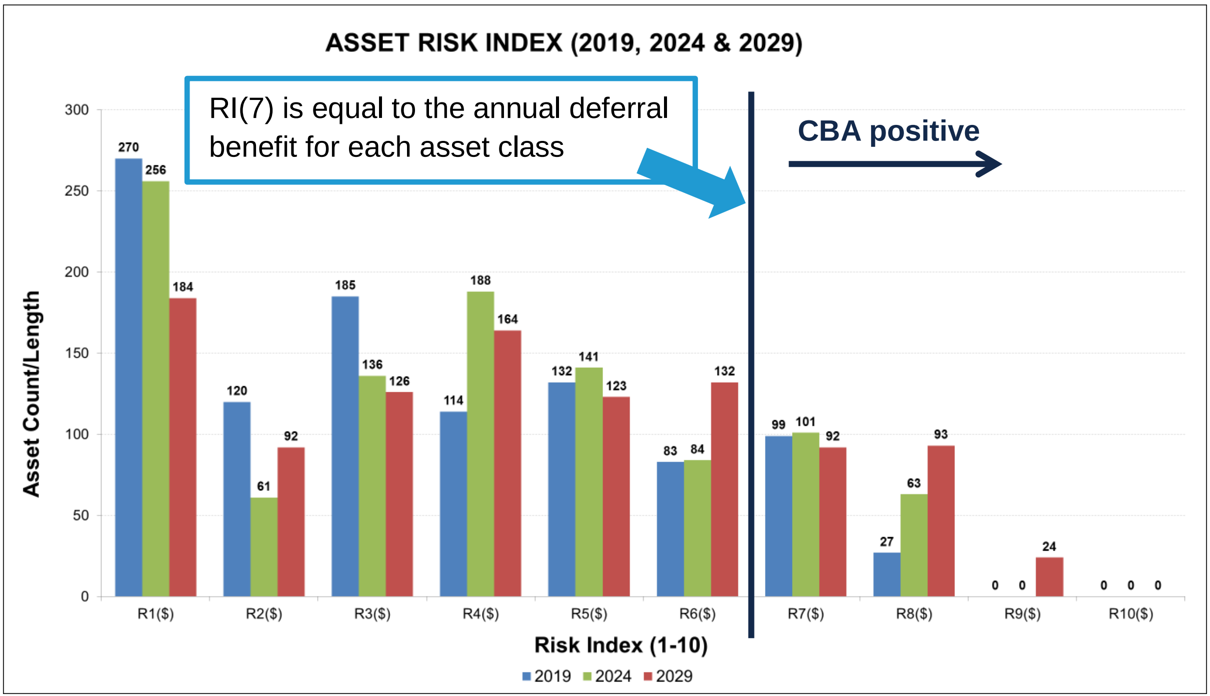
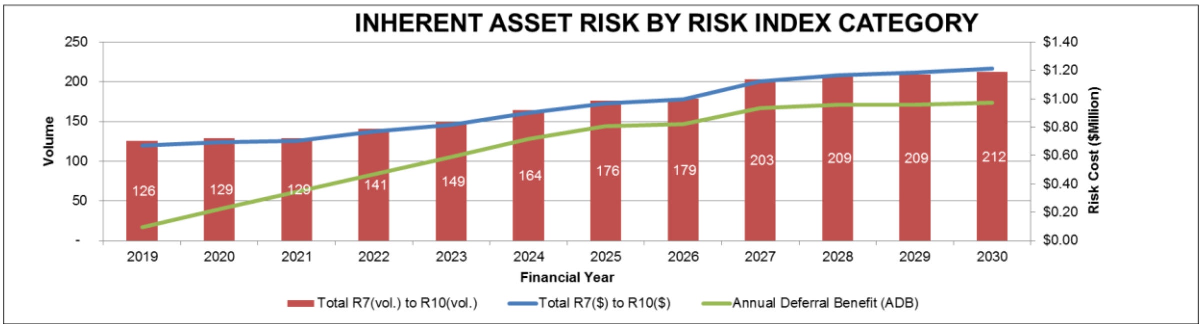


Figure 13 – Cost Benefit Positive Assets Example



From the figure above, the red bars shows the volume of assets that are cost benefit positive and how this increases annually when no investment is taken (inherent risk). Therefore, in this example the total number of expected replacements by the end of the 2019 – 2024 regulatory period would be 164 assets. The blue line represents the total risk cost for all assets that are cost benefit positive and the green line represents the annual deferral benefit for the proposed volume of replacement.

4.2 Evaluation

Once the cost benefit analysis is complete and risk is defined and understood, Ausgrid completes a final evaluation of the investment. Ausgrid only invests where the investment demonstrates value.

The following options may be considered:

1. Base Case (Reactive Replacement only)

2. Invest based on a net customer benefit (i.e. asset Risk Index with positive cost benefit)
3. Invest based on Risk Index offset by understood and well considered option Value (consider options to defer)
4. Manage to an above option and limited by delivery constraints

1. Base Case (Reactive Replacement only)

The analysis undertaken forecasts risk forward ten (10) years. The "Do Not Invest" option relates to the deferral of planned investment of the entire asset class beyond the risk forecast period (outside of ten years) i.e. it does not preclude investment in future years. Where a failure occurs, there will continue to be a reactive investment to replace the asset, where repair is not possible.

This option is adopted where the analysis does not demonstrate sufficient value in the investment or investment is curtailed due to a lack of financial resources for this investment.

2. Invest based on a net customer benefit (i.e. asset risk calculation demonstrates a positive cost benefit)

The year in which an investment is made on an individual asset is based on the year in which a positive cost benefit is expected to be realised as informed by the CBA.

3. Invest based on Risk Index offset by understood and well considered option Value (consider options to defer)

This is similar to the previous, however, this approach also includes a deferral factor where there may be an alternative solution or future synergies that can be suitably described to provide sufficient confidence regarding this potential alternative option that has not been explicit in the base analysis. Under this option the individual consequences are further examined to determine where Ausgrid may be able to take on more risk in the short to medium term for potential future benefit that would provide a net customer benefit in the longer term.

4. Manage to delivery constraints

In conjunction with one the above options (as a preferred option), Ausgrid considers constraints in delivering the risk based forecast and will make adjustments where the recommended investment is limited by delivery constraints and cannot be reasonably delivered to meet the cost benefit positive investment profile.

5 Assumption Summary

Ausgrid has made a number of key assumptions in developing these models. A summary of these is shown below:

5.1 Adjustment Factors

1. Factor scoring is appropriate to adjust the risk

For both the probability of failure and the probability of consequence, Ausgrid has applied scoring factors so that any factor that will reasonably impact the risk from either the probability of failure or the probability of consequence, for each asset within the asset class, is taken into account.

2. Factor scoring fits within a normal distribution

Ausgrid has applied a normal distribution in developing z-scores for the factor adjustments. Using a normal distribution allows the possible combination to be spread evenly around the mean.

3. Factor z-score distribution is normalised around the mean probabilities

When the z-score distribution is applied to the probability of failure and probability of consequence, they have been normalised around the mean so that following any adjustment, the mean probability of failure and consequence remains the same.

4. A maximum of ten (10) factors in total is sufficient to model risk

The model currently allows a maximum of ten (10) factors (five for the probability of failure and five for the probability of consequence). This is seen as sufficient to model the effect that different factors contribute to the probability of failure and probability of consequence.

5.2 Probability of Failure

5. Age is a key factor in asset failures

The majority of models have considered the asset age to be a dominant factor that informs asset degradation and therefore the probability of failure. This assumption has enabled Ausgrid to develop the initial probability of failure by correlating asset age to actual failures. Where Ausgrid has not considered age to be the dominant factor, variation two or three as detailed above, have been applied depending on the availability of information and the appropriateness of the approach for the asset class being reviewed.

5.3 Probability of Consequence

6. Incident history ratio remains constant

For the majority of programs, Ausgrid has determined the initial probability of consequence by calculating the ratio of historical incidents to historical failures. This is then used to predict future incidents by maintaining the same ratio as the probability of failure changes over time.

7. Severity ratio remains constant

The probability of consequence is calculated based on the historical incidents in each severity. Past understanding of this ratio is considered appropriate to predict the future.

8. Probability of Consequence maximum and minimum values

Ausgrid has applied an upper and lower bound to the mean probability of consequence. The maximum probability of consequence is 2x the mean value while the minimum is x0.01 the mean value.

5.4 Consequences

9. Logarithmic consequence scaling for most severity classes except “Major” is appropriate.

Ausgrid applies a log scale to the severity classes to produce severities that are orders of magnitude different. Applying log scales to predict risk is common risk management practice[11,12] as most organisations making decisions are concerned with the size of risk in terms of its orders of magnitude away from an alternative risk position.

10. Grossly disproportionate factors

Applying grossly disproportionate factors is common practice as a means of demonstrating what is reasonably practicable for the management of safety risk. Ausgrid have utilised information available from UK HSE to determine an appropriate range of disproportionate factors.

UK HSE was selected for this reference as there is limited information on this approach from within Australia.

5.5 Evaluation

11. Program effectiveness

The model determines the volume of reactive replacements under a Base Case “do nothing” scenario by multiplying the forecast failures by the percentage of failures which require replacement.

Where the forecast exceeds the anticipated volume of reactive replacements, the model assumes that the program will be 100% effective i.e. no additional reactive replacements required.

[11] Standards Australia 2008, Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA), AS IEC 60812.

[12] U.S. Department of Defense 1980, Procedures for Performing a Failure Mode, Effects and Criticality Analysis, MIL-STD-1629A.

6 APPENDIX A – Health Index Logic

Each adjustment factor or “Factor” was scored from one (1) to five (5) based on appropriate industry information and subject matter expert knowledge.

Health Score Factors				
Factor 1	Factor 2	...	Score	z-score
1	1	y1	2	x1
2	1	y1	3	x2
3	1	y1	4	x3
4	1	y2	5	x4
...	...	...	....	...

Factor 1 - Test Result		
Min.	Max.	Score
-	>90%	1
<=90%	>70%	2
<=70%	>50%	3
<=30%	>15%	4
<15%	-	5

Factor 2 - Location	
Risk Level	Score
-	1
Low	2
Medium	3
Medium	4
High	5

Once the adjustment score table has been completed and z-scores determined, this table is combined with the initial probability of failure to determine the adjustment probability of failure. This is then matched to Ausgrid's population information to assign an adjusted probability of failure and a health index to each asset. The worked through logic is based on the application of **Variation One** in treating the probability of failure as it relates to age as this is the most common method adopted.

Probability of Failure	
Age	Initial PoF
1	a1
2	a2
3	a3
4	a4
…	…
60	a60

Adjusted Probability of Failure at Age						
Score	z-score	0	1	2	3	…
2	x1	b1	b1	b1	b1	b1
3	x2	b2	b2	b2	b2	b2
4	x3	b3	b3	b3	b3	b3
5	x4	b4	b4	b4	b4	b4
…	…	b5	b5	b5	b5	b5
…	…	b6	b6	b6	b6	b6

Health Score Factors				
Factor 1	Factor 2	…	Score	z-score
1	1	y1	2	x1
2	1	y1	3	x2
3	1	y1	4	x3
4	1	y2	5	x4
…	…	…	….	…

Finally, the adjusted probability of failure is allocated to asset population data to build the asset class Health Index.

Population Data			
Age	Factor 1	Factor 2	Population
1	1	1	p1
1	2	1	p2
1	3	1	p3
1	4	1	p4
1	5	1	p5
...	...	...	...

Health Index		
Population	Adjusted PoF	Health Index
q1	b2	1
q2	b6	1
q3	b7	2
q4	b9	3
q5	b14	4
...	...	...

Adjusted Probability of Failure at Age						
Score	z-score	0	1	2	3	...
2	x1	b1	b1	b1	b1	b1
3	x2	b2	b2	b2	b2	b2
4	x3	b3	b3	b3	b3	b3
5	x4	b4	b4	b4	b4	b4
...	...	b5	b5	b5	b5	b5
...	...	...	...	...	...	...

7 APPENDIX B – Risk Index Logic

Again, each adjustment factor or “Factor” was scored from one (1) to five (5) based on appropriate industry information and subject matter expert knowledge.

Factor 1 - Bushfire	
Risk Level	Score
No BF	1
Buffer	2
Cat 3	3
Cat 2	4
Cat 1	5

PoC Score Factors				
Factor 1	Factor 2	…	Score	z-score
1	1	y1	2	x1
2	1	y1	3	x2
3	1	y1	4	x3
4	1	y2	5	x4
…	…	…	….	…

Factor 2 - Customer Density	
Risk Level	Score
-	1
Low	2
Medium	3
Medium	4
High	5

Incident conversion and severity analysis and is considered separately and then multiplied together to determine the probability of consequence before any adjustments are made. The values shown in the tables below are only used as an example and are not intended to represent the actual values used in the modelling.

Severity Analysis			
Severity	Safety	Enviro	Fire
Insignificant	0.495	0.6	0.4
Minor	0.3	0.2	0.2
Moderate	0.15	0.1	0.14
Major	0.05	0.08	0.259
Severe	0.005	0.02	0.001

Incident Conversion		
Safety	Enviro	Fire
0.02	0.1	0.01

PoC			
Severity	Safety	Enviro	Fire
Insignificant	0.0099	0.06	0.004
Minor	0.006	0.02	0.002
Moderate	0.003	0.01	0.0014
Major	0.001	0.008	0.00259
Severe	0.0001	0.002	0.00001

As was the case with the probability of failure, the factor scoring is applied to the initial probability of consequence to get a range of adjusted probabilities of consequence.

PoC Score Factors				
Factor 1	Factor 2	...	Score	z-score
1	1	y1	2	x1
2	1	y1	3	x2
3	1	y1	4	x3
4	1	y2	5	x4
...	...	...	....	...

Adjusted PoC			
Score	z-score	Initial PoC	Adjusted PoC
2	x1	a1	d1
3	x2	a2	d2
4	x3	a3	d3
5	x4	a4	d4
...	...	...	...
...	...		...

Initial PoC			
Severity	Safety	Enviro	Fire
Insignificant	0.0099	0.06	0.004
Minor	0.006	0.02	0.002
Moderate	0.003	0.01	0.0014
Major	0.001	0.008	0.00259
Severe	0.0001	0.002	0.00001

Finally the Risk Index is developed by combing the probability of failure, consequences, probability of consequences and population data.

Consequence Analysis					
Severity	Safety	Enviro	Fire	Loss of Supply	Financial
Insignificant	$	$	$	$	$
Minor	$	$	$	$	$
Moderate	$	$	$	$	$
Major	$	$	$	$	$
Severe	$	$	$	$	$

Adjusted PoC			
Score	z-score	Initial PoC	Adjusted PoC
2	x1	a1	d1
3	x2	a2	d2
4	x3	a3	d3
5	x4	a4	d4
...	...	...	...
...	...		...

Health Index		
Population	Adjusted PoF	Health Index
q1	b2	1
q2	b6	1
q3	b7	2
q4	b9	3
q5	b14	4
...	...	...

Population Data		
Factor 1	Factor 2	Population
1	1	p1
2	1	p2
3	1	p3
4	1	p4
5	1	p5
...	...	...

Risk Index				
Population	Adjusted PoF	Consequence	Adjusted PoC	Risk Index
q1	b2	$	d2	1
q2	b6	$	d6	1
q3	b7	$	d7	2
q4	b9	$	d9	3
q5	b14	$	d14	4
...	...	...	...	...