ElectraNet

ElectraNet Transmission Network Revenue Proposal

Asset Risk Cost Modelling Guideline

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Company Information

ElectraNet Pty Ltd (ElectraNet) is the principal electricity transmission network service provider (TNSP) in South Australia.

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Contents

Figures

Tables

1. Purpose

The purpose of this guideline is to explain how ElectraNet uses risk-cost modelling to quantify the risk cost reduction of replacement and refurbishment projects as input to economic cost benefit analysis to justify expenditure on physical assets.

2. Scope

The risk-cost modelling framework is used to quantify or monetise risk for replacement and refurbishment projects, whether they are capital or operating expenditure projects.

ElectraNet has adapted and applied the Investment Risk Tool (IRT) developed by AMCL Pty Ltd quantify risk. This guideline explains how the IRT is used to determine the risk cost reduction related to project options under consideration.

The risk-cost reduction outputs of IRT are used as input to the full economic assessment of a project, which includes calculating the net present value of the costs and benefits associated with each project option to determine the option that delivers the greatest net benefits from a customer perspective. The economic assessment methodology is not within the scope of this document.

3. Terms and Acronyms

Term/Acronym	Definition
CoF	Consequences of Failure
CoC	Cost of Consequences
IRT	Investment Risk Tool
LoC	Likelihood of Consequence
PoF	Probability of Failure

4. Guideline details

4.1 Framework overview

The Investment Risk Tool (IRT) determines the risk cost per year avoided by implementing a replacement or refurbishment project. This is achieved by first determining the asset failure modes that could occur if the project was not implemented. For each failure mode, the likelihood of it occurring within the year being analysed and the likely cost when it does occur is determined. The cost of each failure mode is then summed to provide an annual risk cost for the project. This process is repeated for each year over a typically 20-year period.

The risk-cost avoided by implementing the project is a benefit that is inputted to the economic assessment model along with any additional quantifiable benefits and costs to determine the net present value (NPV) for the project and to test if there is a positive economic case to justify the proposed expenditure.

The primary steps in the overall evaluation framework are outlined in Figure 1.

Note that it is not the intention of this guideline to cover the process of performing the economic assessment.

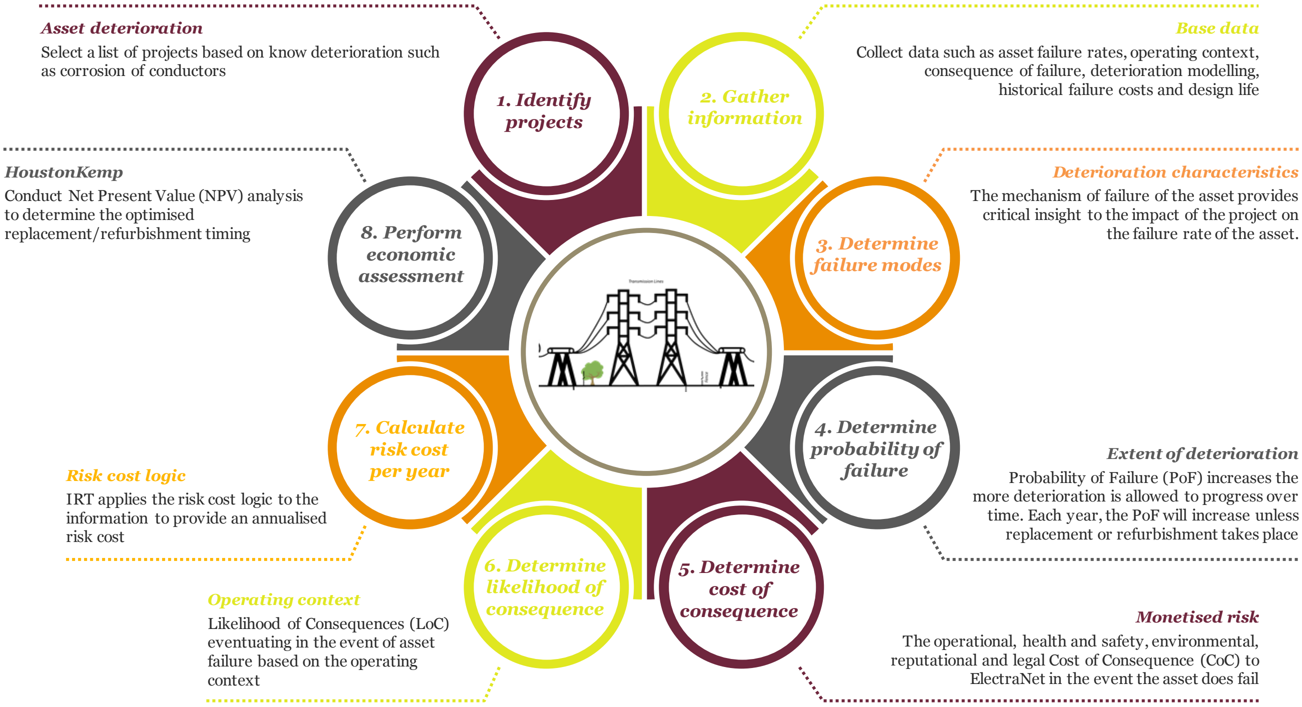


Figure 1: Risk cost modelling framework

The Investment Risk Tool is a Microsoft Access database where all configuration and project data is stored and calculations are performed. The tool provides basic reports which provide information about each project analysis. Figure 2 and Figure 3 show the two main screens of the tool where analysis is undertaken.

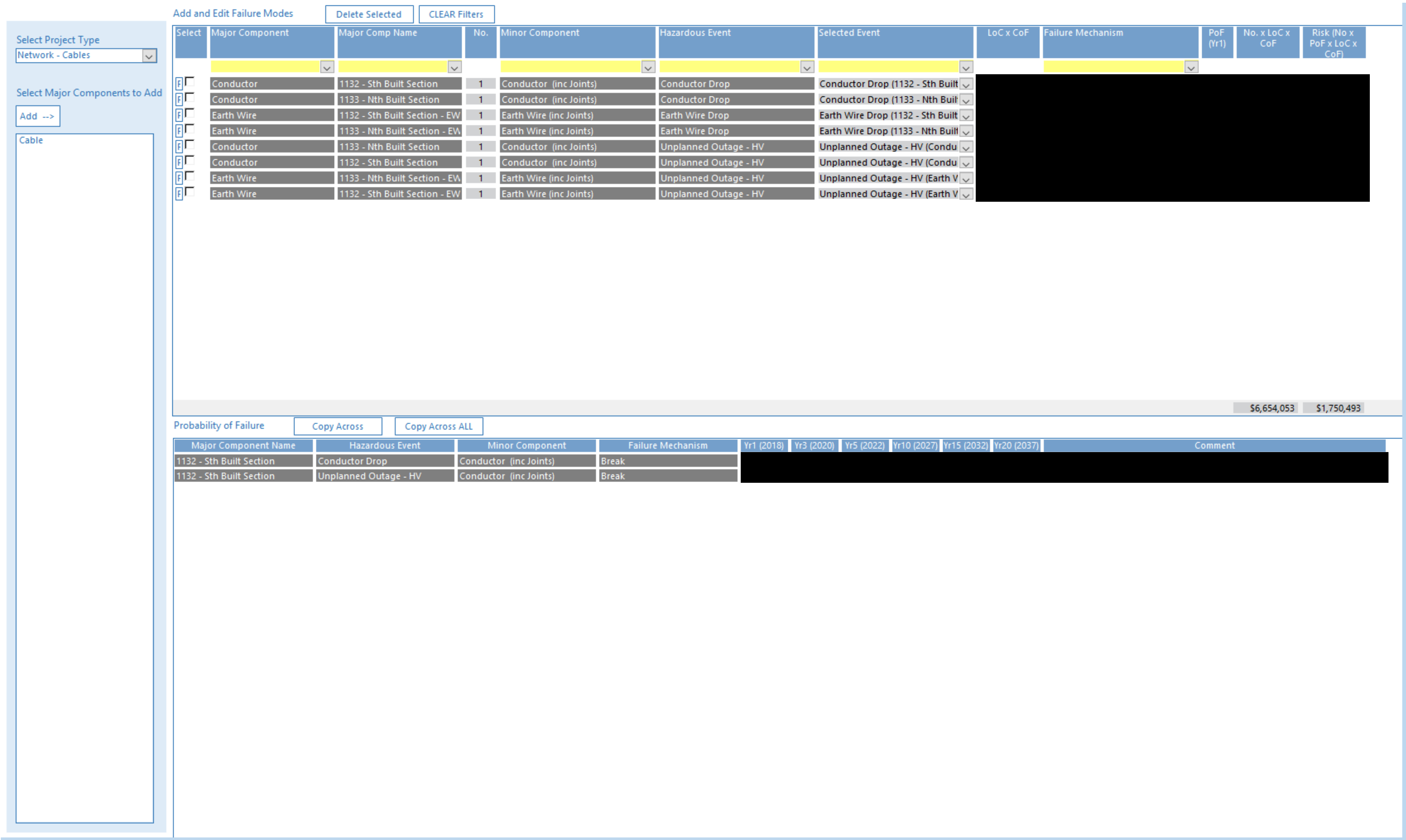


Figure 2: Risk Cost Model failure modes and risk screenshot

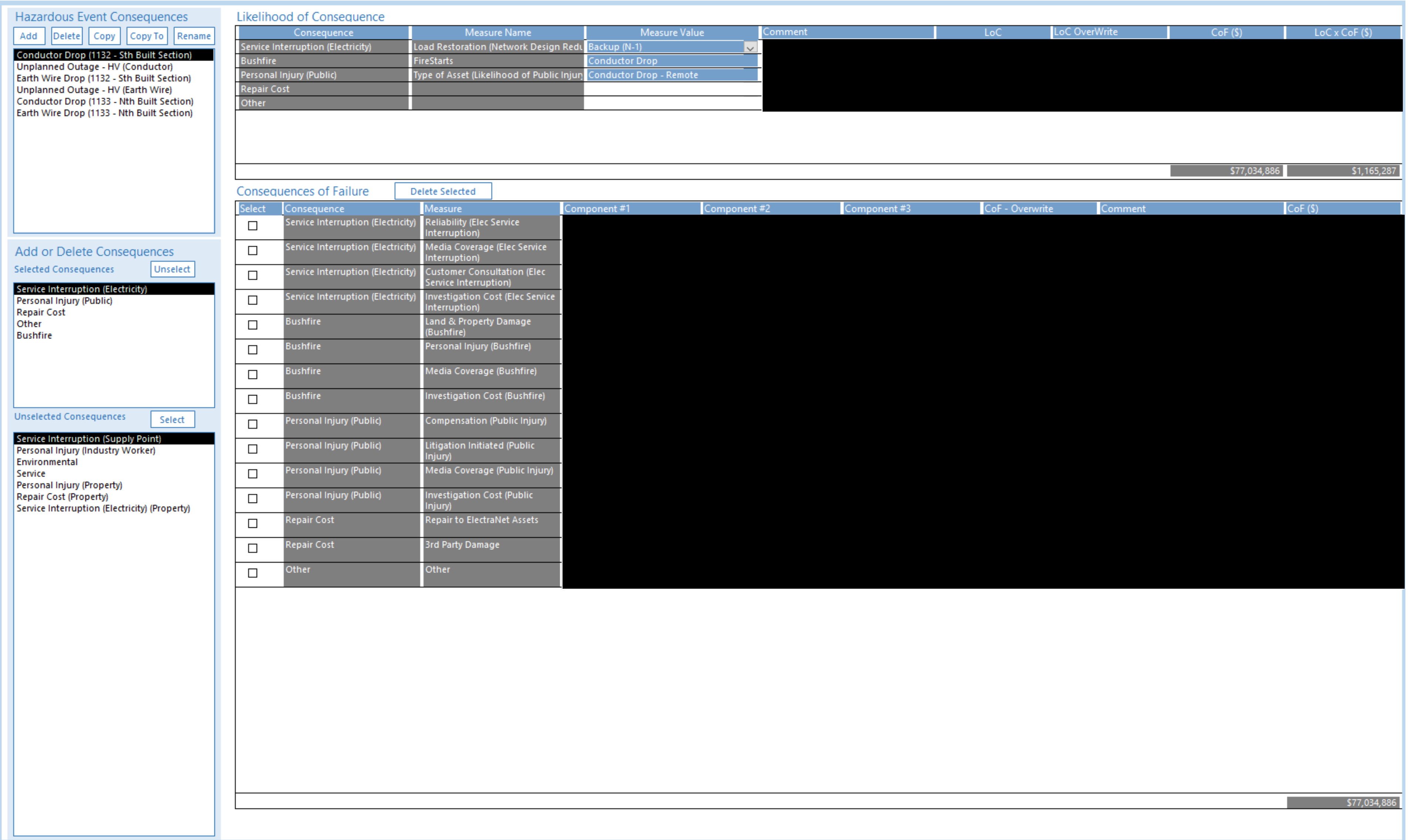


Figure 3: Risk Cost Model consequences screenshot

4.2 Step 1: Identify projects

Projects evaluated using IRT are those that are primarily driven by risk mitigation (e.g. safety, environmental or reliability risk).

The IRT is not used to evaluate projects that are primarily driven by market benefits, improved reliability, improved efficiencies and/or reduced maintenance costs, or if the project is required to comply with a legislative or regulatory obligation. These projects are evaluated using only the Economic Assessment Model.

4.3 Step: Gather information

To enable risk-cost evaluation, base information about the asset is required. This includes but may not be limited to:

- Failure history relating to the failure mode that the project is addressing;
- Number of assets in service and the duration of service;
- Level of redundancy within the system;
- Number of times the asset is visited;
- Location of the asset and its bushfire rating; and
- Consequence of asset failure and its severity.

Relevant project information gathered is added to the IRT. The guidance provided in Table 1 is used to decide at what level of granularity risk cost modelling should be applied to evaluate particular projects.

Table 1: Application of analysis rules

	Rule	Rationale
1	Analysis can be applied to either a single asset or a group of similar assets	For example, a single pole replacement is analysed using the Investment Risk Tool based on its location and condition as inputs to PoF and LoC estimates. A group of poles considered for replacement can be analysed in a single analysis, however, the analysis of each individual pole further refines risk assessment as varying operating contexts and current condition level can be included within the PoF and LoC estimates. For assets such as conductors, sections (Built Sections) of conductor with identical material specification and similar operating contexts are analysed as opposed to a complete section of the network.
2	Projects are analysed at the failure mode level	Estimation of PoF requires knowledge of the failure pattern specific to the failure mode that the project is addressing. Estimation of CoC relies on knowledge of the consequences of the specific failure mode that the project is addressing.

4.4 Step 3: Determine failure modes

Using the principles of Reliability Centred Maintenance, failure modes are determined as well as the failure patterns they most reflect. This enables risk modelling to more accurately reflect the change in PoF over time. Typical failure patterns are illustrated in Figure 4.

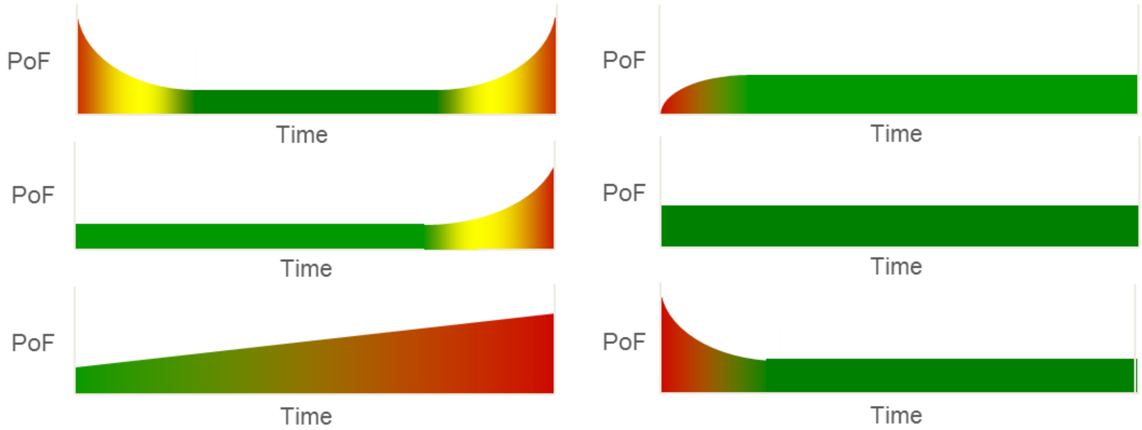


Figure 4: Typical failure patterns

Using asset information and knowledge of failure modes (failure mechanisms), adverse events related to each failure mechanism are identified. A summary of how the IRT is applied for various types of asset replacement considerations is summarised in Table 2.

Table 2: Examples of project types, their failure modes and adverse events

Project Type	Failure Mode	Adverse Event (explanation of how failure mode could lead to adverse event)
Line Conductor and Earth Wire Refurbishment	Conductor fails	Conductor drop Unplanned outage – HV (The deterioration of the conductor could be identified during inspections resulting in an unplanned outage or if the conductor failure is not detected this could result in the conductor dropping.)
	Earth wire fails	Earth wire drop Unplanned outage – HV (The deterioration of the earth wire could be identified during inspections resulting in an unplanned outage or if the earth wire failure is not detected this could result in the earth wire dropping.)
Line Insulator Refurbishment	Insulator failure	Conductor drop (The insulator failure would result in the conductor dropping.)
	Fitting failure	Conductor drop (The fitting failure would result in the conductor dropping.)
	Structural failure	Unplanned outage – HV (If failed insulators are not repaired prior to the bushfire season, then lines would be shutdown to prevent fires resulting in unplanned outages.)

Project Type	Failure Mode	Adverse Event (explanation of how failure mode could lead to adverse event)
Transformer Bushing Replacement	Bushing fails	Explosive Failure of asset (Failure results in an explosive failure.)
Transformer replacement	Insulation failure	Explosive Failure of asset Failure that releases pollutants Unplanned outage – HV (Failure results in an explosive failure, release of oil (pollutants) or unplanned outage.)
Substation Local Control Facility (LCF) Replacement	LCF control fails	Unplanned outage – HV (Delay in switching due to having to coordinate switching through control centre causing extended unplanned outage.)
Protection System Unit Replacement	Protection fails with no CB trip or Protection trip alarm	Explosive Failure of asset Failed compliance obligations (Network) Uncontrolled electrical contact Unplanned outage – HV (Protection failure with no alarm could result in an explosive failure, non-compliance, uncontrolled electrical contact or an unplanned outage.)
	Secondary system protection fault	Unplanned outage – HV (Protection fault results in an unplanned outage.)
	Inadvertent tripping	Unplanned outage – HV (Trip results in an unplanned outage.)
Online Asset Condition Assessment Equipment Replacement	Asset condition assessment equipment fails	Unplanned outage – HV (Although this project does impact transformer monitoring and power quality monitoring this project only assessed the consequence of the fault locators failing. The loss of the fault locators would delay the repair of a conductor due to the additional time to locate the fault.)

4.5 Step 4: Determine probability of failure

The Probability of Failure (PoF) is the likelihood that an asset will fail during a given period (i.e. number of estimated failures within a year) resulting in a particular adverse event.

To determine the Probability of Failure you need to know whether the failure mode has a random or age related failure pattern. Once this is determined, historical failure data can be analysed as summarised in Table 3.

For a random failure pattern the PoF is constant over time. For example, if there is an asset population of 206 and there has been 1 failure over the last 5 years, the PoF is calculated as:

$$PoF = \frac{Number\ of\ failures\ within\ population}{Service\ time\ of\ population} = \frac{1}{5\ x\ 206} = 0.001\ = 0.1\%$$

Year	1	3	5	10	15	20
PoF	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%

The PoF calculated above is that of a population. However, if the actual condition of the asset in relation to the failure mode is known, then the PoF should be adjusted to reflect the actual condition; i.e. for an asset in very poor condition that is known to be close to failure should have its PoF increased to a value approaching 100% for that year.

If allowed to fail, or the asset is replaced, the replacement asset's PoF would drop down to the random figure previously calculated. This is demonstrated in Table 4.

For an age related failure pattern data may exist which can be analysed to calculate an annual PoF over time, or ageing models may be used to predict this degradation over time; e.g. paper insulation degrading within a transformer.

This analysis is to be used to calculate the annual PoF based on the age of the asset pre and post replacement. This is also demonstrated in Table 3 and illustrated in Figure 5.

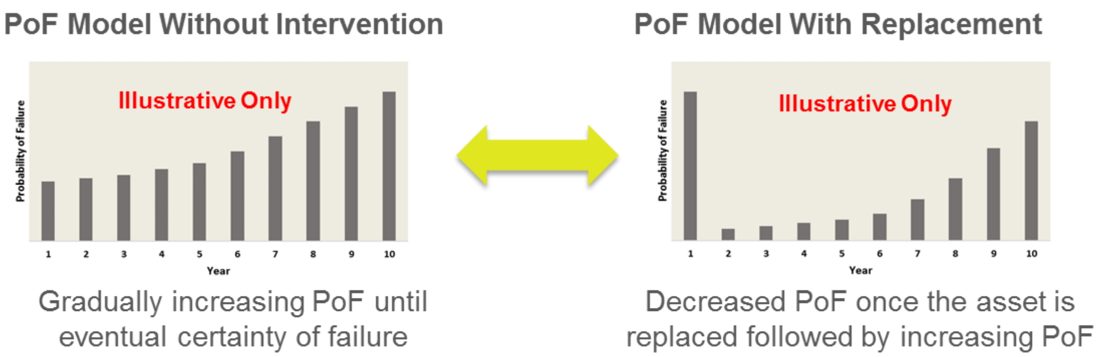


Figure 5: PoF modelling before and after intervention

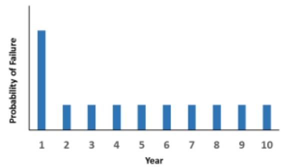
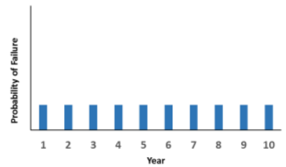
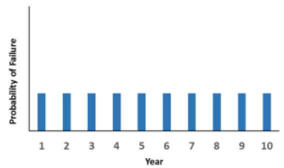
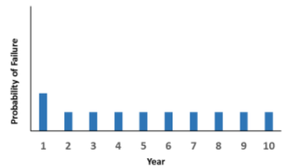
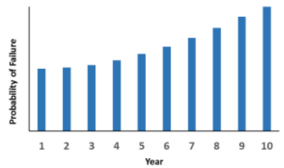
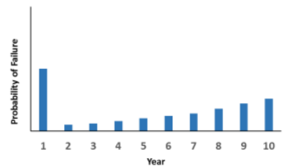
Note: When determining the PoF for age related failures it is assumed that each asset can only fail once because of the failure mode over the period analysed. Therefore, the total PoF for the period can only be a maximum of 100%.

An example of a Probability of Failures analysis for a protection control unit failing is shown in Appendix 7.1.

Table 3: Probability of failure analysis options

Scenario	Description	Analysis Options	Annual PoF
Random failure compulsory redesign	This random failure mode is related to either a hidden function and or has safety/ environmental consequences which does not respond to maintenance intervention. The project must replace the asset with another design which has different failure characteristic to the existing asset.	Average life of the population in service for that specific failure mode	Same PoF for each year except when it is known to be in the process of failing
Age related failure compulsory redesign	This age related failure mode is related to either a hidden function and or has safety/ environmental consequences which does not respond to maintenance intervention. The project must replace the asset with another design which has different failure characteristic to the existing asset.	Age modelling approved by ElectraNet.	Different PoF for each year based on failure analysis
Age related failure	This failure mode displays a significant age or usage failure pattern. It may have any range of failure consequences but respond well to maintenance intervention to reduce the probability of failure to an acceptable level.	Age modelling approved by ElectraNet.	Different PoF for each year based on failure analysis
Random failure	This failure mode is predominantly random in nature. It may have any range of failure consequences but respond well to maintenance intervention to reduce the probability of failure to an acceptable level.	Average life of the population in service for that specific failure mode	Same PoF for each year except when it is known to be in the process of failing

Table 4: Probability of failure for various project scenarios

Scenario	Project Implementation Options	
	Do nothing	**Project Implemented in Year 2 (next regulatory period)**
Random failure where the asset is in poor condition and implementing a like for like asset replacement.	 The full cost of consequence of failure is realised before replacement	 The full cost of consequence is avoided due to proactive replacement
Random failure where the asset is replaced with a more reliable design	 No change in PoF	 Reduced PoF if replacement asset is more reliable
Age related failure and implementing a like for like asset replacement	 Gradually increasing PoF until eventual certainty of failure	 Decreased PoF once the asset is replaced followed by increasing PoF

4.6 Step 5: Determine cost of consequence

The Cost of Consequences (CoC) (also referred to the Consequences of Failure (CoF)) is the estimated financial impact of each consequence. The CoC is determined for each failure with consideration made to various adverse effects as illustrated by the large circles in Figure 6. Each of these effects has a subset of related consequences as illustrated for Personal Injury.

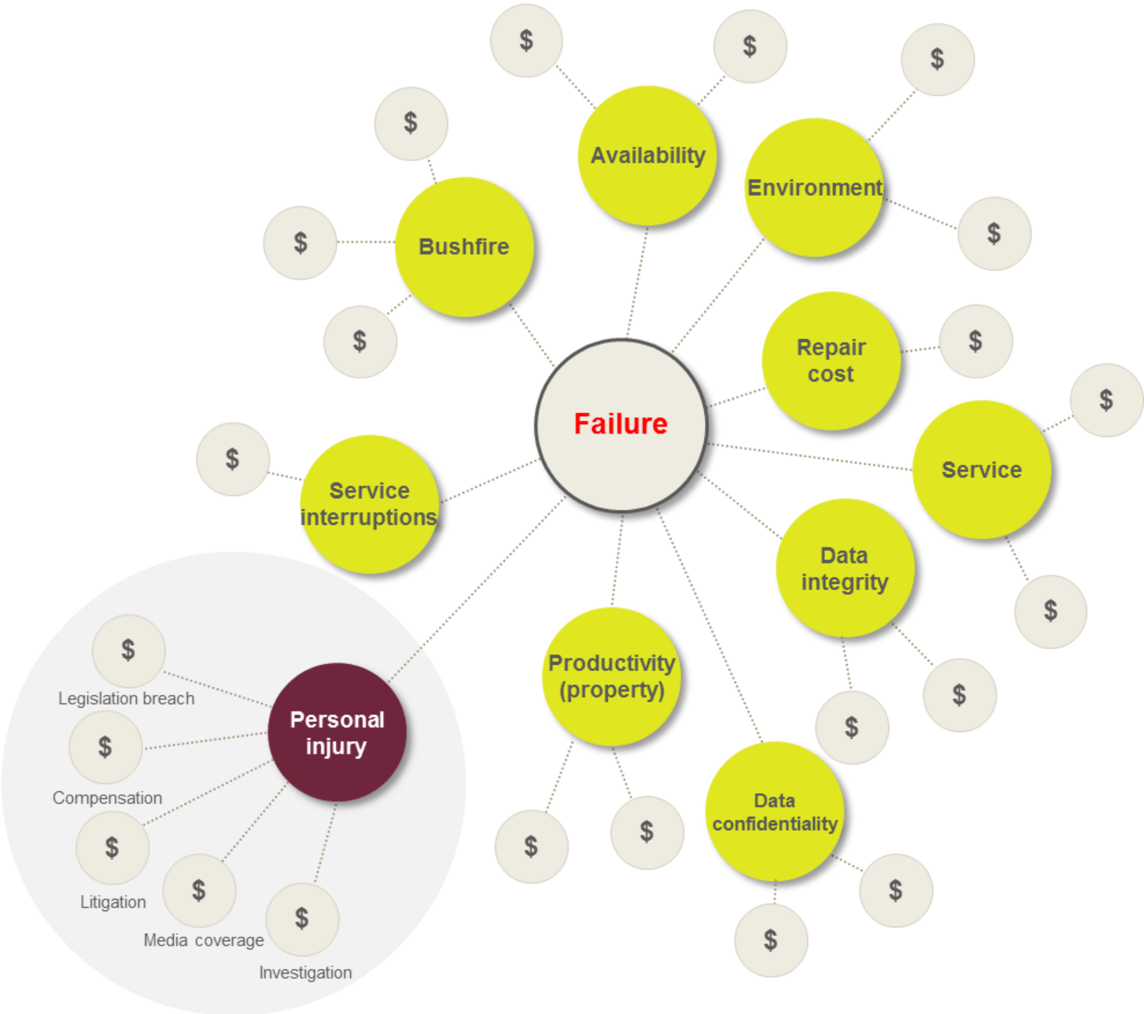


Figure 6: Adverse effects and CoC

For each consequence, the CoC is selected using various drop down menus and data entry boxes in the IRT to determine the cost. The cost related to various consequences has been obtained from various sources, and validated by ElectraNet with the assistance of AMCL Pty Ltd.

A sample of the CoC's, cost driver for each consequence, source of cost data and a sample of the costs is shown in Table 5.

Table 5: Examples of cost of consequences - Complete list contained in the IRT

Consequence of Failure Category	Cost driver	Source	Sample CoC Values
Repair duration	Time to repair asset	ElectraNet	[redacted]
Customer type	Economic loss for the various customer types	AEMO VCR September 2014[1]	
Property damage from a bushfire	Based on the type of land use within each built section and potential for different sizes of bushfire	ElectraNet's Bushfire model	
Personal injury	Compensation based on the level of injury	Best practice Regulation Guidance Note Value of Statistical Life (VSL)[2]	
Litigation	Legal costs based on the severity of the breach/incident	Estimated	
Media coverage	Level of media attention	Estimated	
Customer consultation	Level of customer consultation required	Estimated	
Investigation cost	Size of the investigation	Estimated	
Environmental	Clean-up costs based on volume discharged, area impacted and site sensitivity	Estimates that have been calibrated from actual incidents	
Service obligation violation	Size of penalty based on level of breach	ElectraNet	

1 See AEMO report at www.aemo.com.au/-/media/Files/PDF/VCR-final-report--PDF-update-27-Nov-14.pdf

2 Australian Government Best Practice Regulation Guidance Note – Value of Statistical Life (VSL), December 2014 available at www.dpmc.gov.au/sites/default/files/publications/Value_of_Statistical_Life_guidance_note.pdf

3 [redacted]

4 [redacted]

An example of the CoC for an explosive failure caused by the protection system unit failure on a 132 kV rural line is shown in Appendix 7.3.

Additional points considered when assessing CoC include:

- For transmission lines, assessments have been split within a built section if the base data varies along the built section;
- IRT includes unplanned repairs and physical failures. Preventive maintenance costs are not included in the IRT analysis, but are included in the Economic Assessment model.
- For substation projects (e.g. protection relay replacement) a separate assessment is made at each of the various voltage levels because the CoC changes based on the voltage

Port Lincoln related projects are a specific example where additional considerations are required to take account of the operation of a back-up Gas Turbine (GT) network support arrangement at Port Lincoln. Due to the radial network configuration, there will always be a 15-minute service interruption period when the transmission line is taken out of service while the back-up generation becomes operational.

4.7 Step 6: Determine likelihood of consequence

Likelihood of Consequence (LoC) is the probability that an asset failure will result in a particular consequence.

For each adverse event, the consequences of that event are selected. The options for the consequences include, but are not limited to[5]:

- Electricity service interruption;
- Bushfire;
- Personal injury;
- Repair cost;
- Service obligation violation; and
- Environmental.

For each consequence, the Likelihood of Failure is selected using various drop down menus based upon the system design, location of asset and frequency in which the asset is visited. A summary of how these LoC are determined is summarised in Table 6.

5 Additional consequences can be added if required

Table 6: Examples of likelihood of consequences - complete list contained in the IRT

Consequence	LoC Estimation	LoC Values
Electricity service interruption	Based on the level of redundancy within the system design.	[redacted]
Bushfire (fire started)	Based on ElectraNet's bushfire model	[redacted]
Personal injury	Estimated based on the likelihood of a person being present during asset failure	[redacted]
Environmental	Based on the ability to contain the pollutant	[redacted]

An example LoC analysis for a protection system unit failure on a 132Kv rural line resulting in an explosive failure is shown in Appendix 7.2.

4.8 Step 7: Calculate risk cost per year

Once the PoF, LoC, and CoC have been determined, the IRT then calculates the risk cost per year that the failure mode (risk) poses to ElectraNet. The tool uses the following calculation:

$$Risk\ cost\ per\ year\ (\$) = (PoF_1\ x\ No_1\ x\ LoC_1 x\ CoF_1) + (PoF_2\ x\ No_2\ x\ LoC_2 x\ CoF_2) + \cdots (PoF_N\ x\ No_N\ x\ LoC_N x\ CoF_N)$$

$PoF_N = Probability\ of\ Failure\ N\ (\%)$

$No_N = Number\ (length)\ of\ assets\ being\ replaced/refurbished$

$LoC_N = Likelihood\ of\ Consequence\ N\ (\%)$

$CoF_N = Cost\ of\ Failure\ N\ (\$)$

An example of the risk calculation for a protection system unit asset replacement is shown in Appendix 7.4

4.9 Step 8: Perform economic assessment

The risk cost per year information from the IRT is used as an input to the Economic Assessment model. The Economic Assessment model evaluates the costs and benefits of all factors, including the risk cost reduction for three possible cases to determine a Net Present Value (NPV) for each project. These cases include:

- Base case – status quo over the next 20 years if the project was not implemented;
- Investment in next regulatory period; and
- Investment in following regulatory period (next + 1).

The resulting NPVs for each case are compared and used as a guide to determine the most economic investment option and timing. This comparison is illustrated in Figure 7.

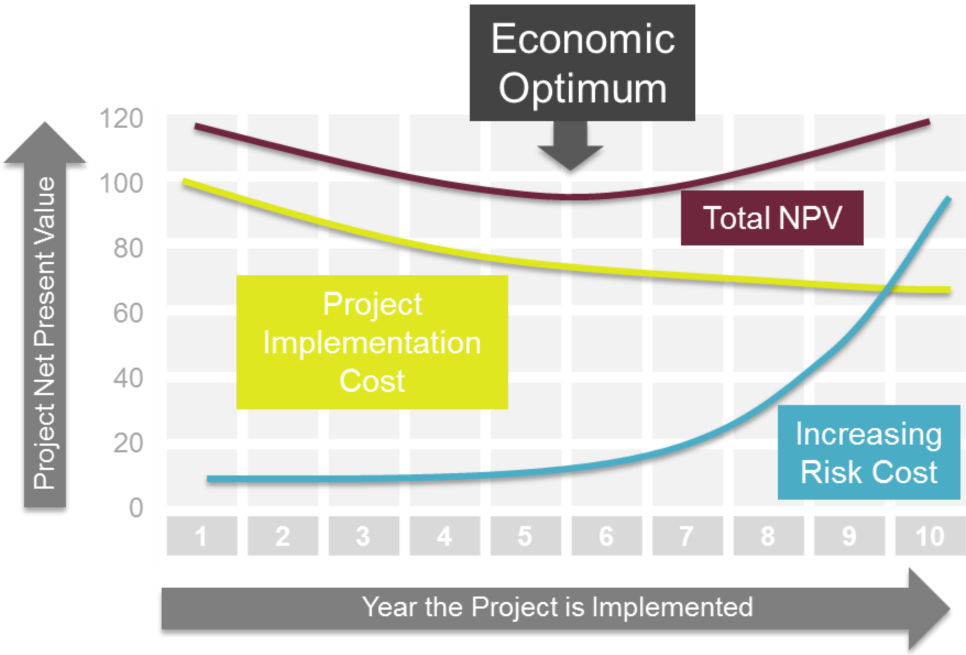


Figure 7: Economic analysis optimum intervention decision making

A description of the rationale behind the risk cost assessment and NPV calculation should be provided within the Project Economic Assessment.

Appendices and references

Example of PoF analysis

Figure 8 shows the Probability of Failures of one out of the 206 protection control unit failing for each type of failure mechanism and adverse event.

Probability of Failure   Copy Across   Copy Across ALL

Major Component Name	Hazardous Event	Minor Component	Failure Mechanism	Yr1 (2018)	Yr3 (2020)	Yr5 (2022)	Yr10 (2027)	Yr15 (2032)	Yr20 (2037)	Comment
Protection Contol - 132kV Rural	Unplanned Outage - HV	Protection & Protection Control	Sec Sys Prot FAULT	[redacted]						
Protection Contol - 132kV Rural	Unplanned Outage - HV	Protection & Protection Control	Inadvertent tripping							
Protection Contol - 132kV Rural	Unplanned Outage - HV	Protection & Protection Control	No:CBtrip Or ProtTripAlarm whe							
Protection Contol - 132kV Rural	Uncontrolled Electrical Contact	Protection & Protection Control	No:CBtrip Or ProtTripAlarm whe							
Protection Contol - 132kV Rural	Failed Compliance Obligations	Protection & Protection Control	No:CBtrip Or ProtTripAlarm whe							
Protection Contol - 132kV Rural	Explosive Failure of Asset	Protection & Protection Control	No:CBtrip Or ProtTripAlarm whe							

Figure 8: PoF for various failure mechanisms and adverse events

Example of LoC analysis

Example of the LoC's for a protection system unit failure on a 132Kv rural line resulting in an explosive failure is shown in Figure 9.

Likelihood of Consequence

Consequence	Measure Name	Measure Value	Comment	LoC
Service Interruption (Electricity)	Load Restoration (Network Design Redu	Backup (N-1)		[redacted]
Personal Injury (Industry Worker)	Type of Asset (Likelihood of Industry Wo	Substation - Small		
Environmental	Control Mechanisms (Containment)	Contained on site		
Repair Cost				
Other				

Figure 9: Probability of failure example

Example of CoC analysis

Example of the CoC for an explosive failure caused by the protection system unit failure on a 132 kV rural line is shown in Figure 10. The figure shows the total consequence of failure is $293,978,200.

Consequences of Failure   Delete Selected

Select	Consequence	Measure	Component #1	Component #2	Component #3	CoF - Overwrite	Comment	CoF ($)
☐	Service Interruption (Electricity)	Reliability (Elec Service Interruption)	[redacted]					
☐	Service Interruption (Electricity)	Litigation (Elec Service Interruption)						
☐	Service Interruption (Electricity)	Media Coverage (Elec Service Interruption)						
☐	Service Interruption (Electricity)	Customer Consultation (Elec Service Interruption)						
☐	Service Interruption (Electricity)	Investigation Cost (Elec Service Interruption)						
☐	Personal Injury (Industry Worker)	Compensation (Industry Worker Injury)						
☐	Personal Injury (Industry Worker)	Legislation Breach (Industry Worker Injury)						
☐	Personal Injury (Industry Worker)	Litigation Initiated (Industry Worker Injury)						
☐	Personal Injury (Industry Worker)	Media Coverage (Industry Worker Injury)						
☐	Personal Injury (Industry Worker)	Investigation Cost (Industry Worker Injury)						
☐	Environmental	Land OR Water (Cleanup / Impact / Comp.)						
☐	Environmental	Legislation Breach (Env. Fines)						
☐	Environmental	Litigation Initiated (Environmental)						
☐	Environmental	Media Coverage (Environmental)						
☐	Environmental	Investigation Cost (Environmental)						
☐	Repair Cost	Repair to ElectraNet Assets						
☐	Other	Other						
								$293,978,200

Figure 10: Consequence of failure example

Example of risk calculation

Figure 11 is a screen shot showing the risk calculation for Year 1 for a protection system unit asset replacement. The figure shows the risk cost in year 1 is $2,039,609. Since this is a random failure, the risk cost for the following years is also $2,039,609/ year. The replacement of the protection system would mitigate these costs.

Add and Edit Failure Modes | Delete Selected | CLEAR Filters

Select	Major Component	Major Comp Name	No.	Minor Component	Hazardous Event	Selected Event	LoC x CoF	Failure Mechanism	PoF (Yr1)	No. x LoC x CoF	Risk (No x PoF x LoC x CoF)
F	Protection Contol Indicating	Protection Contol - 132kV Ru	19	Protection & Protection Control	Explosive Failure of Asset	132kV Rural - Explosive Failure o	[redacted]				
F	Protection Contol Indicating	Protection Contol - 132kV Ru	190	Protection & Protection Control	Failed Compliance Obligations (Netv	132kV Rural - Failed Compliance					
F	Protection Contol Indicating	Protection Contol - 132kV Ru	190	Protection & Protection Control	Uncontrolled Electrical Contact / Dis	132kV Rural - Uncontrolled Elect					
F	Protection Contol Indicating	Protection Contol - 132kV Ru	190	Protection & Protection Control	Unplanned Outage - HV	132kV Rural - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 132kV Ru	190	Protection & Protection Control	Unplanned Outage - HV	132kV Rural - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 132kV Ru	190	Protection & Protection Control	Unplanned Outage - HV	132kV Rural - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 275kV M	7	Protection & Protection Control	Explosive Failure of Asset	275kV Metro - Explosive Failure c					
F	Protection Contol Indicating	Protection Contol - 275kV M	71	Protection & Protection Control	Failed Compliance Obligations (Netv	275kV Metro - Failed Compliance					
F	Protection Contol Indicating	Protection Contol - 275kV M	71	Protection & Protection Control	Uncontrolled Electrical Contact / Dis	275kV Metro - Uncontrolled Elec					
F	Protection Contol Indicating	Protection Contol - 275kV M	71	Protection & Protection Control	Unplanned Outage - HV	275kV Metro - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 275kV M	71	Protection & Protection Control	Unplanned Outage - HV	275kV Metro - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 275kV M	71	Protection & Protection Control	Unplanned Outage - HV	275kV Metro - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 275kV Ru	16	Protection & Protection Control	Explosive Failure of Asset	275kV Rural - Explosive Failure o					
F	Protection Contol Indicating	Protection Contol - 275kV Ru	155	Protection & Protection Control	Failed Compliance Obligations (Netv	275kV Rural - Failed Compliance					
F	Protection Contol Indicating	Protection Contol - 275kV Ru	155	Protection & Protection Control	Uncontrolled Electrical Contact / Dis	275kV Rural - Uncontrolled Elect					
F	Protection Contol Indicating	Protection Contol - 275kV Ru	155	Protection & Protection Control	Unplanned Outage - HV	275kV Rural - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 275kV Ru	155	Protection & Protection Control	Unplanned Outage - HV	275kV Rural - Unplanned Outag					
F	Protection Contol Indicating	Protection Contol - 275kV Ru	155	Protection & Protection Control	Unplanned Outage - HV	275kV Rural - Unplanned Outag					
										$2,721,100,842	$2,039,609

Figure 11: Risk calculation for protection system unit asset replacement