Electricity network service providers

Replacement model handbook

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1 Introduction

This handbook sets out the Australian Energy Regulator's (AER) replacement model (repex model). The repex model is intended for use as part of building block determinations for the regulated services provided by electricity network service providers (NSPs). The repex model is a series of Microsoft Excel spreadsheets developed for the AER to benchmark replacement capital expenditure. It was first deployed in the Victorian electricity distribution determination for the 2011-2015 regulatory control period.

The purpose of this handbook is to:

- provide background and context for the repex model
- explain the use of the model.

This handbook is intended for NSPs to familiarise themselves with the repex model and its principles, or be involved in the application of the repex model.

This handbook is structured as follows:

- section 2 provides some background and context to NSP capital expenditure and replacement modelling, summarising the various expenditure categories and their drivers, and the relationship to replacement modelling within this mix
- section 3 introduces replacement modelling, providing an overview of asset replacement and explaining how it can be modelled for regulatory purposes
- the AER's repex model is then described in section 4, summarising its form, and its input and outputs
- the application of the repex model is then described in section 5, covering how a model is developed and used to prepare benchmark forecasts
- Appendix A details the repex model reference manual.

2 The nature of capital expenditure and replacement modelling

In order to assess capital expenditure (capex) it is essential to first understand the nature of capex, including the activities NSPs may undertake and the drivers of these activities.

At its most aggregate level, NSPs' capex can be considered in two broad categories:

- Network capex, which broadly covers investment in assets in the "field" i.e. those assets that constitute the physical network
- Non-network capex, which broadly covers investment in assets that support those assets out in the "field", for example offices and equipment, central control facilities, plant, vehicles, and tools.

Network capex generally is the major proportion a NSP's capex. Network capex can be further disaggregated into two categories as follows.

Table 2.1 Network Capex Categories

Capex type	Comments
Demand driven capex	The need for demand-driven-capex is due to changes in the customer demand for electricity; most notably, the connection of new customers or the increase in demand of existing customers. The activities associated with demand-driven-capex involve increasing the capacity or capability of the network to support the change in demand. These activities generally involve two forms: the development of new parts of a network (e.g. new feeders or substations) or the replacement of existing parts of the network with assets of a higher capacity. The timing of the need for one of these activities is normally directly related to the demand via regulatory obligations (e.g. security of supply standards) or the predicted worsening of the current performance due to the change in demand (e.g. the expected level of electricity that will not be served to customers).
Non demand driven capex	By exclusion, non-demand-driven-capex is due to all other matters that may require investment in the network. This broadly however relates to the need to maintain service levels provided by the existing network assets within appropriate performance bounds. The activities associated with non-demand-driven-capex generally involve two forms: the replacement of existing parts of the network with modern equivalent assets[1] or the addition of new assets within the network to enhance its performance. The timing of the need for one of these activities can be due to a number of factors: the maintenance and operating costs of the asset, its performance (e.g. asset reliability), the risks associated with its failure (e.g. safety, environmental, network reliability), the associated network performance (e.g. power quality), and issues associated with the management of the asset.

[1] Note the distinction here with replacement driven by demand. Demand driven replacement will, by its nature, require assets of a higher capacity. Non-demand-driven replacement should not require additional capacity; although, additional capacity may result as a product of the modern equivalent asset.

These factors often are related to the age of the asset and the management of the asset over its life cycle. But other factors, such as specific safety, environmental or power quality regulatory obligations, can explicitly define the need to invest.

The categorisation described above can be viewed more simply in terms of the driver versus activity mapping shown in the table below.

Table 2.2 Network Capex Categories

Driver	**Activity**	
Demand driven	Replacement of assets with increased capacity (higher service level)	Development of new network
Non-demand driven	Replacement of assets with modern equivalent (similar service level)a	Installation of new assets

[a] -highlighting indicates region where replacement modelling can be applied

Under this definition, the replacement and replacement modelling discussed in this handbook specifically relates to the following:

Non-demand-driven replacement of an asset with its modern-equivalent, where the timing of the need can be directly or implicitly linked to the age of the asset.

This capex generally accounts for 30-60 per cent of the network capex, and as such, its assessment for regulatory determinations can be very important.

3 Replacement capital expenditure modelling

The previous section described the various categories of NSP capex, the factors driving this capex and the resulting activities that generate capex. This categorisation was used to explain where age-based replacement modelling, of the form discussed in this handbook, can be used when making regulatory determinations.

This section explains the principles of age-based replacement modelling and explaining how it can be applied.

3.1 Predicting the replacement of assets

With time, network assets age and deteriorate. This can affect their condition, which in turn, can impose risks associated with the assets' failure. These risks can relate to a number of matters, including:

- Network performance (e.g. loss of supply to customers)
- Safety (e.g. an explosive failure could harm personnel or public in the close vicinity)
- Environmental (e.g. the failure may release substances with an environmental consequence)
- Operational (e.g. there will be a cost associated with repairing the asset and restoring supply to customers).

Further, as some assets age, costs associated with their maintenance may increase. In effect, maintenance costs may increase to reduce the deterioration of the asset, and in turn, manage the condition of the asset.

For many assets, following any installation wear-in issues[2], the risks and operational costs will be relatively constant. However, as the assets become older they can reach an age where the risk and costs begin to increase substantially year-by-year - or in effect the probability that the asset will fail increases substantially. As shown in Figure 3.1, this relationship can be viewed as a relatively constant line for the majority of an assets life, which rises more rapidly near the end of its life. This relationship is often known as the "bathtub curve" due to its form[3].

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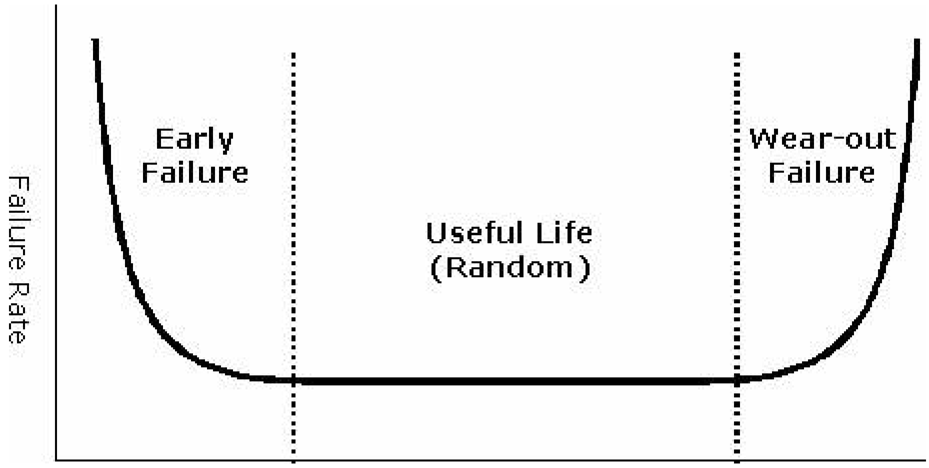
2 Note that as initial failures are normally replaced under warranty, they are ignored in this discussion.

3 Initial "wear in" failures are common in manufactured items. When included in the bathtub curve their occurrence creates a steep declining curve on the left hand vertical axis that completes the bathtub shape from which the curve derives its name.

Figure 3.1 Bathtub curve



1-5 years 50+ years

* Note: Useful life can also be defined as the economic life[4]

When trying to predict replacement needs, the replacement life of an asset is important. Some assets will generally be operated until failure. This is known as replace-on-failure, and is often used for assets on the high voltage and low voltage networks of a distribution business, where condition assessments cannot be efficiently applied and the risks of failure are low. The replacement life in these circumstances is the anticipated life up to failure. This life is sometimes called the technical life of an asset.

For other assets, particularly larger sub-transmission and transmission assets, the risks of failure can be large. Consequently, these assets will often be planned to be replaced prior to their technical life, often based upon the measured condition of the asset. The replacement life in these circumstances should be the life that minimised costs (operating plus risks). This life is often called the economic life of an asset.

Furthermore, for a population of similar assets, it would be expected that the replacement life may vary across the population. This can be due to a range of factors, such as its operational history, its environmental condition, the quality of its design and installation. This can mean that the remaining life of an asset is a function of a number of factors, most notably its condition, and therefore a population of similar assets will have a range of lives.

Clearly, accurately predicting the replacement of individual assets is a non-trivial exercise, and requires extensive data and modelling techniques.

3.2 Replacement modelling for regulatory purposes

Given the complexity discussed above, the aim of a regulatory model is to simplify the analysis, but still maintain some accuracy at the aggregate level. To achieve this,

4 Early failure indicates that the component has a higher likelihood of failure early in its life than later. In other words, it will likely fail close to the time it comes on line or into service. If it survives the initial start up period it will likely have a long life.
Wear out failure patterns indicate that the component has a useful life and that time is definitely a factor in the life of the component.

assets are considered as populations rather than individuals. The key parameter for predicting asset replacement needs across the population is the replacement life. This life could be the technical or economic life depending on the circumstances of the particular asset population.

The replacement life needs to be defined in such a way that it adequately reflects the aggregate replacement needs across the population, given the age of the assets in the population - even if at the individual level it will not be accurate. In effect, asset age is used as a proxy for the many factors that drive individual asset replacements.

In developing the AER's repex model, it was decided that the concept behind the model should have similar characteristics to those used by the UK regulator, Ofgem. For this form of model, the replacement life is defined as a probability distribution applicable for a particular population of assets. This probability distribution reflects the proportion of assets in a population that will be replaced at a given age.

The shape of the probability distribution should reflect the replacement characteristics across the population. The AER's repex model, similar to the Ofgem approach, assumes a normal distribution for the replacement life.

The repex model can be used to develop a volumetric or expenditure benchmark for the asset replacement. Developing volumetric benchmarks require benchmarks lives to be defined. Developing expenditure benchmarks requires both benchmark lives and benchmarks unit costs to be prepared.

4 Overview of AER repex model

The previous section explained the nature of asset replacement and replacement modelling, and introduced the principles behind the repex model. This section provides a more functional overview of the repex model.

This section should be sufficient for a broad familiarisation with the repex model. However, for users of the model, Appendix A provides more detailed reference material, including what the purposes for the various worksheets within the model, where model inputs and outputs are contained, and how the model is run. Attachment A sets out in some detail a typical information request that encompasses the data needs for undertaking repex modelling.

As discussed in Section 3, the repex model is a high-level model that forecasts replacement needs (both in terms of asset replacement volumes and replacement expenditure) based upon the age of the NSP's asset base. The key features of the repex model are:

- asset categorisation and grouping
- model inputs and outputs
- replacement algorithm.

These features are discussed in turn below.

4.1 Asset categorisation and grouping

Asset categorisation

The model requires the NSP's network asset base to be broken down into a number of discrete asset categories. This categorisation is required to reflect variations in asset lives and unit costs between different asset types.

This categorisation can assist both in the accuracy of the model and in its interpretation. In particular, this categorisation can assist when comparative assessments between NSPs are undertaken.

This form of asset categorisation is essential to capture variations between broad asset classes (e.g. poles, transformers, switchgear). However, it is often also necessary to capture variations within an asset class.

For example, the typical life of a pole may vary depending on the material (and treatments) using in its construction (e.g. hard wood, soft wood, steel, concrete). It may also vary depending on environmental conditions (damp or dry, or coastal or inland). The unit costs will often vary depending on the voltage level, which reflects the height and diameter of poles. As such, most NSPs will require a number of categories to adequately reflect these variations.

Asset grouping

The model requires each asset category to be assigned to a more limited set of asset groups. These groups should generally reflect the broader asset classes (e.g. poles, power transformers, etc).

The aim here is too provide a high-level framework, based upon the asset groups, for presenting model findings and comparative analysis.

The model presently allows 15 asset groups to be defined. In the recent Victorian distribution determination, 13 groups were used as defined in table 4.1.

Table 4.1 Asset groups

Asset categories	
Poles	Distribution Switchgear
Pole Top Structure	Distribution Other Assets
Conductor	Zone Transformers
Underground Cables	Zone Switchgear
Services	Zone Other Assets
Distribution Transformers	SCADA and protection
Other	

Considerations for categorisation and grouping

Generally, the NSP is in the best position to determine the level of categorisation required to adequately reflect the replacement requirements of its network. However, the AER needs consistency in how it presents its analysis and findings.

Therefore, the intention presently is to allow NSP's to develop the individual asset categories as they see fit for their network. However, all asset categories are given a one-to-one mapping to a set of asset groups, which are defined by the AER.

Generally, a NSP asset base may need to be split into between 50 to 100 categories. Although, some NSPs may consider that more or less categories are required to accurately model their network. The number of asset categories can be increased or decreased as necessary within the model, bearing in mind that there will be a practical limit to the number of categories that can be usefully analysed. Too few categories may make data so diffuse as to be meaningless whilst too many categories may result in excessive analysis for relatively little gain in precision.

In the future, the AER may consider standardising on a set of asset categories in order to improve its ability to benchmark between NSPs.

With regard to asset groups, those used for the Victorian distribution determination (shown above) may be a useful starting position for modelling a distribution NSPs.

These groups however can be customised by the AER if the need arises. This may be particularly relevant if the model is used for a transmission business.

4.2 Inputs and output

For each individual asset category, the following inputs are required:

Age profile	The age profile reflects the volume of the existing assets at the various ages within the asset category at a static point in time. It is essentially a vector that contains the volume of installed assets, where each element of the vector represents an installation date going backwards in time. The model allows the installation dates to go backwards up to 90 years from the current date of the age profile. For example, if the age profile reflects the asset base in 2009, the age profile can hold installation dates going back to 1919[5].
Mean life and standard deviation	These two parameters define the probability distribution of the replacement life for the asset category. Given a normal distribution is assumed, these two parameters are sufficient to completely define this distribution.
Unit replacement cost	This parameter defines the average unit cost to replace one unit within the asset category. This unit cost must reflect the volume unit used within the age profile.

The model takes these inputs and produces the following outputs for each asset categories:

5 If a NSP has assets older than this, then they could all be placed in the earliest installation date. If this would result in a material error then the model would need to be revised to allow earlier installation dates.

Age and asset value statistics and charts of the age profile	To aid in the appreciation of the asset base, the model provides summary information of the age profile. This is presented at the asset category and asset group level. This covers information such as total volumes and replacement costs, proportions of the total network, average ages and lives, and proportions of aged assets. The model also provides summary charts of the age profile, indicating the profile by installation date and remaining life. This type of information is helpful in rapidly understanding the nature of the asset base i.e. its age and make-up. This information is also helpful when making comparisons of replacement needs between NSPs. Importantly, this information only reflects the age profile as input to the model. It does not account for any forecasts that may be simulated by the model.
20-year replacement forecasts	Based upon the input data, the model produces year-by-year forecasts of asset replacement for the following 20 years. The forecasts prepared include individual asset category forecasts and aggregated asset group forecasts. The asset forecasts covers: - replacement volumes - replacement expenditure (which is calculated as volume x unit replacement cost) - average age - at the group level, the weighted average age is calculated - average remaining life - at the group level, the weighted average remaining life is calculated. When calculating weighted averages at the asset group level, the total replacement cost of the relevant asset category is used for the weighting.

4.2.1 Replacement algorithm

The model produces a replacement forecast for each asset category based upon a probabilistic replacement algorithm. The critical factor being simulated is the year-by-year replacement volume. Other forecasts indicated above, can be simply calculated via these forecasts volumes.

As discussed in section 3, the repex model assumes a normal distribution for the replacement life across the population. For each asset category, this probability function can be generated from the mean and standard deviation, which are provided as inputs for each asset category.

The following indicates how the model predicts the replacement needs of a specific asset category, using:

- the age profile for that asset category
- the mean and standard deviation for that asset category, whereby it is assumed that these reflect the "unconditional" probability density function (i.e. the probability

that an asset will be replaced at a specific age - assuming it has just been installed).

The important point in this process is that, given we have an age profile that reflects the ages of the assets at a specific point in time, we know that some assets already have survived to a given age. Therefore, the unconditional probability function needs to be transformed into a "conditional" probability function. This is a relatively trivial procedure, based upon standard probability theory.

For example, figure 4.1 depicts the "unconditional" probability density function for the replacement life of an asset type. This figure represents the probability that an asset will be replaced at a specific age, assuming the average replacement life for such an asset is 40 years.

Figure 4.1 Unconditional normal distribution of replacements

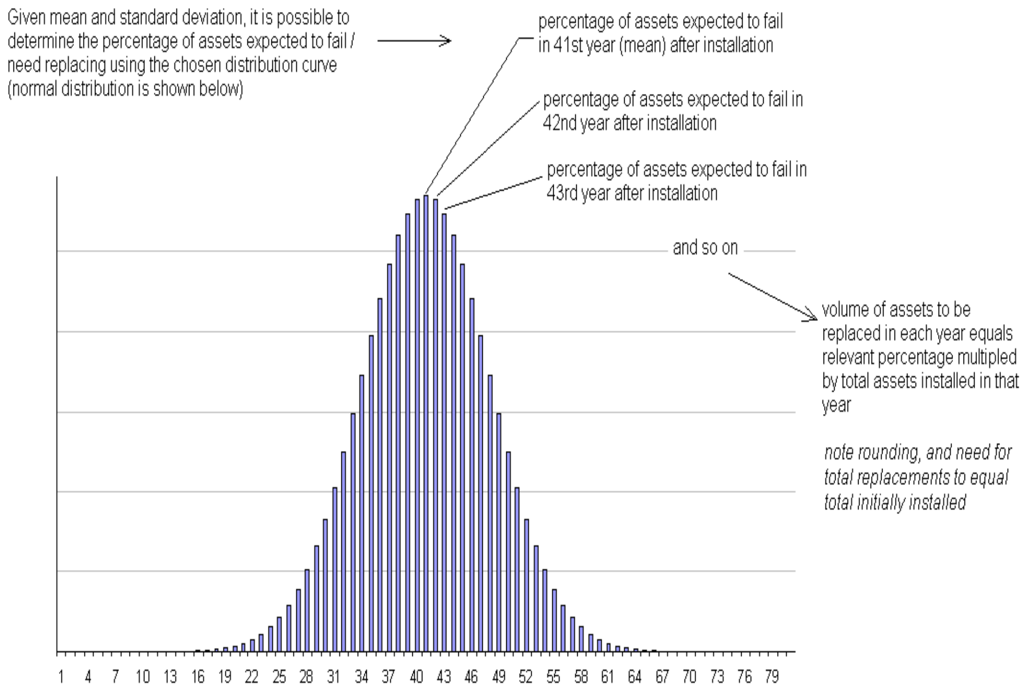
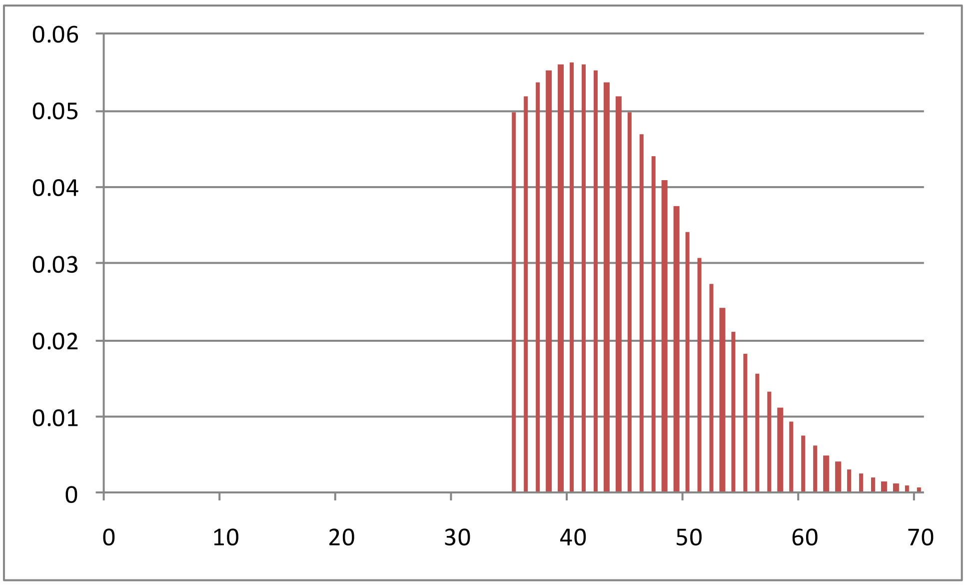


Figure 4.2 shows a condition probability function, derived from the unconditional function that reflects any assets that are currently 35 years old. Essentially for each age, such a conditional probability function is derived internally by the model.

Figure 4.2 Normal distribution of replacements, given 35 years old



To calculate to total forecast for each asset category, the model simply steps through each element in the age profile:

- preparing a conditional probability function from the unconditional parameters, that reflect the age of assets in that element of the age profile
- calculates the year-by-year forecast volume of assets to be replaced by multiplying the volume of assets in that element of the age profile by the appropriate probability taken from the conditional probability function.

The total year-by-year volume is simply the sum for each age profile element calculated as above. The replacement expenditure for the asset category is calculated simply as the asset volume multiplied by the unit replacement cost.

The replacement algorithm is written as a visual basic array formula within excel. As such, provided excel is set to have calculations automatically update, any alterations to inputs should be result in the output forecasts being automatically updated. The user is not required to run any macros.

A.1 Repex model reference manual

This Appendix provides a detailed reference to the repex model to support the descriptions in the main body of this handbook. This reference describes the contents of each sheet within the repex model. The purpose of this appendix is to provide more detailed information that may be relevant to users of the repex model.

In the descriptions below, *italics* indicates that these cells are input by the user.

It is important to note that care should be applied when using the model, as the input of erroneous data or altering the structure may result in unreliable results. This may not be easily identifiable from the model outputs.

A.2 Macros and setting up a model

When setting up a model of an NSP, the following process should be applied:

1. Set required initialisation data in Sheet: Tables (e.g. asset group names, age profile years, etc)
2. Input asset category data in Sheet: Asset data. Blank rows can be left between asset categories, to help with the visualisation. However:
    a. Asset categories should not be placed below the coloured table
    b. Rows (or columns) should not be inserted or deleted
3. The macro "initcalcs" should be run. This macro calculates the number of asset categories and automatically sets up other calculation sheets.

The model should now be able to produce replacement forecasts. Note however, if additional asset categories are added below the final asset category, then the macro "initcalcs" should be run once again.

A.3 Data Input sheets

4.2.2 Sheet name: Tables

This sheet holds the data that is required to initialise the repex model, as follows:

Asset group names	A2:B16	This table holds the names for each of the 15 asset groups in column B. These names generally represent asset classes, and can be input by the user. The ID in column A represents the number that is input into the appropriate cell in the "Asset data" sheet (see description below).
Now	B17	This parameters represent the year that the age profile represents i.e. the latest installation date in the age profile is this year.
Recursive	B18	If this parameter is set to 1, the model will perform a recursive calculation of replacement volumes i.e. forecast replacement volumes in one year will themselves be used to calculate replacement volumes in later years. This is the most accurate methodology.
1st year	B19	If this parameter is set to 1, the first year of the forecast is the year after "Now". If this parameter is set to zero, the first year of the forecast is "Now". Setting this parameter to zero may be necessary if the first year of the age profile ("Now") does not contain a significant level of asset i.e. it is not complete.
Profile Type	D1:D4	This table contain internal data. It does not need to be changed by the user.

A.3.1 Sheet name: Asset data

This sheet holds the input data that is required to represent the NSP's asset base (i.e. that discussed in section 4.2):

Meth all	D1	This parameter is used to define the replacement algorithm applied to generate a replacement forecast at a global level. 1 causes the model to replace all assets when they reach their mean life. 2 causes the model to replace all assets assuming a normal distribution - i.e. the methodology described in the main body of this report. 3 causes the model to replace each asset category based upon the methodology defined in Column I for that specific asset category.
Profile type	M1	This parameters represent the type of age profile being input in this sheet: 1 assumes the age profile is defined in terms of the remaining life 2 assumes the age profile is defined in terms of the age 3 assumes the age profile is defined in terms of the installation date
ID	A24:208	*This parameter is used to define the asset grouping for the asset category. The ID is the number of the asset group defined in the asset group table on the "Tables" sheet.*
Asset category	D24:D208	This is the name of the asset group linked to the ID in Column A. This is generated internally by the model.
Asset ID	E24:E208	This is the name of the asset category - any name can be chosen by the user.
Unit cost	F24:F208	This is the replacement unit cost for the asset category in $('000).
Replacement life	G24:H208	This is the replacement life for the asset category. Column G holds the mean life and Column H holds the standard deviation.
Replacement method	I24:I208	This parameter is used to define the replacement algorithm applied to generate a replacement forecast at the asset category level. 1 causes the model to replace all assets when they reach their mean life. 2 causes the model to replace all assets assuming a normal distribution - i.e. the methodology described in the main body of this report.
Age profile - quantities	J24:CV208	This holds the age profile for each asset category, in terms of asset volume.
Age profile - replacement cost	CX24:GJ208	This holds the age profile for each asset category, in terms of its replacement cost. This is calculated internally based upon the volume age profile and the replacement unit cost.

A.4 Output sheets

A.4.1 Sheet name: Age profile summary

This sheet provides a summary of the age profile. Rows 6:20 provide summary results at the asset group level. Rows 24:208 provide similar results at the individual asset category level.

Quantity	Column F	The total quantity of asset within the asset group or asset category.
Unit cost	Column G	The unit cost of the asset category - transferred directly from the "Asset data" sheet.
RC $ millions	Column H	The total replacement cost of the asset group or asset category.
Prop total	Column I	The proportion as a percentage (calculated by total replacement cost) of that asset group or asset category to the total replacement cost of the network.
Rank total	Column J	The ranking of that asset group or asset category (by total replacement cost) compared to other asset groups or categories i.e. a ranking of 1 will have the greatest total replacement cost.
Prop cat	Column K	The proportion as a percentage (calculated by total replacement cost) of that asset category to the total replacement cost of the associated asset group.
WARL	Column M	The weighted average remaining life of the asset group or category, using the total replacement cost as the weighting.
WAL	Column O	The weighted average life of the asset group or category, using the total replacement cost as the weighting
WAA	Column Q	The weighted average age (as a percentage of the life) of the asset group or category, using the total replacement cost as the weighting.
RC of aged assets	Columns W:AA	The proportion of assets (by replacement cost) in 5 bands of age.
Proportion of aged assets	Columns W:AA	The proportion of assets (by percentage) in 5 bands of age.
Aged asset bands	W4:Z4	*The parameters used to define the age bands for the above two outputs. These are defined as a proportion of the life.*
Asset group life ranges	AG6:AI20	The range of lives in an asset group: Maximum - column AG Minimum - column AH Average - column AI

A.4.2 Sheet name: RRR hist-forc

This sheet provides the results of the replacement forecast. Rows 6:20 provide summary results at the asset group level. Rows 24:208 provide similar results at the individual asset category level.

Replacement expenditure forecast	Columns AY:	Provides the year-by-year forecast over a 20 year period of replacement expenditure ($'000). Row 22 shows the total expenditure as a percentage of the total replacement cost of the network.
Weighted average age	Columns BS:CM	Provides the year-by-year forecast over a 20 year period of weighted average age. Row 23 shows the weighted average age of the whole network as a percentage of the weighted average life of the whole network.
Weighted average remaining life	Columns CN:DH	Provides the year-by-year forecast over a 20 year period of weighted average remaining life. Row 23 shows the weighted average remaining life of the whole network as a percentage of the weighted average life of the whole network.
Replacement quantity forecast	Columns AY:	Provides the year-by-year forecast over a 20 year period of the replacement volumes.

A.5 Chart sheets

A.5.1 Chart sheet name: age profile chart

This chart sheet provides two charts of the age profile:

- The age profile at the asset group level, showing the total replacement cost ($'000) by installation date.
- The age profile at the asset group level, showing the total replacement cost ($'000) by remaining life.

A.5.2 Chart sheet name: Forecast Ch1

This chart sheet provides two charts of the replacement forecast:

- The stacked bar chart at the asset group level, showing the year-by-year replacement expenditure forecast ($ millions).
- An z-y plot at the asset group level, showing the forecast weighted average age for each asset group and the weighted average age of the total network as a percentage of the weighted average life of the network.

A.5.3 Chart sheet name: Forecast Ch2

This chart sheet provides one chart of the replacement expenditure forecast, represented as a 3-dimensional chart showing the expenditure forecast for each asset group.

A.6 Internal sheets

The model also includes three other sheets that are used for internal purposes i.e. producing charts and aiding with the calculations. These sheets are called:

- Age profile (Inst)
- Age profile (RL)
- Age profile (years)

These three sheets have the same structure, and as the names suggest, are used to hold different representations of the age profile. The user should not need to interact with these sheets and as such they are not described in detail here.