Producing Robust Forecasts of Replacement Expenditure – Overhead Line Pole Assets

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This paper examines the use of asset survivor curves for improving replacement expenditure forecasts for Powerco's overhead line pole assets.

The concept of age profiles and their use in extrapolating future replacement expenditure using standard asset average lives is common place. However this method is considered insufficient in producing robust forecasts of a type required for business planning. Age profiles using standard average asset lives give only an indication of the scale of possible replacement expenditure.

This paper explores the use of asset survivor curves for predicting end of physical life and presents a systematic method for developing these using available data. The focus of this paper is on overhead line pole assets and uses hardwood poles as an example. The methodology is then applied to all main pole types on Powerco's network to develop a robust population forecast for end of physical life to be used in determining forecast replacement expenditure.

Background

Powerco is undertaking an Asset Management Maturity (AMM) Programme to improve asset management practices. The AMM requires preparation of robust asset life-cycle plans and the plan for overhead lines is critical since overhead lines represent the greatest impact on network reliability performance, perhaps the greatest cumulative risk levels and the highest level of capital expenditure requirements.

Powerco faces many challenges from its aging asset stock and principally from the large levels of construction that took place in the 1960's that have been reaching the end of their physical life.

One of the principle requirements for developing asset specific life-cycle plans is to produce robust forward forecasts of replacement capital expenditure requirements. Age profiles have typically been used with the application of some arbitrary asset standard life (typically ODV Handbook lives are used). It is generally accepted that these only provide an indication of the scale of the requirements[1].

Powerco has been correcting and populating its asset information following years of mergers and acquisitions. Powerco has been undertaking systematic overhead line inspections and collecting condition and defect data since 2005 and more fully computerised since mid-2009. The computerised data can now be linked to other key asset information to enable more sophisticated asset analysis.

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[1] "Valuation Issues and the Impact on Asset Management" by Wilson and Clifton presented originally at a conference on Best Practice Asset Management for Utilities held in Wellington, New Zealand on 30-31 October 1997

Reasons for Pole Replacement

It is important to make the distinction between pole service life and pole physical life. The service life is when it is retired i.e. when it is no longer used and is removed and disposed. The physical life is based on its condition and where it is deemed to be no longer fit for continued service.

There is often general confusion outside of the organisation as to why a pole is sometimes retired when it still has some remaining physical life. With the exception of forced retirement due to faults / failures, retirements are by decision of management. In most cases, a subjective decision is made to retire a pole from useful service. The following table outlines the typical reasons for pole replacement:

Increasing Individual Pole Replacement Cost	**Faults** (Reactive Replacements)	**Foreign Interference Vehicles vs poles**	Most noticeable in Tauranga and Te Puke.	Little control on this aspect.
		Vegetation (trees)	Trees / branches within and outside corridor can cause failures.	High control by level of vegetation management.
		Wind	Things generally don't fail without a bit of wind. Wind tests the network.	Partially within Powerco's control by the regular maintenance and attention to defects.
		Storms	Storms clear out the defects that haven't been actioned. It cleanses the network but at a risk and cost of wide spread damage and delays to getting the lights back on during and following a storm.	Partially within Powerco's control by the attention to defects.
	Actual **Planned** Pole Replacements based on identified defects / condition data caused by physical decrepitude of the pole.	Red Defects (Actioned <3 months)	Actioned on a fairly consistent and immediate nature.	High level of control.
		Amber Defects (Actioned <12 months)	Only partially actioned due to limited capital resources.	High level of control. Inattention just leads to failures and reactive renewals.
		Green Defects (Actioned <5 years)	Only partially actioned due to limited capital resources.	High level of control. Inattention just leads to failures and reactive renewals.
	A **secondary effect** due to **conductor replacement programs**.	Up to 60% of the overhead line poles can require replacement when the line is reconducted on engineering grounds to meet current minimum conductor sizes or due to current construction standards.	Conductor failures have a large and increasing impact on Powerco's network reliability performance. Replacement programs are large and expensive. Unfortunately old small conductor can't be and shouldn't be replaced like for like. This together with the latest construction standards means many poles have to be replaced at the same time to meet the mechanical / structural engineering requirements.	Little or no control. Poles effectively retired due to inadequacy or insufficient capacity i.e. for reasons other than physical decrepitude.
	Overhead line upgrades to meet **growth** in demand or where construction based on historical standards is no longer acceptable.	As above.	Historically mainly limited to main trunks / backbones but will increasingly occur on spurs.	

Table 1 Typical Reasons for Pole Replacement

Powerco classifies its defects in accordance with a traffic light system, red for critical, amber for urgent and green pending (see Table 1). Red defects are required to be actioned within 3 months, amber within 12 months and green within 5years. This system is purely a planning and initial risk management tool but, if followed, ensures defects are actioned before the next planning cycle.

An analysis of asset disposals provides information on service life, but not physical life unless detailed information is retained on reasons for pole disposals. This information has only been started to be collected since around August 2010 in any appreciable detail. Basic asset disposal data from Powerco's accounting (JDE) system shows the following historical pole disposals based on all the reasons of pole replacement as shown in the table above.

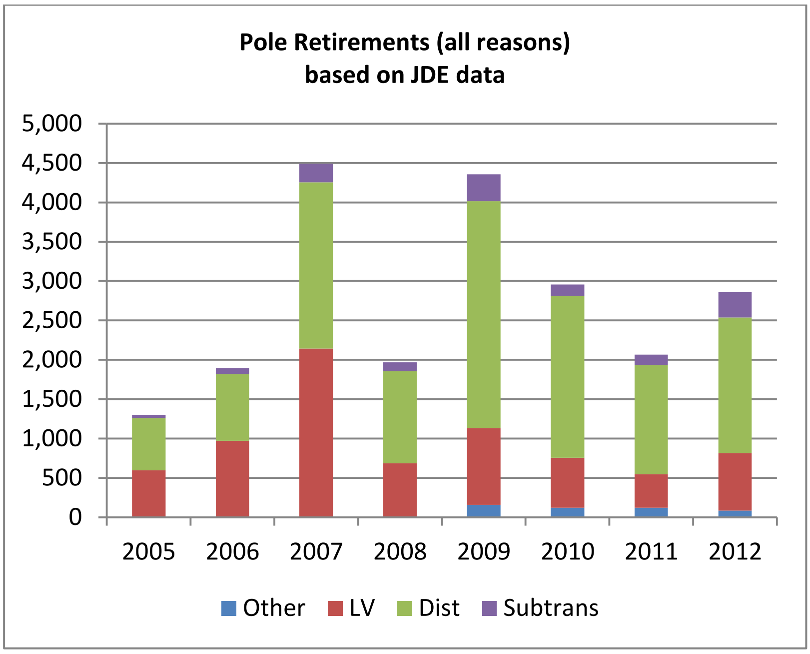

Figure 1 Pole retirements (disposals) by voltage class

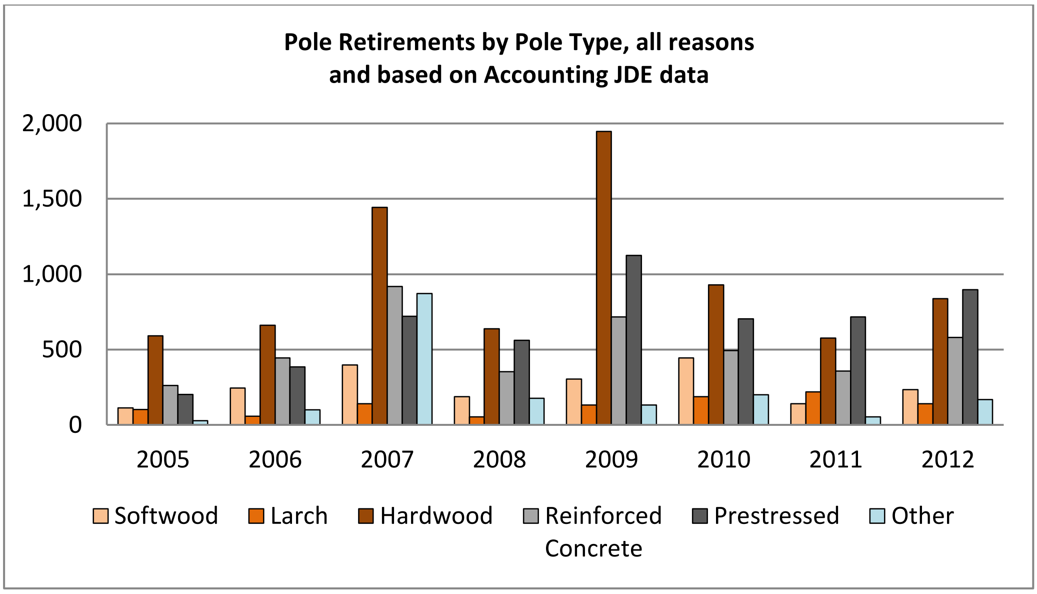

Figure 2 Pole retirements by pole type

Pole defects and condition data

Powerco conducts regular inspections of its pole assets, 5-yearly for distribution and LV poles and 2.5-yearly for sub transmission poles. Inspection data has been computerised since around 2005 but more fully since mid-2009. Total poles owned and inspected as at August 2013 are shown in the following table (the figures only account for the last inspection of a particular pole).

Pole Type	Total in service poles owned by Powerco or with ownership blank or unknown.	Poles Inspected as at Aug 2013		Total Defects or poles marked for retirement for % inspected		Prorated Defect Numbers for 100% inspections
		Qty	%	Qty	%	
Reinforced Concrete	80,338	70,838	88%	2,030	3%	2,302
Hardwood	12,784	8,277	65%	3,481	42%	5,377
Prestressed	133,849	98,791	74%	795	1%	1,077
Softwood	22,740	15,931	70%	478	3%	682
Steel	594	138	23%	56	41%	241
Larch	9,084	6,723	74%	2,908	43%	3,929
Other or unknown	5,458	353	6%	4	1%	62
Grant Total	264,847	201,051	76%	9,752	5%	12,847
Data based on poles in service as at Aug 2013 (i.e. excludes any disposed poles)						

Table 2 Basic statistics on pole populations, inspections and defects

Note that in Powerco's case, Larch refers to a grouping of species with durability in between softwood and hardwood.

The key points from the table above are:

- As at Aug 2013, 76% of the pole assets had been inspected.
- Of those inspected, reinforced concrete and pre-stressed concrete show defect levels that would commonly be expected.
- Although wood pole total numbers are small relative to concrete, they nevertheless show high defect levels with hardwoods at 42% and larch at 43%.

Although Powerco has yet to complete a full inspection cycle electronically, there is sufficient data to analyse and provide sound models.

This paper focuses on hardwood poles as an example because although the number of these poles is low in comparison to some other types, the number of defects is significant. There is also more experience given that these poles have been installed and used since the early 1900's (although few of the early poles remain and any significant populations remaining occur from around 1940).

The following figure shows the age distribution of inspected hardwood poles.

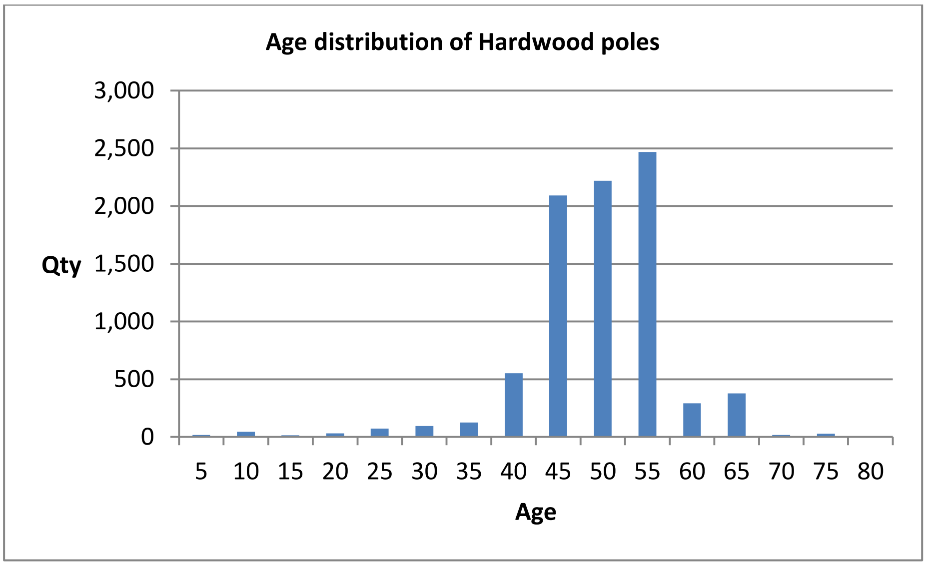

Figure 3 Age distribution for Powerco's hardwood poles inspected up to Aug 2013

The distribution is very steep and focused around a 15 year age period with very high installation levels having occurred around the late 1950's and 1960's. This steep age profile is one of the reasons why there are currently so many defective hardwood poles.

Pole condition assessments are based on a variety of tests, depending on pole type and provide a coarse scale for each test. A scoring system has been developed using the individual pole tests to provide an overall condition score. The range of tests undertaken for wood poles includes:

- Visual condition
- Observed decay
- Internal decay (sounding)
- Longitudinal splitting
- Ground line splitting
- Splitting at pole head
- Extent of sapwood decay
- Rotten knots
- Insect attack

The distribution of condition scores for these hardwood poles is shown in the following figure as a percentage of the poles in any given 5 year age bracket. It is necessary to develop the distribution this way in order to remove bias from different historical investment concentrations. Note the distribution is only shown up to 65yrs to avoid small numbers of remaining poles over 70 yrs from skewing the results in this particular figure.

			Condition of Inspected Hardwood Poles - Cummulative % of age bracket starting worst to best condition (based on 4yrs of inspection data mid 2009-mid2013)												
			Age Bracket												
Condition Level		Total	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	60 - 65
Very Poor	13	27%	Potential Amber Defects						0.8		0.1	0.1	0.0	0.3	0.3
	12								0.8		0.4	0.4	0.2	0.3	0.3
	11								3.2	0.2	0.8	0.6	0.4	1.0	0.8
	10								3.2	0.5	1.9	1.8	0.9	1.0	2.4
	9							1.1	3.2	0.9	2.7	2.3	1.7	1.4	3.2
	8							2.2	3.2	2.0	4.6	4.4	2.9	2.4	6.6
	7							2.2	5.6	3.4	7.5	8.6	7.2	6.2	6.6
	6					6.7	4.2	4.3	10.5	7.1	16.8	16.2	13.0	13.1	9.8
Poor	5					16.7	8.3	6.5	15.3	10.7	22.6	24.9	20.1	18.6	15.6
	4					16.7	20.8	7.5	21.0	18.5	28.6	32.1	26.1	24.8	21.0
	3	29%	Potential Green Defects		6.7	26.7	20.8	17.2	37.9	26.1	46.7	44.4	40.9	37.9	31.6
	2				26.7	33.3	37.5	36.6	57.3	47.3	64.3	59.8	54.2	52.8	43.0
Good	1	44%			100.0	36.7	41.7	44.1	60.5	50.5	67.8	61.7	58.0	59.3	47.7
	0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Figure 4 Condition summary of Powerco's hardwood poles by 5 year age group

The figure above shows the bands of condition which approximate either a green or amber defect, these bands being a preliminary risk management tool. The tests and scores favour a larger range in the defect area than the non-defect area but the later could be extended by using scores to 1 decimal place from 0 to 2.

The figure shows the following key points:

- The condition data shows the highest amber level 4 defect percentages at around 45-50 years.
- The percentage of hardwood poles in very poor condition is very high. This is perhaps tempered by the fact that we have relatively low numbers of hardwood poles that still remain in service.
- The figure clearly shows the increasing percentage of defects in a given band the higher the age bracket but it also shows that percentages fall after hitting a peak at the 45 – 50 yr age bracket. In other words this follows the typical survivor curve an experienced engineer would expect from such assets.

The condition scoring results shown above closely matches the level of defects identified (to be expected). Since identification of a defect is simply marking an asset for retirement, the defect information can be used as a surrogate for asset retirement. This therefore removes the bias from any potentially low historical replacement programs (if they exist) when using just asset disposals.

The Concept of Survivor Curves

Survivor curves are not new. They have been around for some 250 years in the life insurance industry and in relation to physical properties, since the early 20th century. The most widely recognised curves relating to physical assets are the Iowa curves developed by Kurtz in the 1930's and subsequently documented in the widely referenced Bulletin 125 (1967) of the Engineering Research Institute at Iowa State University: "Statistical Analyses of Industrial Property Retirements".

The use of basic standard lives has traditionally been the only choice for the distribution industry due to the lack of historical records or attempts to record such data for use in an organisation. Physical decrepitude of assets is influenced by specific asset types, location and environments which can all differ between organisations. In addition there may be differences in definition of pole types and classifications eg pole species classed as softwood, larch or hardwood pole types. There is a range of durability in each class. It is important to recognise that survivor curves for one organisation may only bear slight relevance to another. The application of survival curves (life distribution) provides a superior forecast estimate because it applies known survivor statistics and retirement frequencies by age to the problem rather than just a single figure. The concept of a survival curve recognises that in the real world, some assets can have shorter lives than the average life and others can have longer lives either due to an inherent durability of a specific asset or due to a specific locational factor.

There are multiple methods for determining survivor curves. This paper does not debate one method over another but rather uses the tried and proven Retirement Rate Method (a life table method) given in the text “Engineering Valuation and Depreciation” by Marston, Winfrey and Hempstead, seventh printing edition 1976. The position taken here is to use a tried and proven technique with as large a dataset as possible (using both in-service and retirement asset data).

There are traps with using survivor curves but these mainly relate to those who use the Iowa-curve methodology (ICM) when available data on retirements extend only a fraction of the life of the property[2]. Other instances involve the use of other asset types to emulate survivor statistics of the asset type in question. These methods are not employed in this paper.

Data and Methods Used

The survivor curves in this paper use actual asset retirement data (disposals) and assets marked for retirement (defects is the term used by Powerco) that goes beyond the average service life and the average physical life (true in the case of wood poles and a stretch in the case of concrete poles). Pole asset disposal data was sourced from the JDE accounting system with data available from 2005 to Aug 2013. Asset defect data was sourced from Powerco’s GEM asset management system.

There are traps with using this data (no data is perfect). Firstly an asset disposal (what is actually retired) is influenced by:

a) The managerial decision to replace a pole before the end of this physical life for whatever valid reason. Asset disposals therefore do not necessarily reflect physical life. This is not necessarily a problem provided one is only interested in Service Life.
b) Capital constraints (if they exist in an organisation) which may or may not artificially extend service lives with the commensurate increase in risk levels. This can be a valid management decision.

Secondly, the point in time when assets are marked for retirement (defects), while reflecting end of physical life, does not necessarily reflect end of their service life since there may be delays between identification of defects and action of those defects. These delays can relate to valid risk management approaches to asset replacement.

Three systematic methods for calculating asset survivor curves are discussed by Marston, Winfrey and Hempstead:

- Original Group Method (data of one vintage installation)
- Individual Unit Method (uses only data of retired assets)

[2] “A Bear Trap in Using the Iowa-Curve Methodology for Property Retirements and Depreciation Charges” Eming, W. and Singpurwalla, published in The American Statistician, Feb 1989, Vol 43, No,1.

- Retirement Rate Method (uses data of assets recently in service and recently retired)

This paper uses the third method, the Retirement Rate Method which is described as the best since it is based on the collection and compilation of all assets in service over a period of time, both assets retired and those remaining in service. We also show results using the Individual Unit Method on defects for comparison but note that authors describe this as an inferior method. Unabridged asset disposal data (derived from Powerco's JDE accounting system) is used with GIS asset data to derive assets in service each year over a period of experience, in our case 2005 to 2013. Asset retirements are in our case based on defects which are a proxy for assets marked for retirement and based simply on condition as determined over the same period of experience. No methodology is perfect and fault can possibly be found with all, however, the reader should be mindful that the objective is to improve on just using age profiles and standard lives.

The following figure shows the results of the analysis for the hardwood pole example. The figure is busy and requires explanation.

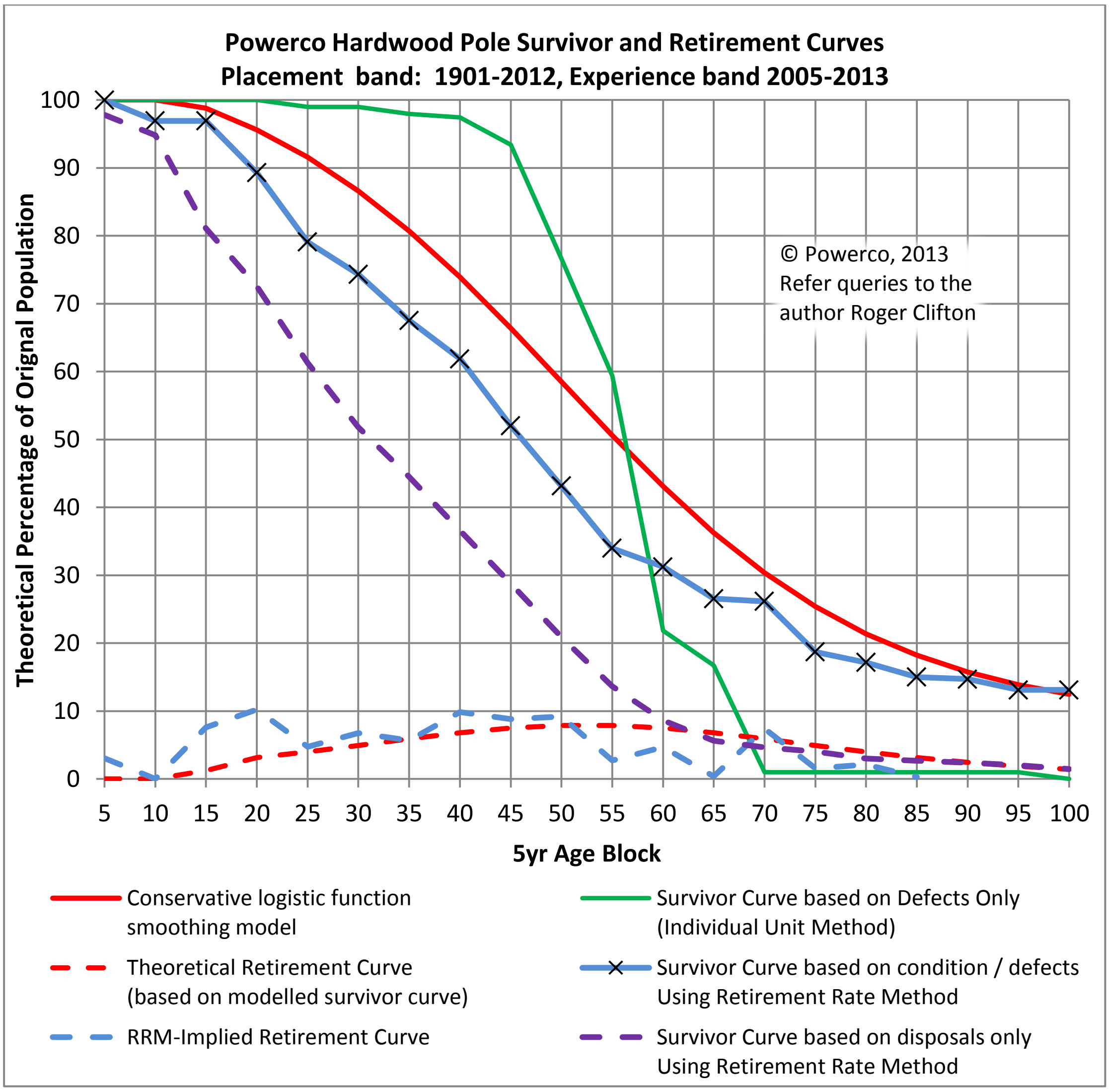

Figure 5 Survivor curve estimation of Powerco's hardwood poles

The blue lines represent the results of the analysis using the Retirement Rate Method for an asset placement band of 1901 to 2012 (ie period over which the assets are installed) and an experience band of 2005 to 2013 (i.e. the period over which we have electronic inspection records). Note that the analysis uses unabridged data and the data points shown are just those at 5 year intervals.

The red line represents the conservative and smoothed survivor curve that has been modelled purposely to the right of observations. The modelled survivor curve is a modified logistic function and is purposely modelled here to the right of the survivor curve by approximately 5 years which is slightly higher than the typical delay between identification of defects and their attention.

Conservative Survivor Curve model for Powerco Hardwood Poles in summary form only:

Equation 1: $$\min\{100, 100 * \left(1 - \frac{1}{1+(0.47e)^{(13-0.26x)}}\right) + 8.5\}$$

Where x is the age in a 5 year age block

Note, the authors are not prescribing strict use of this function or getting into debate about the most appropriate function to use. The exact form of the function is irrelevant provided it approximates the observations, enables smoothing and can be used for the intended purpose which in this case is to assist in making estimates of future replacement capital expenditures.

The green line represents an estimated survivor curve derived using the inferior Individual Unit Method and using defect identifications only. In addition to the inferior method used for this curve, the curve is biased by potential inadequate historical asset replacement levels and inadequate historical inspection levels[3].
The dashed purple line uses the Retirement Rate Method but is based only on disposed poles. Note that the disposed poles are for all reasons of replacement and so does not relate to the attention to defects alone. This curve shows earlier retirements caused by other reasons of replacement and is more an estimate of service life rather than physical life.

Implied Average Lives

The average life of the pole is given by:

Equation 2: $$average\ life = \frac{\Sigma(Nxf)}{\Sigma(f)},\ where\ N = age\ at\ retirement\ and\ f = number\ retired\ at\ that\ age.$$

The survivor curves based on the Individual Unit Method using defect levels and the more correct survivor curve modelled using the Retirement Rate Method both give an average physical life estimate of 50 years. Average lives implied by each of condition level 2 and 3 both give similar physical life estimates.

Average Physical Life = 50 years for Hardwood Poles <u>remaining</u> at 2005

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[3] Asset inspections in the past (pre 2005) were not computerised as they are now and may not have been undertaken systematically in the past as they are now. There were periods of mergers and acquisitions up to 2005 with the common resulting issues related to asset dataset integration and issues of missing asset data.

The average service life[4] is also 50 years (in this particular instance) and is based on disposals (poles retired for all reasons) with an age distribution as shown in the following figure.

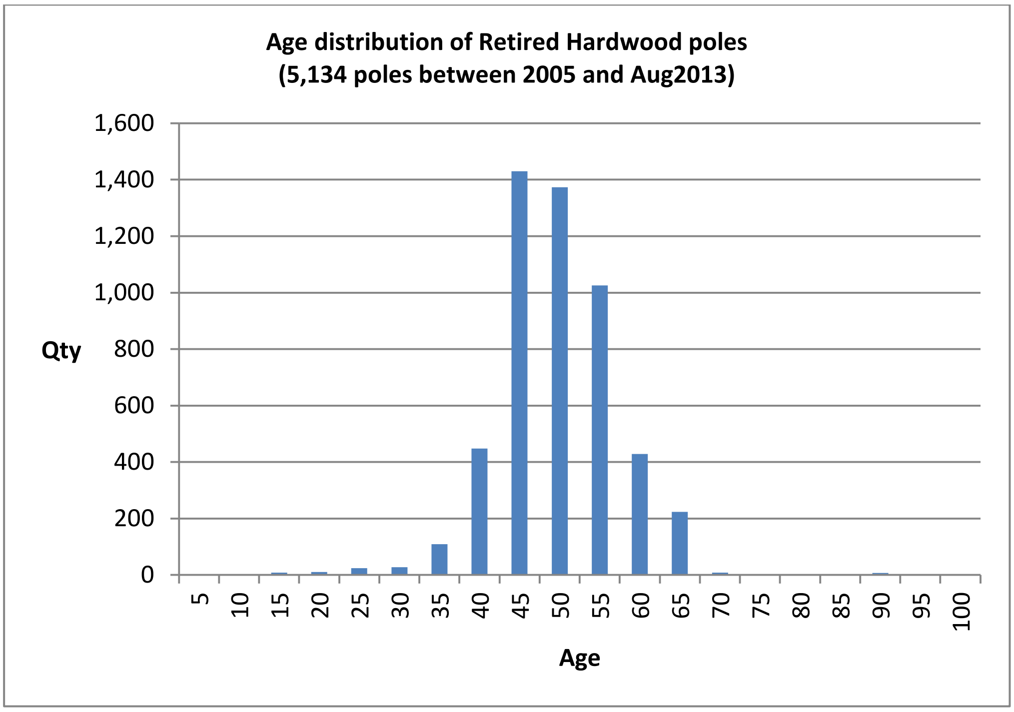

Figure 6 Age distribution of Powerco's retired (disposed) hardwood poles

One of the most surprising aspects of this work was the lower than expected average physical life for hardwood poles at around 50 years. It is perhaps that as engineers we are influenced by the older longer surviving part of the hardwood pole population. In addition, the hardwood pole class includes many timber species with different durability classes and there is also likely to be some minor errors in type classification of some wood poles. Work by Spencer and Elder in their paper "Pole Service life – An Analysis of Country Energy Data" shows similar results for all-timber with survival curves showing 50% survival at around 50 years for all-timber and higher for specific hardwoods such as ironbark (to be expected).

Those results are based on poles located around in-land NSW, Australia. There are obvious differences between these areas and those in New Zealand where Powerco's poles are located.

Using Survivor curves to forecast expected defect levels and expenditure

One of key uses of these survivor curves is in forecasting expected future defect levels and therefore pole replacement requirements based on physical condition. The following figure shows the current and expected future age distribution of surviving hardwood poles in 5 yearly time periods using the developed survivor curves.

[4] Note that average service can be different to average physical life since there are multiple reasons for replacing poles, not just solely based on age and condition.

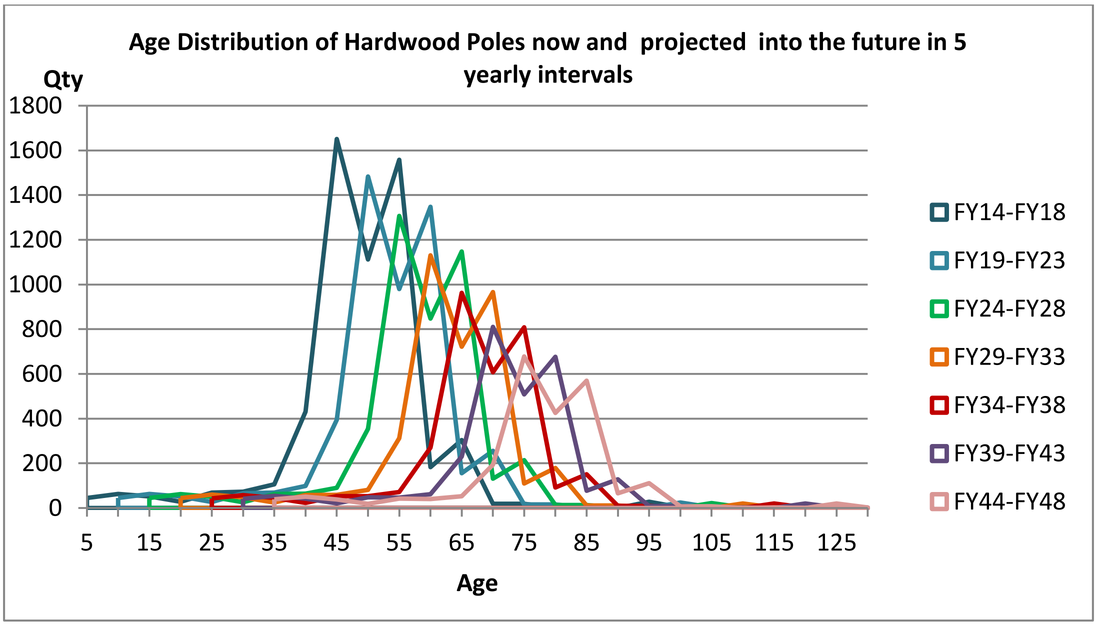

Figure 7: Forecast movements in hardwood pole age distributions using derived Survivor Curve

Pole replacements related to line upgrades (growth) and conductor replacement programs are within Powerco's control. The level of future defects requiring replacement have to-date been uncertain. Replacements using a standard life provide some indication of scale but the use of survivor curves provide a sound basis for estimation.

The following figure shows the pole defects expected (average over 5year blocks) and can be compared to the estimates using a standard life as used by many in the industry. The figures take account of the fact that only 65% of hardwood poles have been inspected. The defect figures have been factored up on the assumption that defect percentages remain the same when 100% of hardwood poles are inspected. This assumption while not ideal is considered acceptable in the circumstances.

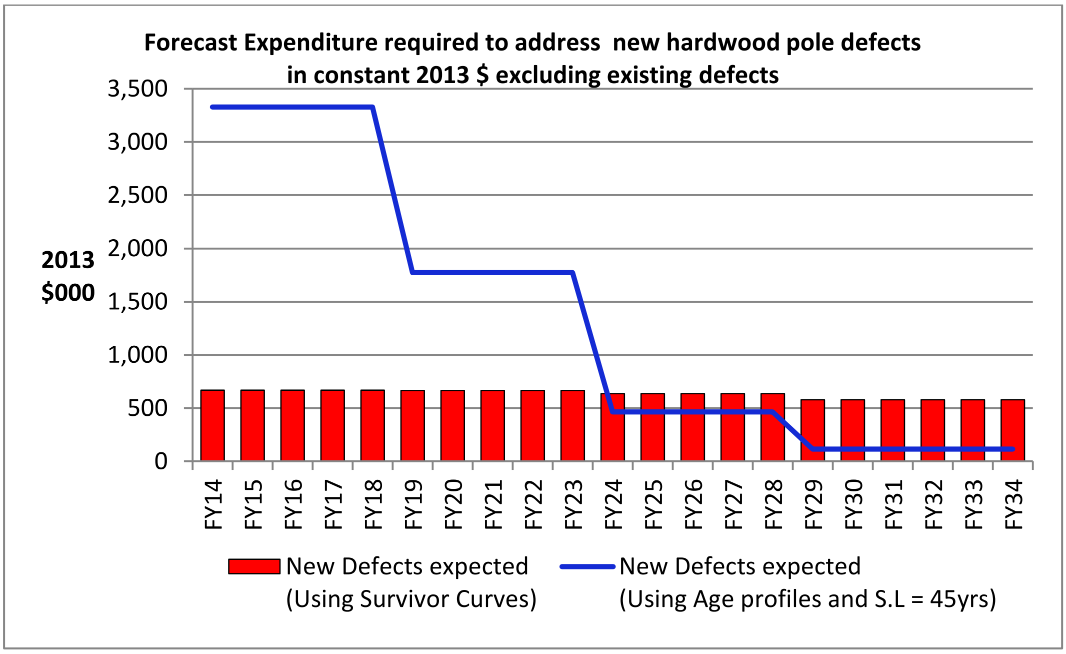

Figure 8: Example replacement capital cost forecasts using survivor curves (red) c.f. age profiles and a standard life (blue)

The figure above shows the required capital needed to address new defects expected in the future. The use of survivor curves to estimate capital requirements (red bars) is considerably smoother than that derived from an age profile and standard life. The use of age profiles and a standard life leads to an under-estimation of capital requirements at ages less than the standard life and over-estimation of capital requirements at ages greater the standard Life.

Applying the methodology to the main pole types

Powerco's pole installation distribution for the main pole types (poles currently in service) is shown in the following figure.

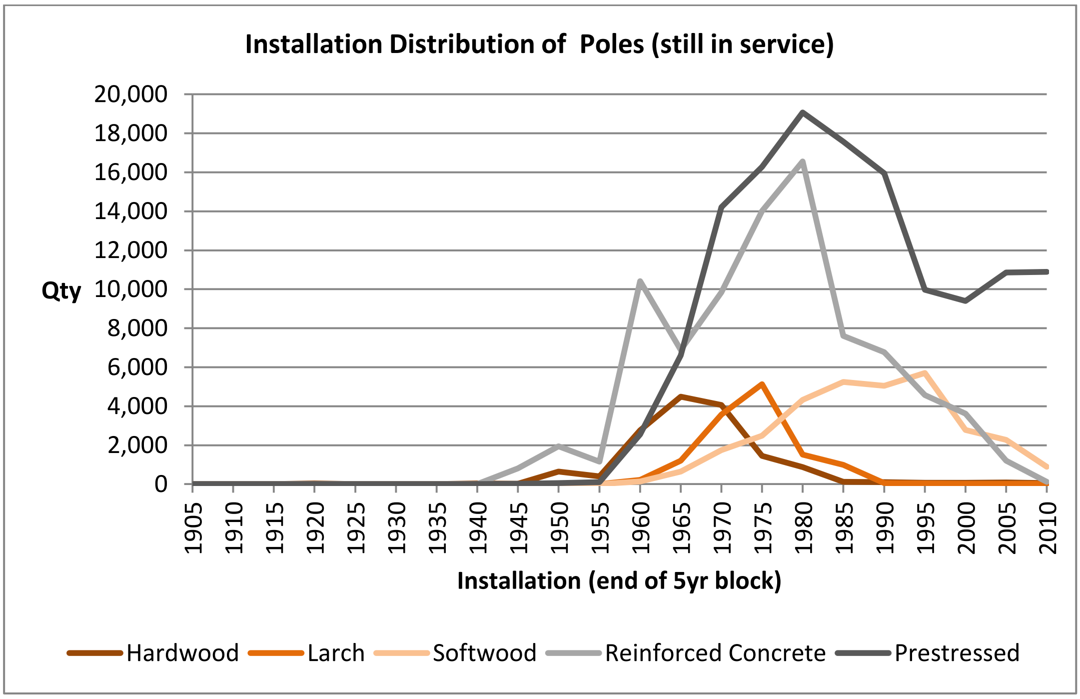

Figure 9: Pole Installation Distribution

The figure above shows:

- Powerco stopped installing hardwoods on any appreciable scale around 1985 and for Larch around 1990.
- Softwoods are installed in increasingly lower numbers as are reinforced concrete poles.
- Pre-stressed concrete poles are the predominant pole type installed today.

The same methodology used to derive the survivor curve for hardwood poles has been applied to the other pole type groups:

- the main wood pole groups
  - Softwood poles
  - Larch poles
  - Hardwood Poles
- The main concrete pole groups
  - Reinforced concrete
  - Pre-stressed concrete poles.

Obviously it would be better to separate out poles by timber species and concrete poles by manufacturer but reliable data for this is simply not available.

The results are shown in the following figure together with reinforced concrete poles split between those in the Egmont area and those not. This is shown as an example of what may be achieved to identify specific location issues. Egmont was chosen since it has a high percentage of reinforced pole defects and shows susceptibility of poles to on-shore salt air conditions (a particular problem in this area).

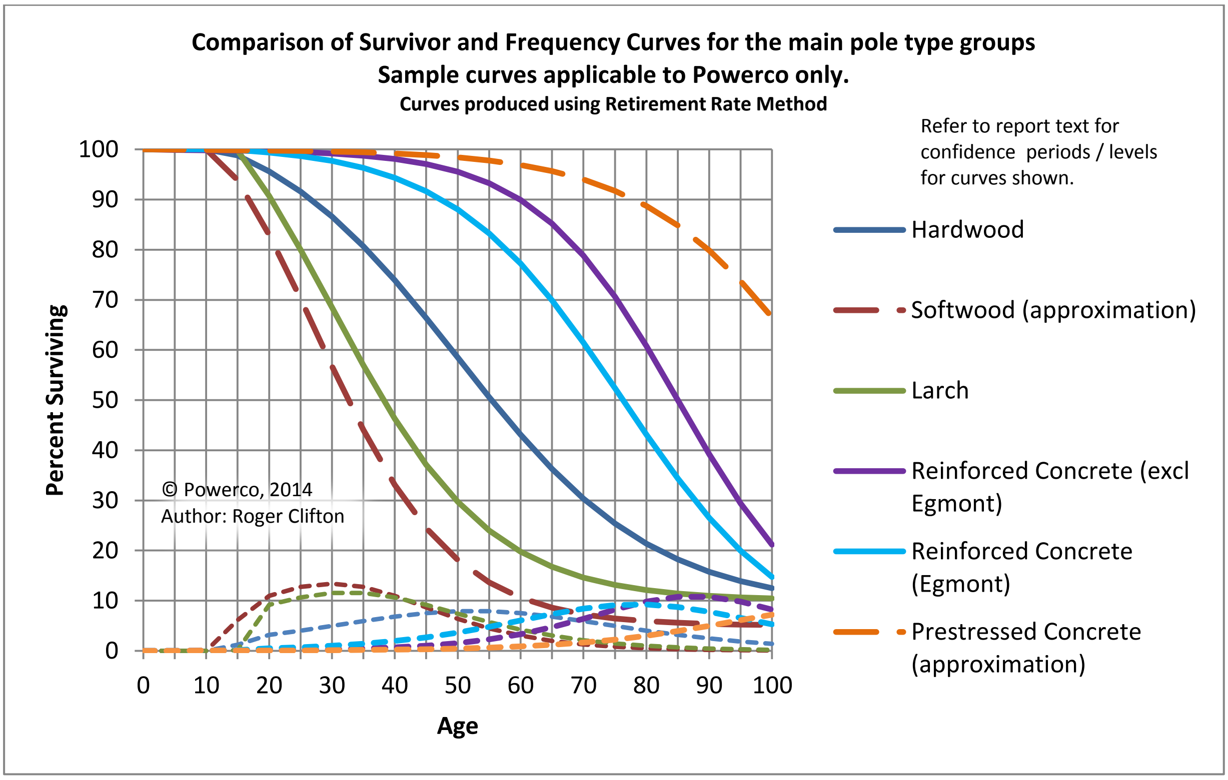

Figure 10: Comparison of Survivor Curves for Powerco's main pole types derived using the Retirement Rate Method

The reliability of the curves are based on the age distribution (numbers of poles at the extremities) as at 2005, the start of the "Experience Period". The Survivor curves produced here can be considered to be fairly reliable up until the following ages:

- Hardwood, 100 years
- Larch, 65 years
- Softwood, 50 years
- All Concrete types, 75 years.

Projections along the survivor curves past the periods indicated above are based on subjective and conservative opinion / model. However the net affect past these periods is fairly negligible in the short to medium term and Powerco is likely to have a larger and extended dataset within the next decade by the time it is material.

Expect within the next decade; a confirmation and refinement of retirement rates of softwood poles and improved concrete pole survivor curves.

The following figure shows the application of the survivor curves to produce projection estimates of new pole defects. A curve (blue line) is also included to show what the projections look like if one uses age profiles and standard lives. The standard lives used are those given in the 2004 ODV Handbook; 45yrs for wood and 60yrs for concrete.

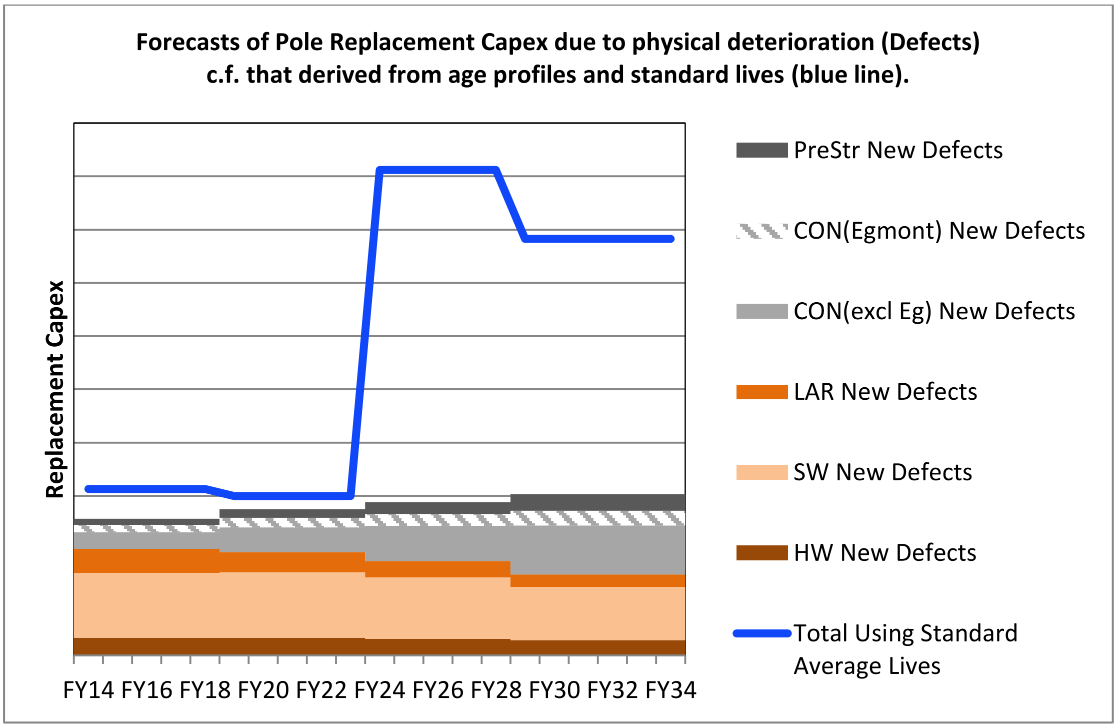

Figure 11: Projections of new defects expected based on derived Survivor Curves together with comparison to that derived from age profiles and standard lives

The projections (based on Survivor Curves) show:

- Powerco appears to have moved past the worst of the high defect rates for wood poles with future annual new defects levels dropping for these poles, albeit slowly.
- Expect concrete pole defects to gradually rise simply due to the large numbers of concrete and pre-stressed concrete poles installed.

Note that the use of standard lives, at this stage for Powerco, would give rise to a slight net over-estimation of pole replacement capex in the short term and significant over-estimation over the longer term. This would be the case whether one used some rolling average or just the average of 5-year blocks as shown above.

Summary

This paper attempts to provide an improved methodology for the derivation of replacement capex for end of physical life pole components of overhead lines. The methodology employed can be employed for other assets where there is sufficient data available.
The paper attempts to show the benefit of using Survivor curves and finds that this reduces the future estimates of capital requirements for poles (at this point in time for Powerco) as compared to similar estimates using age profiles and standard lives.

The use of survivor curves provides an improved estimate of future defect levels and enables better estimates of the replacement capex associated with pole defects.

- The current high level of pole defects is made up mostly of wood poles and we can reasonably expect annual new wood pole defects numbers to decrease gradually over time.

- Concrete pole defects are likely to increase simply due to the large numbers of these pole assets and expect survivor curves to be improved over the next decade for these assets as the “experience period” is extended.

Bio notes:

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Karen is a chartered electrical engineer and senior manager at Powerco, currently working in the asset management planning and strategy team of the electricity business.
As Powerco’s asset management maturity manager, she is responsible for delivering Powerco’s asset management continuous improvement programme.

Roger Clifton
Roger Clifton has over 25 years’ experience in the electric power industry. Qualified in electrical engineering and commerce, he provides advice and support, to Powerco in all areas of Asset Management including risk management, analysis and forecasting.