

# REPAIR / REPLACE DECISION MAKING PRACTICES

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**Summary:** In a large asset organisation the renewal of assets forms a significant portion of the ongoing annual capital works programme. Over recent years there has been an increasing focus by the energy regulators on evidence of prudent expenditure. The development of tools and processes that provide this objective evidence has become essential for the support of modern asset management practices. The approach taken by EnergyAustralia has been to develop concepts presented at past ICOMS conferences into a working repair/replace model with a simple user interface.

This paper outlines the evolution of repair/replace decision making within EnergyAustralia by exploring the technical, financial and change management techniques required for practical implementation, and finally, reviews some practical examples via case studies.

The model developed incorporates asset failure history to develop a view of the future risk of failure and total cost of ownership. It takes into account the realised and unrealised costs of the existing assets, and compares these to the expected costs of the replacement asset to provide a recommendation for the decision maker.

**Keywords:** Repair, Replace, Decision, Electricity,

## 1 INTRODUCTION

The decision to repair or replace an asset can be an easy or difficult decision. Minor low cost failures on young assets and major failures of assets, particularly aged assets, are often very clear and easy decisions to make. But how should we address failures on assets that may be considered 'mid-life'? An issue for the asset or plant manager is "How much can we justifiably spend on repairing the asset or equipment before replacing it?". There are often a number of technical issues involved, which as engineers we have become competent to address, and deliver a range of possible technically feasible solutions. But how do we assess the financial impacts of our solutions to arrive at a decision, particularly in terms of the asset economics and future risk costs?

## 2 ASSET MANAGEMENT ENVIRONMENT

Energy Australia operates its electrical network as a monopoly, and is subject to regulation by the Australian Energy Regulator (AER). Therefore, at each regulatory determination EnergyAustralia needs to be able to demonstrate that the investment in our assets is prudent, and that money is not being 'wasted' on excessive asset renewal, or in continuing to maintain or repair an asset when it is no longer prudent to do so.

In developing and implementing our approach to asset management it was recognised that we would need to also develop a set of tools to assist the asset decision makers. The decision to repair or to replace an asset must incorporate the technical issues, risk costs and economics. Engineers are well schooled in the technical aspects, but often not in the economics and the quantification of risk into financial impacts.

The work published in ICOMS 2002<sup>i</sup> by Buckland and Hastings, and in ICOMS 2004 by Hastings and Sharp<sup>ii</sup> were used as the basis for the development of firstly a transformer repair/replace model (as a proof of concept) followed by the development of a generic model which could be used for any asset. These models were produced to assist the determination of the lowest future cost of ownership arising from the repair the existing asset or renew the asset decision, and to enable objective support of the resulting decision.

Since the model was going to form an essential part of our asset management toolkit, and likely to be reviewed and challenged by the AER, the decision was made to have the model independently reviewed. To do this we also elected to utilise a firm of consultants who had been previously used by the ACCC to review our 2004-2009 regulatory submission, with the objective that they not only independently check the model, but also review and challenge the model as if they were working for the

regulator. This provided a report<sup>iii</sup> which we were able to use to ensure we addressed any likely issues before being challenged by the new regulator, but most importantly confirmed the validity of our approach and model implementation.

### 3 MODEL DEVELOPMENT

The development of the first repair / replace decision model and tool for power transformers quickly identified that there were a number of critical issues. These were:

The method of calculation of the equivalent annual cost (EAC) for the existing and the new assets impacts the determination of the spend limit

- The model is sensitive to the risk profile selected

Once these issues were addressed, and the model independently checked and validated, a more generic repair /replace decision tool was developed that could be used on any asset.

#### 3.1 EAC Calculation considerations

The determination of a spend limit is in itself fairly straight forward, and is described by Hastings and Sharp<sup>2</sup> at equation (1) of their 2004 ICOMS paper:

$$\text{Spend-Limit} = \text{Remaining life of old machine} \times (\text{Annualized cost of new item} - \text{Annualized cost of old item}) \quad (1)$$

To calculate the annualised cost, or EAC, of an asset at any age during it's life, the equation derived by Buckland and Hastings<sup>1</sup> can be used.

$$EAC = \left[ A + \sum_{i=1}^{i=n} p^i G(i) - p^n S(n) \right] / \left[ \sum_{i=1}^{i=n} p^i \right] \quad (2)$$

where

- A = Acquisition cost
- p = Discount factor {p=1/(1+r)}
- r = capital discount rate
- i = Year of life from 1 to .n.
- G (i) = M (i) + R (i)
- M (i) = Maintenance cost and losses in year .i.
- R (i) = Risk cost in year .i.
- n = Age of asset at disposal
- S (n) = Net disposal value at year .n.(resale value less expenses)

Similarly if we consider the future EAC of an existing asset of age k years, which is repaired at a cost B, it can be determined using the following adjustment to the above formula:

$$EAC_{existing} = \left[ B + \sum_{i=k}^{i=n} p^i G(i) - p^n S(n) \right] / \left[ \sum_{i=k}^{i=n} p^i \right] \quad (3)$$

where

- B = Repair Cost
- k = current age of asset
- i = Year of life from k to .n.

In both cases it is clear that the risk cost in each year, ie the risk profile of the asset, will be required to determine the EAC at any given age.

#### 3.2 Risk profile considerations

The determination of the risk profile was identified as a significant input from early trials of the model. The reason for this in the case of power transformers was that the risk costs were generally equal to the installed asset costs, and in some cases significantly greater when secondary damage costs to adjacent assets are considered.

The establishment of a linear risk profile starting at a given age was initially proposed and tested, with the analyst providing 1, 2 and 5 year future risk estimates which were then subject to linear regression to project a future risk. Whilst this approach was found to be relatively simple, the problems with this method were it is very subjective, it was difficult to objectively support the risk points used, and the risks into future years could end up un-realistically high . Multiply this high degree of subjectivity with the large risk costs, and it clearly would be a significant component in the EAC determination when using equations 2 or 3 (above). Therefore better means of incorporating the future risk of the asset needed to be established, and it was decided to base this upon the statistical failure rates of the transformers.

The development of the model was paused whilst statistical analysis of our sub-transmission and zone type transformers was undertaken. This analysis was grouped by voltage and design technologies to produce the failure probability density and cumulative density curve shown respectively in figure 1 and figure 2 below.

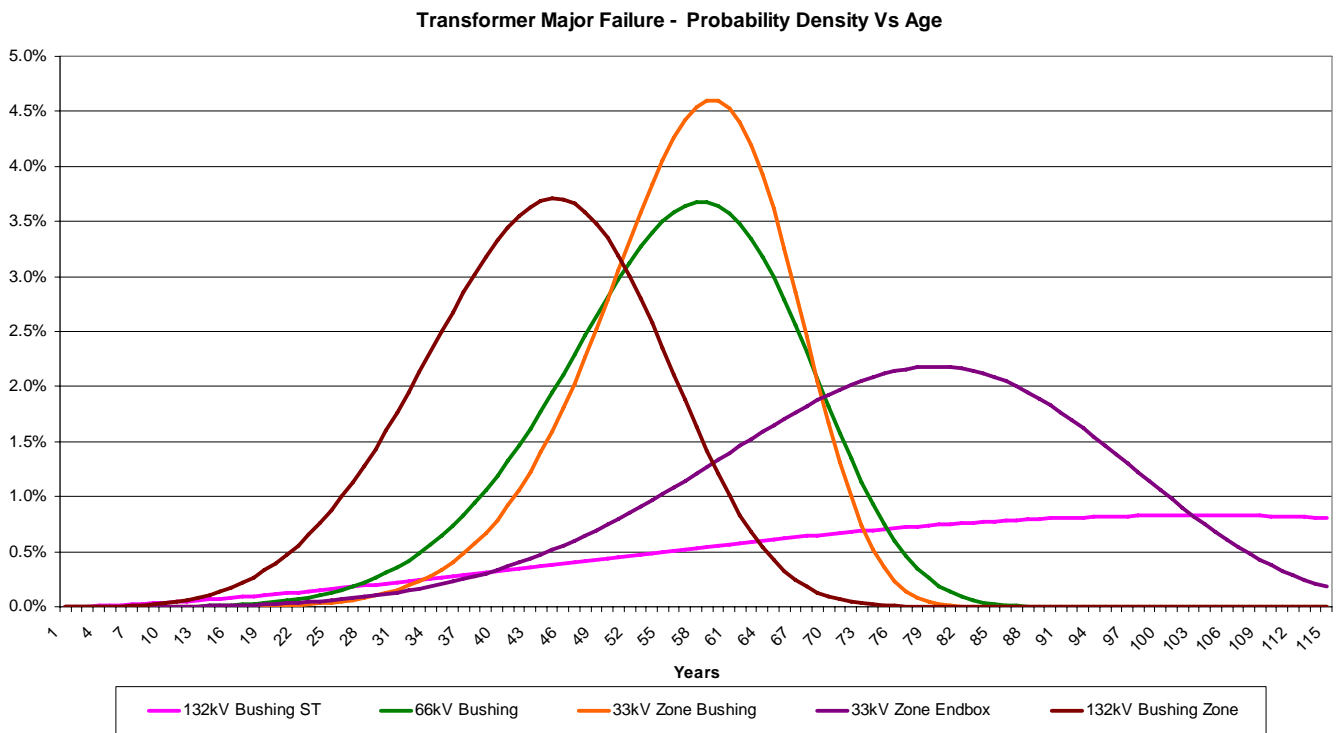


Figure 1

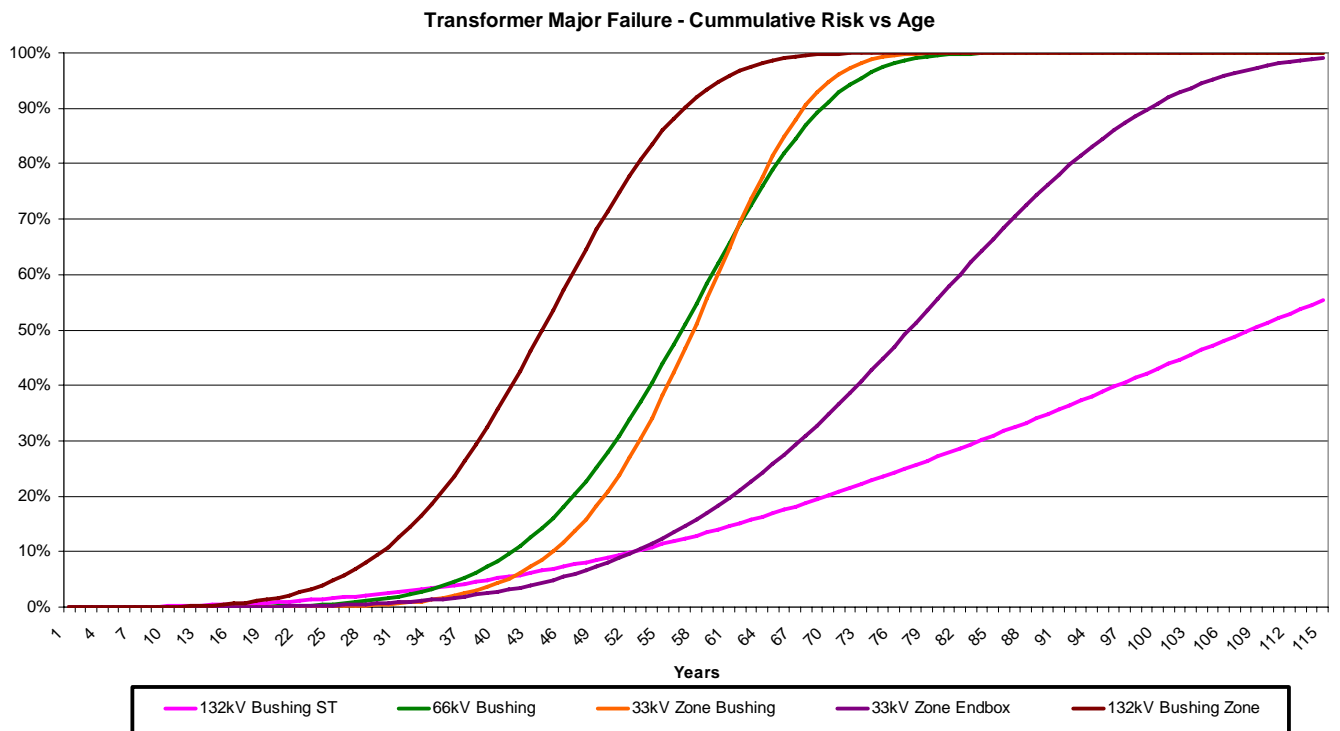


Figure 2

Now we could link our future risk probability with our asset type and age. The next challenge was to determine the recommended replacement age.

### 3.3 Determining the recommended replacement age

In section 4 of their ICOMS 2004 paper, Buckland and Hastings described how to determine the recommended replacement age using the cumulative undiscounted costs, and this is shown in figure 3 below.

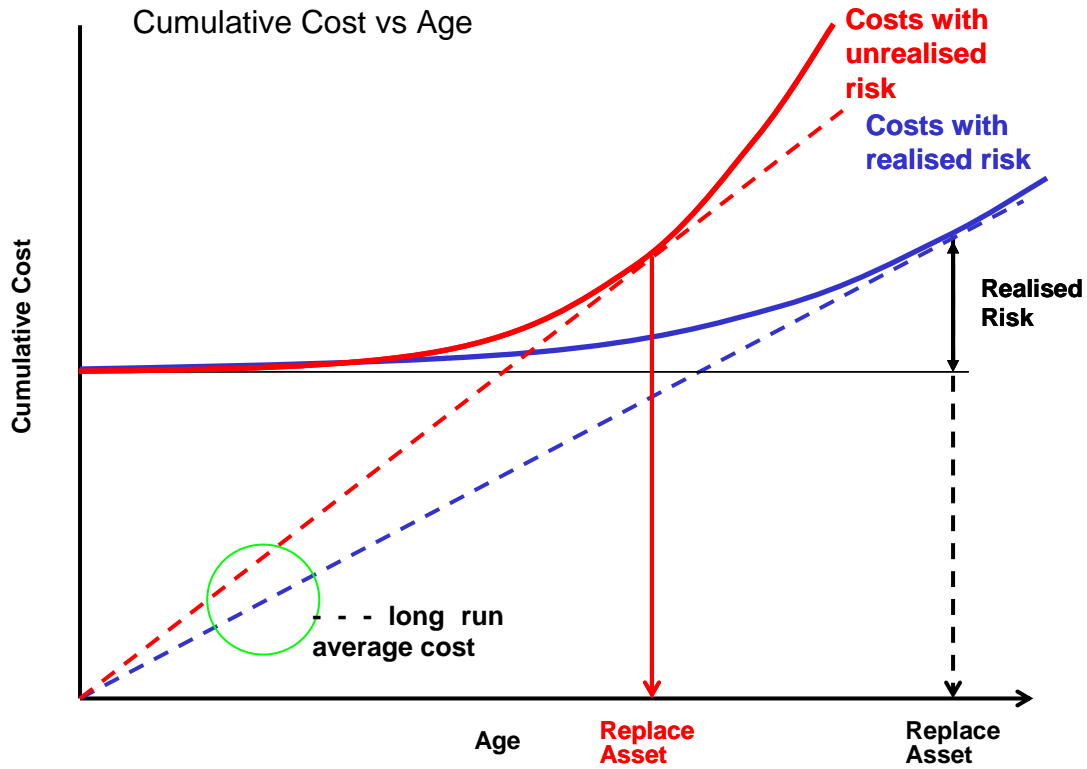


Figure 3

So to determine the optimum replacement age all you had to do was determine the tangent to the curve in figure 3, which represents the lowest long run average cost per year, and read off the corresponding age. This is a simple process where the maintenance costs of the asset are not significant, and easily performed in a spreadsheet. However for real world assets this is not so simple, as the cumulative cost 'curve' is not so smooth, as can be seen in figure 4 below.

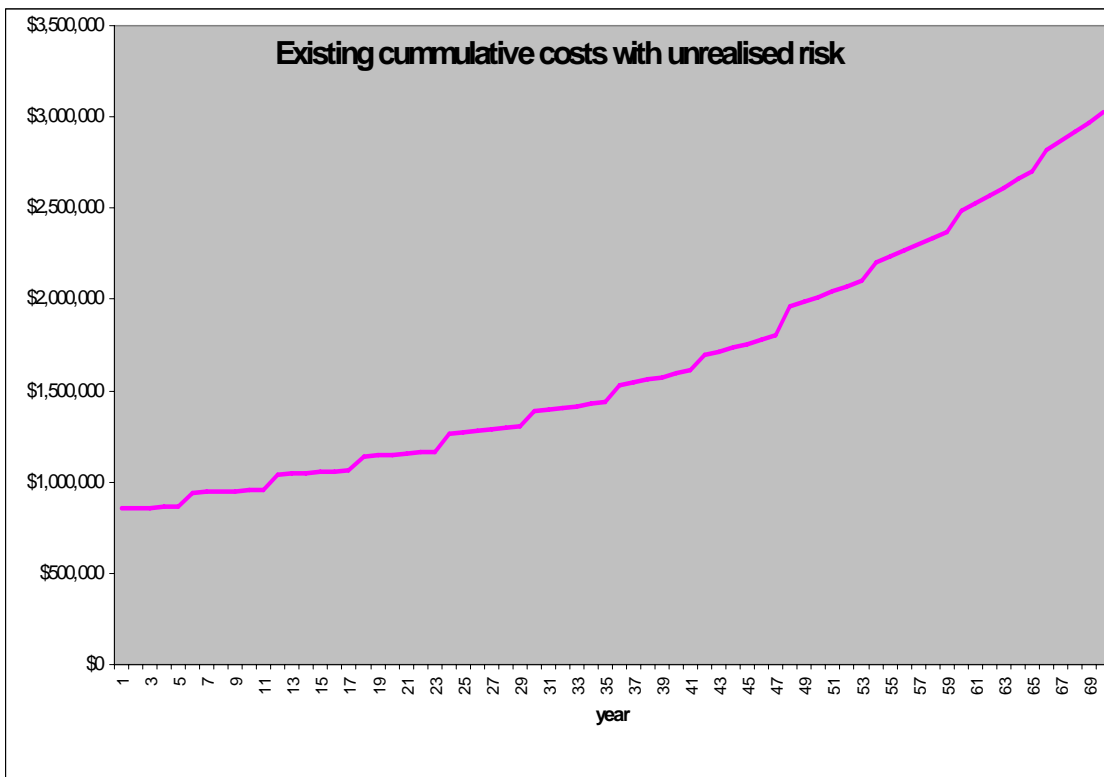
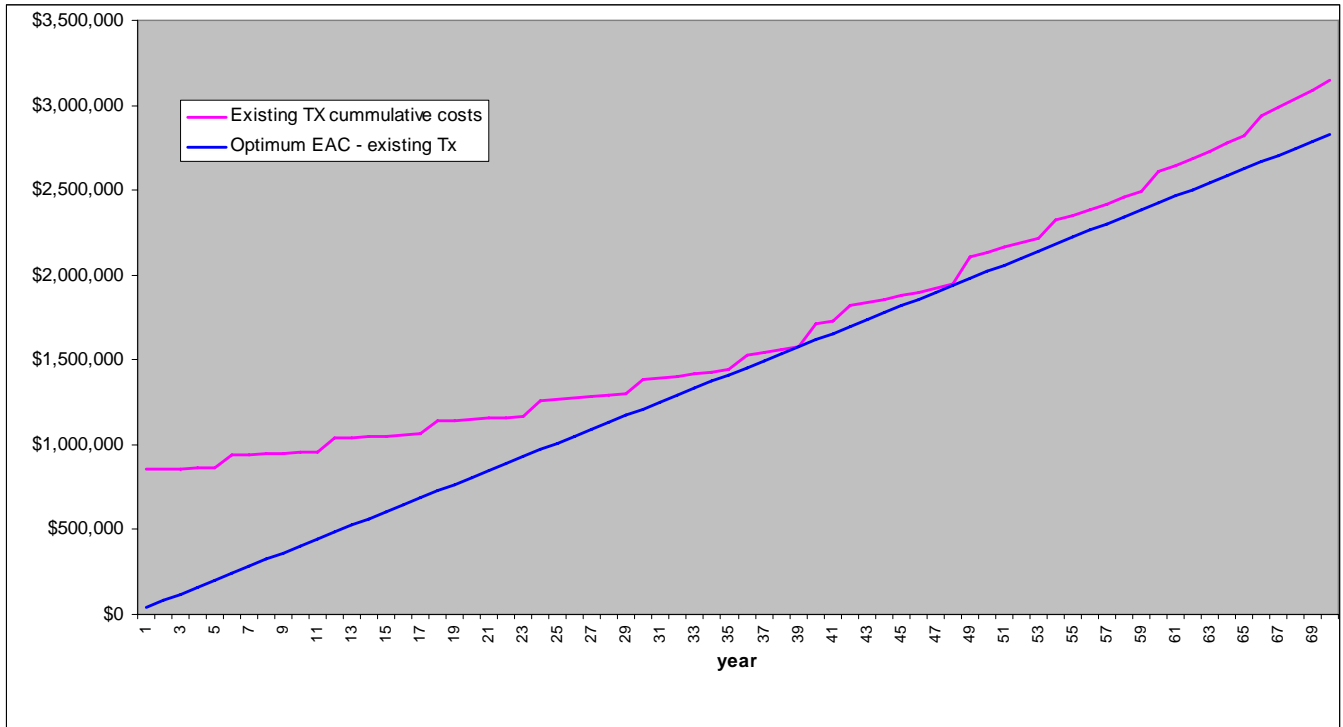


Figure 4

As can be seen, there are a number of potential 'tangent points'. Clearly we need more than just mathematical analysis to make a decision as there may be a case for not repairing the asset at it's optimum recommended replacement age. Consider the case in figure 5 below.



**Figure 5**

In this case the optimum replacement age is the current age at 39 years, however there is another point which has almost an identical long run average cost at 49 years. This age can be reached by reducing the scope of the repair work and deferring the maintenance due in yr 48 to the following year. The benefit of this solution, whilst not the economic optimum, is that it extends the transformer life to the retirement of the substation, and thus avoids unnecessary capital expenditure with an almost identical long run average cost. Therefore the asset manager needs to combine analysis tools with an understanding of the business needs as well as the asset itself to be able to establish a sound decision for the future of the asset.

## 4 CASE STUDIES - TRANSFORMERS

### 4.1 Repair/Replace Case Study – SURRY HILLS STS T1

EnergyAustralia has a Sub-Transmission substation in the Surry Hills area of the Sydney CBD which has some unique logistical issues from the standpoint of replacing transformers. The substation was built in 1964 and houses four (4) 132 / 33 kilovolt 120 MVA transformers in separate enclosures.



**Substation Tx Entrance**



**Transformer Runway**

The transformers are approximately 36 years old and their condition is considered fair for their age. EnergyAustralia has an oil testing regime where samples taken from the transformers are analysed to determine the dissolved gases contained in the oil. The chemical composition of the dissolved gases generally gives a good indication of any insulation deterioration which may be occurring in the transformer. By trending the gases we can receive a picture of its condition and assume its remaining life.

In 2003 the No.3 transformer was refurbished in situ by EnergyAustralia staff to repair significant oil leaks which were requiring constant attention having to top up the transformer reservoir and also required the pump-out and removal of drained oil from the oil interception tank. The repairs carried out included replacing all cork gasket seals, welding of the top plate flange, major overhaul of the tap-changer and clean-up of all excess oil from the transformer bay area.

In 2005, the oil leaks affecting the No.1 transformer were raised as a concern with records showing approximately 700 litres a month being lost from the transformer seals. By this stage, EnergyAustralia had introduced a transformer review committee to oversee the condition of the ageing population and manage the most cost effective replacement solutions. A new Repair/Replace Model had been developed by our Operations Investment Group, and ratified by the committee. We decided to use it as a trial to assist with the repair/replace decision on the Surry Hills T1. The model was in its first stage of development with a linear risk curve incorporated which had to be manually adjusted. (Later versions incorporate a specific risk model for the transformer configuration as described previously).

The details of the No.1 transformer and the measured characteristics of the oil sample taken are as follows:

Manufacturer: Toshiba      Year of Manufacture: 1969      Age: 36 years

Tap Changer Type: Reinhausen "F" Type

Oil Electric Strength: 71kV

Water Content: 13 ppm                      Total Furans<sup>1</sup>: 0.48 ppm

The condition of the No.1 transformer was assessed as follows:

The standard life of a power transformer according to the NSW Treasury Guidelines<sup>iv</sup> is 50 years so we still had 14 years of undepreciated value left in the asset registers for this transformer.

The internal engineering consulting group reviewed the oil sample results and indicated this transformer showed minimal signs of deterioration of its insulation compared to other similar aged transformers so recommended, barring an unusual or unexpected event (like a 3 phase bolted fault in close proximity to the transformer), that the transformer winding should have at least another 10 plus years of remaining life.

The main issue was the major leaks in the transformer and the condition of the tap-changer. The Reinhausen type F tap-changer history was examined and the technicians interviewed to assess if there were any pending issues which may cause a major refurbishment of the tap-changer which could 'tip the scales' towards a complete replacement. The feedback received was that the tap-changer was in good condition, so we looked at comparing the cost of repairing the oil leaks under a major refurbishment capital plan.

## OUR OPTIONS

### 1. Do Nothing

The leaks coming from the No.1 transformer were significant (700litres per month) but were being contained by the oil bunding, interception tank and staff topping up the conservator once a month. The problem was the interception tank needed to be emptied each month. It could be extended to 2 months but if an incident occurred on any of the other oil equipment in the substation the capacity of the tank could be compromised and then the oil would escape to the local stormwater drainage network which eventually would reach Darling Harbour. The cost of pumping out the interception tank each month was estimated at \$2,000 so the annual cost was \$24,000.

During the times when the transformer is being topped-up the Surry Hills Sub-Transmission substation has to be reduced to an N level of reliability (ie there was no redundancy in the electrical network normally designed for N-1) with a consequential increase in the "System Risk Profile" for this duration. Usually the switching is carried out the evening before and the evening after the work so the duration of the transformer outage could be up to 18 hours in total each month.

In addition, the do nothing option has a high likelihood of an incident impacting the environment which would result in corporate and/or individual fines.

To represent this scenario in the model we escalated the risk by increasing the consequential cost of failure to \$1 million.

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<sup>1</sup> The degradation of the paper insulation in transformers releases Furans, which is measured in transformer oil using Dissolved Gas Analysis. The magnitude (in ppm) is an indicator of the level of degradation of the transformer winding cellulosic insulation. The higher the furans, the worse the condition of the insulation, with a level of 2 ppm being indicative of the onset of significant insulation degradation.

## 2. Refurbish the Tank

As the EA staff had some experience from the previous refurbishment of No.3 Transformer earlier we thought it to be a low risk to ask them to carry out the same work on the No.1 transformer. We first reviewed the current state of the No.3 transformer leaks to see how successful their previous project turned out. Since completing the No.3 transformer there were no signs of leaks from the many flanges, seals or welds. This outcome gave us a high level of confidence that they could repeat the task on the No.1 transformer, which was a 'sister' to the previously repaired transformer. The supervisor and his staff were all still in the section and staff movements would therefore not affect the quality of the work as essentially they were the same crew.

The scope of the work was set-out as follows:

Timeframe: 30 days

- Manufacture new lid bolts
- Weld turrets if required
- Weld lid
- Replace bolts – lid & turrets
- Replace 132kV bushings
- Remove and replace all other bushing gaskets
- Remove and replace all radiator gaskets
- Remove and replace flapper valve, pipe work and oil pump gaskets
- Remove and replace all hatch cover gaskets
- Remove and replace tap changer outer oil cylinder tank lid sealing gasket
- Filter oil and vacuum fill transformer
- Supply oil spill clean up materials
- Clean floor and cable ducts and dispose of soiled materials
- Cost including all materials and crane hire.

The estimate for this work was \$255,000.

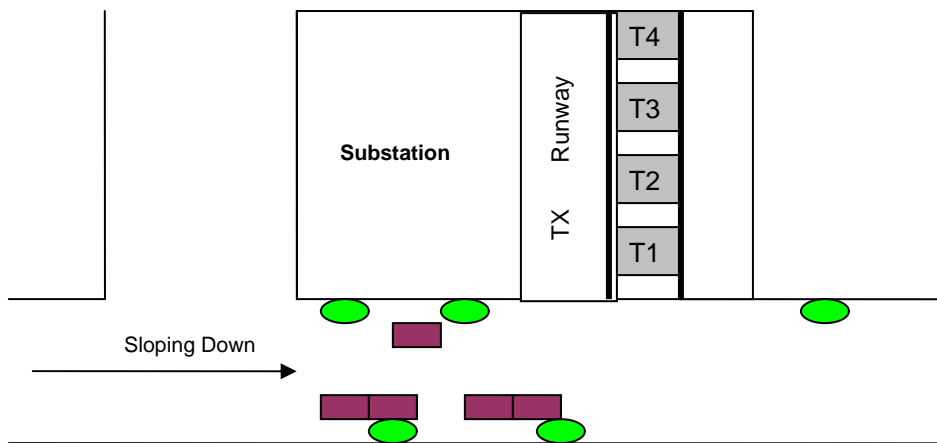
## 3. Replace the Transformer

The logistics of replacing the transformer was considered on site with the local supervisor, project manager and design manager. The problems which would have to be addressed are numerous and local council and various government entities would have to be co-ordinated to achieve the end result.

The substation is built on a long block with a downward sloping access road. On the opposite side of the street there are light commercial premises mixed with terrace style domestic residences. The street is lined with trees and vehicles are parked both sides of the street.



There has not been a transformer replacement carried out at this substation since it was built. During the time EnergyAustralia has owned the substation there have been civil variations carried out which has changed the levels of the transformer entrance roadway and all the transformers have been enclosed behind sound enclosures.



The cost of the replacement logistics was estimated at \$548,000 excluding the value of the transformer, with a total estimated installed cost of \$1,748,000.

### Scenario Analysis

A number of scenarios were developed which tested both the sensitivity of the model and the estimated cost of the work.

Option No.	Refurbish Cost	Expected Life after Refurbishment	Significant Cost of Failure	Risk Profile	EAC	Replacement Age	Model Result
Do Nothing	\$0	N/A	\$1,000,000	0.25;1.0;2.5;5.0	\$107,772	41 years	N/A
1B	\$255,000	24 years	\$250,000	0.25;1.0;2.5;5.0	\$82,637	59 years	Refurb
1C	\$300,000	24 years	\$250,000	0.25;1.0;2.5;5.0	\$82,637	59 years	Refurb
1D	\$323,000	24 years	\$250,000	0.25;1.0;2.5;5.0	\$82,637	59 years	Refurb
1E	\$324,000	24 years	\$250,000	0.25;1.0;2.5;5.0	\$82,637	35 years	Replace

The primary parameters were entered into the model and the results assessed and entered into the above table.

An example of the Do Nothing screen and graph is shown below:

Transformer Repair / Replace Model			27-Feb-07
Existing Transformer	Transformer ID: Surry Hills STS (T92609) - Do Nothing (\$24,000 pa)	New Transformer	View Graph
132kV	Primary	132kV	Risk Based Replacement Age <b>41 Years</b>
33kV	Secondary	33kV	
120	MVA	120	
ONAN with B testings	Cooling Type	OFAF with B testings	
Reb kase F	Tapchanger	Reb kase R	
\$2,000	Operating Losses (pa)	\$2,000	
\$1,000,000	Acquisition Cost (incl installation)	\$1,748,000	
50	Expected Age at Disposal (n)	50	
2.00%	Transformer depreciation rate	2.00%	
7.5%	Discount rate	7.5%	
0.930232558	Discount factor (p)	0.930232558	
10%	Minimum Residual life value (%)	10%	
\$100,000	Calculated Book Value at Disposal age	\$174,800	
\$20,000	Disposal Costs	\$20,000	
36	Current Age		
50	Repair Cost		
\$180,000	New Expected Disposal Age after repair		
\$1,000,000	Residual Book value at repaired replacement age		
	Cost of Significant failure		
	Estimated Future Hazard Rates		
0.25%	next Year		
1.00%	Following Year		
2.50%	In 5 years		
5.00%	In 10 years		
\$107,772	EAC	\$139,041	

Steve Buncombe: Cost of the transformer is \$1,200,000 plus the installation costs which have been estimated at \$548,000

Steve Buncombe: The original value of the transformer is not known so is assumed to be \$800,000 plus installation of \$200,000.

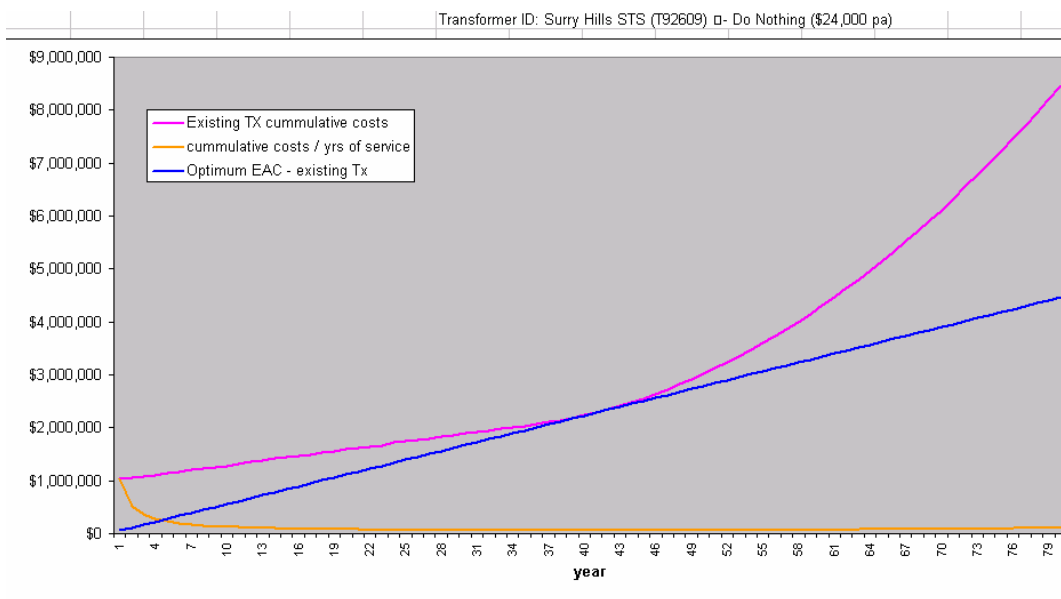
Steve Buncombe: Assume \$1500 per month for Oil Leak Top up and \$500 per month for Oil Tank draining for 14 years.

Steve Buncombe: If we do nothing and just continue the monthly topping up process we are risking a fine from the EPA. Say \$1000,000 for the corporation.

Repairs:	
Estimated Life Gained	5 Years
Mtce EAC over extended life	\$31,698
Spend Limit (Cost Based)	536,714

**Recommendation:**  
**Repair Transformer**

Steve Buncombe: Equivalent Annual Cost



#### 4.2 SELECTED OPTION

The difficult logistics of replacing a transformer on the site became a significant factor in the repair / replace decision. The immediate problem was the risk of an oil leak escaping the interception tank so a short-term solution was a primary objective. In developing the logistics required in replacing the transformer it became clear that it was going to take a number of years to undertake and co-ordinate this work, and as such provide no immediate relief to the current problems and associated risks. The sensitivity checking undertaken with the model provided us with a clear indication that the repair option was cost effective solution. This recommendation was presented to the Transformer Committee and the project approved. The repairs were carried out and the leaks have now been addressed.

#### 5 CONCLUSIONS

The development of a model as a tool to assist making the repair/replace decision has proved valuable from both an academic and a practical perspective. It has provided a more detailed understanding of the asset risks and assisted us to predict the future in a way which can be objectively reviewed by our internal stakeholders, and our industry regulator.

The worth of the approach has been demonstrated in the objective input to the decision making process, especially in what would otherwise have been a very subjective decision. It helps provide the balance between the technical and the economic aspects and provides a valuable tool in our asset management toolkit.

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<sup>ii</sup> Hastings & Sharp, Spend-Limits And Asset Management, ICOMS 2004

<sup>iii</sup> PB Associates, Review of Investment Decision Models - Transformer Repair or Replace, Energy Australia 2006

<sup>iv</sup> NSW Treasury Policy Guideline “Valuation of Electricity Network Assets”, Draft May 2003