Analysis of Substation Asset Life Decisions:
Replacement or Refurbishment?

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Introduction

This paper focuses on decisions as they relate to substations, and in particular whether it is justifiable to replace or refurbish a large asset. These decisions are typically affected by a series of inputs, namely maintenance history, the feasibility of online condition monitoring, refurbishment, or replacement cost. Each of these inputs is affected by financial considerations as well as practicality. For instance, it may be more cost effective to refurbish at an OEM facility. However, the availability of spares or mobiles must be considered, and that will not appear in a strictly financial analysis. Also, the possibility exists that a change in failure rate after an asset is refurbished will affect the decision.

Decision Making Pressures

The pressures associated with a replacement or refurbishment decision are many – starting with the straight financial costs of each approach (replace or refurbish) and then adding in the context of:

- Likelihood of failure of either unit after installation
- Operational costs associated with each activity
- Business interruption costs
- Penalties or fines associated with loss of service
- Transport costs associated with removal and reinstallation
- Possible safety or environmental issues associated with decision

It is impossible to address every possible context in a single paper – through one or several analyses. In this paper we will address some of these issues as illustrations; more complex and deeper analyses, depending on context, can be built from simpler analyses. An example of penalty costs overriding simple analyses may be the case where a rapid return to service is required and an energized spare is the appropriate short term response (1).

Risk

To understand the decision making process, we need to have a good grasp of the concept of risk.

Risk is the combination of the likelihood of an event and the consequence of that event; these are usually given in terms of:

- The probability an event will occur in a given time frame
- The costs of that event in dollars, or some appropriate measure

For example – if the chance of my car being hit by a falling branch while parked, over the next year, is 1%, and the cost of the damage is estimated at $1,000, then my risk, or exposure' is $10 for the year.

How much I would be prepared to pay for insurance may be guided by the exposure.

With large assets, such as power transformers, it is not easy to identify the probability of failure; and the costs associated with the failure may be contingent on network configuration at the time, and the mode of failure (tank rupture leading to fire and oil spillage likely being more costly than a bushing failure with no fire and no oil spillage). Failure rates must be estimated for power transformers, and may vary with design, role, size and location of the unit.

Straightforward Decision Tree Analysis

In theory, the decision to replace or refurbish is a simple financial analysis:

- What are the costs of a replacement unit?
- What are the chances that a replacement unit will fail?
- What are the costs of refurbishing a unit?
- What are the chances a refurbished unit will fail?
- What will it cost for a replacement unit in case either a replacement or a refurbished unit fails?

We can summarize exemplar costs and probabilities in two tables – the values are purely indicative:

Costs	**Dollars**
New unit	$1,000,000
Refurbishment	$650,000
Replacement for new unit	$1,000,000
Replacement for refurbished unit	$1,000,000

Table 1 Example Costs of Refurbishment & Replacement

Probabilities	**%**
Failure of new unit	1%
Failure of refurbished unit	5%

Table 2 Probability of Events

A simple decision tree can summarize the data and also identify the optimal decision.

The decision is summarized on the left; the first two branches identify the two options: replace or refurbish. For each branch there are two sub-branches representing the subsequent failure or survival of the unit. Costs and percentages associated with each branch are given – note the sum of probabilities for events in each sub-branch must add to 100%.

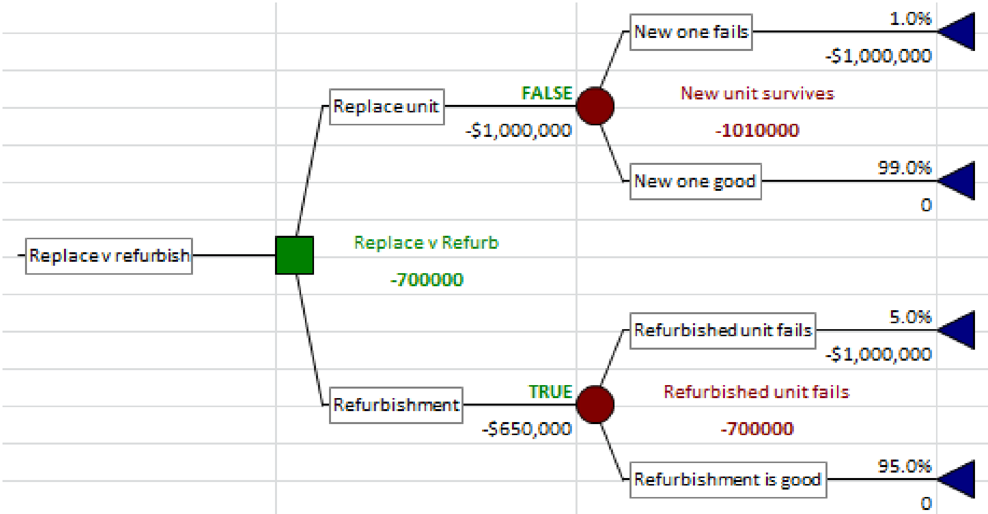

Figure 1 Straightforward Decision Tree

In this version of a decision tree program (2) the decision branch which provides the lowest 'expected value' is identified as "TRUE". The 'expected value' of each sub-branch indicates the sum of the exposure of each sub-branch. In the case above, the refurbishment option is preferred.

More-complex Analysis

In this analysis, we add a contingent failure for the failure of the replacement unit or the spare unit – for illustration we have made the likelihood of a catastrophic failure for a refurbished unit to be much greater – if the unit *does* fail then there is a 60% chance that the unit will fail catastrophically and require major clean up and repairs.

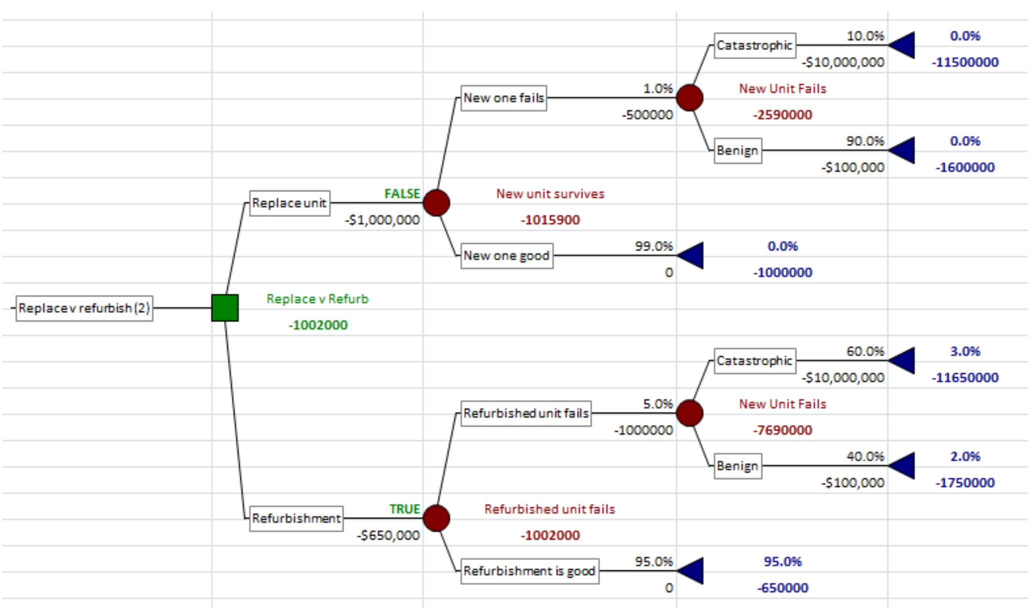

Figure 2 Extended Decision Tree

We have added illustrative costs for both catastrophic and benign failures – noting that these are in addition to the cost of a replacement unit for the newly failed unit. In this case we have also identified the expected value of the new sub-branches and the exposure each brings. (Note that the probabilities at far right are conditional probabilities and follow Bayes rule (3).

It may be that the new unit comes with a new fire suppression system and extended condition monitoring, reducing the likelihood of catastrophic failure - or is built to new standards. But in this case, with these figures, we still find a refurbished unit is the optimal decision.

Finally, we will add some variation based on the refurbishment not being possible – while the work is in progress, say, further damage is found and the unit must be scrapped. Let us add a 5% chance that such a situation may occur. This is the extra 'chance' node on the decision tree at the bottom of the diagram – this means that we will have to obtain a new unit!

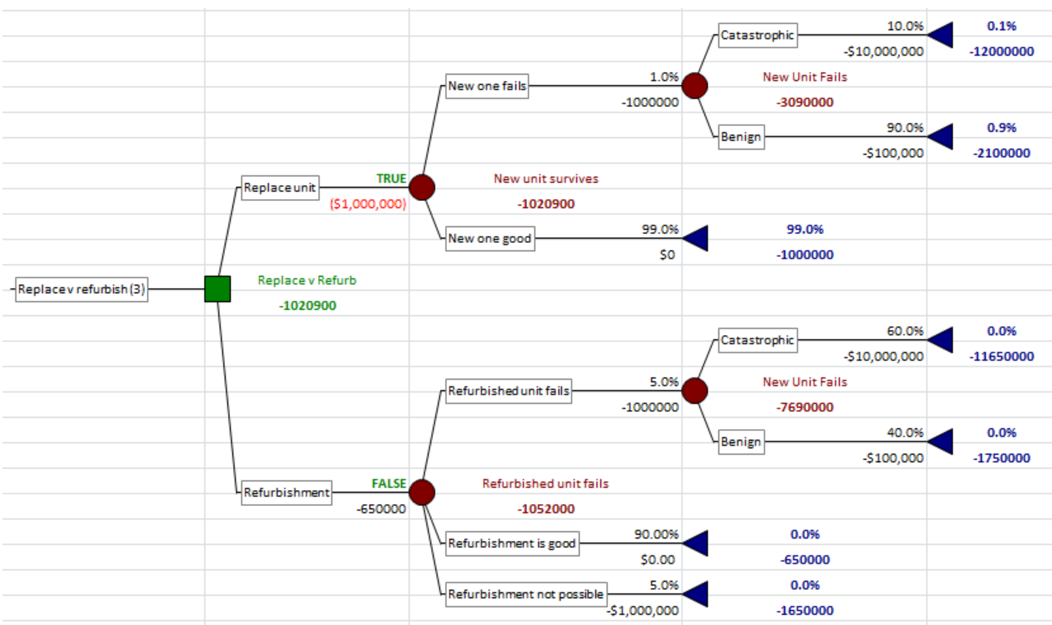

Figure 3 Further Extended Decision Tree

Even the addition of a small, but realistic, chance that a refurbishment is not possible now tips the optimal decision to a replacement.

Discussion

As can be seen from the examples presented, the replace/repair decision is both sensitive to variable analyzed. It is also very sensitive to the percent probabilities used – which will be estimates based on industry expectations or historic values. However, it should be noted that some probabilities are contingent probabilities and are even more difficult to ascertain.

Analyses may become quite complex quite quickly – it is usually best to start with a small model which works well rather than a large model which doesn't work.

In addition, it is worth noting that a decision tree tool, such as the one used here, allows for addition of Monte Carlo simulations to allow for probability distributions and far more complex.

Finally, it is the nature of spreadsheets that numbers can be changed and decision outcomes altered as a result. It is important not to try and 'fix' the numbers to reflect a particular, desired, outcome.

Conclusions

Replacement/refurbishment decisions are complex and highly context dependent- including analysis of costs, probabilities and contingent probabilities. This paper has presented some simple examples.

Decision tree analysis of replace/refurbishment decisions can be very sensitive to estimated quantities, with outcomes varying in what may be surprising ways. It is important to keep in mind that the use of this tool is as an aid to decision making and understanding of the business context, rather than replacing the need for decision making and understanding.

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