Scenario Modelling Cost Outcomes in an Electric Power Distribution Network

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Electrical power distribution networks are complex systems comprising multiple classes of assets with varying costs, risks, interactions and interdependencies. The aim of this project is to determine cost-optimal locations, timing and proportions of section block (group) rebuild and individual asset remediation in the Western Power distribution network. Scenario Modelling is used to aggregate the treatment of individual assets in order to calculate lifetime costs for entire sections of the network. The model projects the present-day network over a long-term (50+ year) time horizon and forecasts asset interactions, replacement timing, capital expenditure and operational costs for a range of section rebuild and asset replacement strategies. The results of this analysis indicate that a greater focus on block rebuild as opposed to a discrete asset replacement strategy can produce significant cost savings in electrical distribution networks while meeting existing network performance and risk requirements. The modelling results demonstrate that the cost benefit of section rebuild varies across the network due to its heterogeneous composition.

1. Introduction

Western Power (WP) builds, maintains and operates the electrical transmission and distribution infrastructure in the South-West corner of Western Australia. Network asset strategy is driven by safety, performance and cost constraints. Major network expansion was undertaken in the 1960/70s and, given the expected service life of 50 years, many of the conductors in the network are approaching end of life and are anticipated to require replacement as shown in Figure 1.

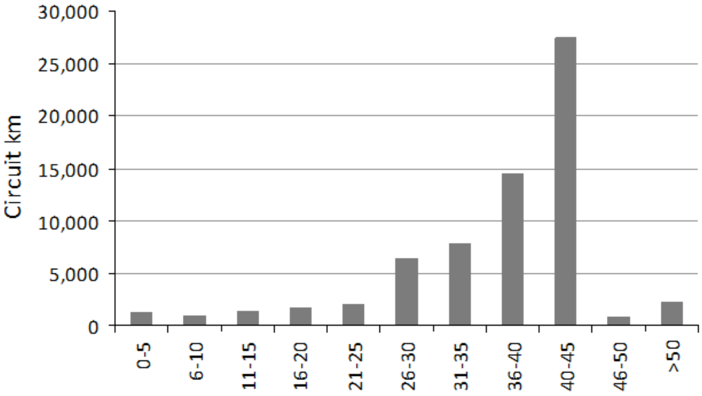

Figure 1 Distribution overhead conductor profile by age and type

The challenges associated with an aging asset base are not unique to WP; aging infrastructure is a problem for many transmission and distribution utilities worldwide (Brown and Humphrey, 2005). The transition to targeted rebuild represents an opportunity to extract scale efficiencies from the asset replacement works program. This project aims to explore the effects of progressively introducing a parallel "rebuild" mode of operation along with the existing discrete asset replacement program where rebuild activities are implemented in selected areas to reduce lifetime capital (capex) and operational (opex) expenditures.

The purpose of this project is to investigate the cost benefits of adjusting the location and timing of concurrent individual asset remediation and network block rebuild programs. Current practice at WP involves discrete asset replacement and remediation that has been shown to have reduced cost and productivity efficiency when scaled to the forecast long-term network requirements. The model is designed specifically for the WP Network, applying established business rules and asset management practices (specific asset replacement triggers, events and business constraints, etc.).

It is beneficial for infrastructure businesses such as WP to address whole-of-life fundamental cost issues due to the long term, asset intensive nature of operations (Brown and Humphrey, 2005). Asset management is not a single function like protection, network control or extension planning. It is a set of simultaneous activities which are performed to find a whole-of-network optimal trade-off between reliability and cost (Kostic, 2003).

Previous investigation into risk and cost optimisation of power distribution networks has largely focused on either individual assets or organisational outcomes (Anders et al., 2001) (Nordgård et al., 2007). Aggregates of individual asset lifetime costs provide a good estimate of total costs when applied over short lengths of network, but this method necessitates like-for-like replacement and excludes works efficiency savings. Other investigations have performed economic evaluation on the basis of failure, maintenance and interruption costs (Bertling et al., 2005). WP acknowledges that these costs are critical to their business. However, analysis of historical network spending indicates that the value of total capital expenditure is more than twice the value of operational expenditures.

Existing studies into network efficiencies have generally investigated two of the following: cost/model scalability, whole of life expenditures and total system cost drivers. This project aims to include all three aspects to determine the cost implications of different network section rebuild programs. This will demonstrate the importance of the behaviour of asset groupings when determining total lifetime network costs by using scalable and interchangeable sections in the model.

The model is scalable to any arbitrary section of network by forecasting costs as a function of the existing composition of the network, capital costs proportional to the length of network delivered and operational costs as a function of network age and location. The model will be one component of a planned whole-of-network strategic decision making tool developed to balance network risk, cost and performance outcomes. This proof of concept model is intended to demonstrate the viability of a scenario modelling tool that will be used to inform long-term business decisions regarding rebuild, asset replacement and maintenance works.

2. Approach

Figure 2 shows the geographic and network topology identifiers used to select sections of network. The model creates a subset of all assets (conductors, poles, transformers, switches etc.) and their attributes for the unique section type and number (e.g. MZ132). Analysis can be performed on single sections of network or run in batches for the entire network.

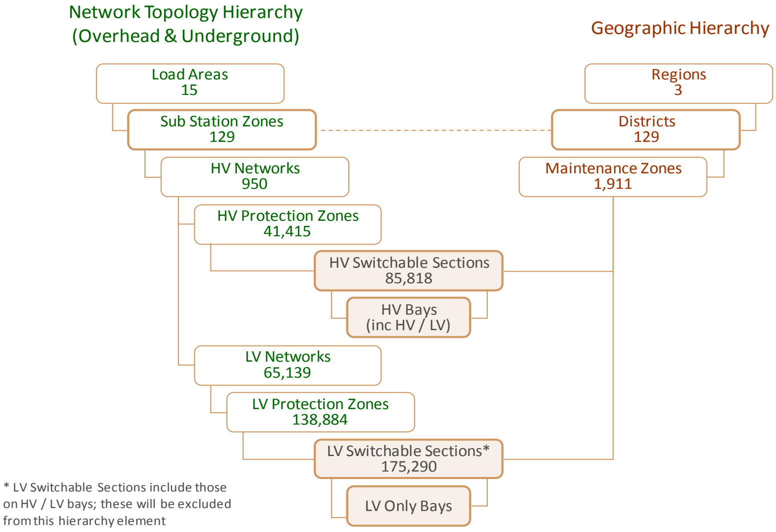

Figure 2 Existing network models

Year 0 (present-day) asset ages in the section are determined from asset install dates. Assets are then aged in single year increments in the "virtual network" and checked against age-based replacement, asset interaction and replacement schedules currently used at WP. Replacement ages for asset used in the model are shown in Figure 3. Capex costs are triggered by asset replacement actions. Opex costs (reactive maintenance, vegetation clearing, inspections etc.) increase with network age in accordance with WP convention based on previous asset cost behaviour investigations and are assigned at the network nodes (poles). This incremental rule-based replacement algorithm is shown in detail in figure 4.

DFIS_EQP_CDE	Asset Type	Replacement Age	DFIS_EQP_CDE	Asset Type	Replacement Age
CBLV	LV Circuit Breaker	50	PINT	Wood Pole	60
CUSA	Customer Service Attachment	50	PNST	Wood Pole	60
DILV	LV Disconnector	50	PSRV	Wood Pole	60
DOF	Drop out fuse	50	PSTY	Wood Pole	60
DSTR	Distribution Transfomer	40	PTOF	Wood Pole	60
FSDO	Fuse Disconnector	50	PTRM	Wood Pole	60
OHST	Overhead Stay	50	PTSD	Switch	60
PANS	Wood Pole	60	PUND	Wood Pole	60
PCNR	Wood Pole	60	RECL	Recloser	50
PILS	Wood Pole	60	RMU	Ring Main Unit	50
PILT	Wood Pole	60	SECT	Sectionaliser	50

Figure 3 Examples of asset replacement age triggers used in the model

For each section, the discounted total cost of the baseline individual asset replacement scenario is calculated over the user-selected time horizon to be used for comparison. The NPV of each possible rebuild scenario (i.e. rebuild in each year over the time horizon) and the expenditure profile for the lowest cost scenario, whether that is the baseline individual asset replacement or one of the rebuild scenarios, are the graphical outputs from the model. For batch calculations, a register of these values for each section is created for further analysis. Rebuild costs are based on existing cost mappings (like-for-like or like-for-similar) used by WP estimators for construction of new network sections by the existing bay (the conductor(s) between two poles) type, geographical location and bay length properties.

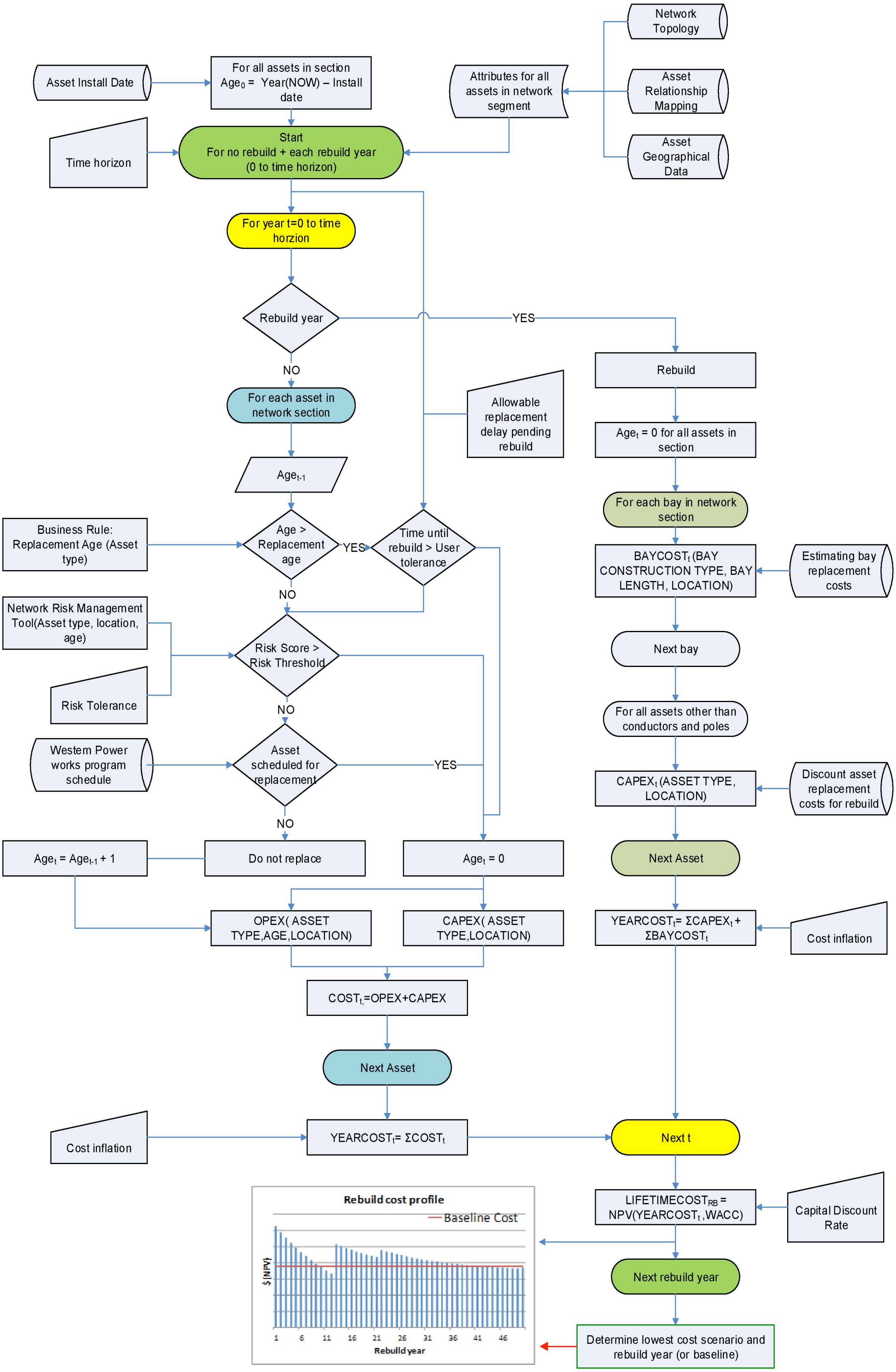

Figure 4 Scenario modelling inputs, algorithm and output

3. Results and Discussion

Figure 5 demonstrates a typical output for a section of network where total rebuild would deliver a lifetime cost reduction when compared to the baseline scenario. The left plot shows the NPV of each possible rebuild scenario and the right plot gives the forecast expenditures in each year for the lowest cost scenario (Year 11 rebuild). In other areas, there are no rebuild scenarios that result in reduced lifetime section cost. This may indicate that a continued cycle of discrete asset replacement is the optimal approach to capital investment in these sections of network.

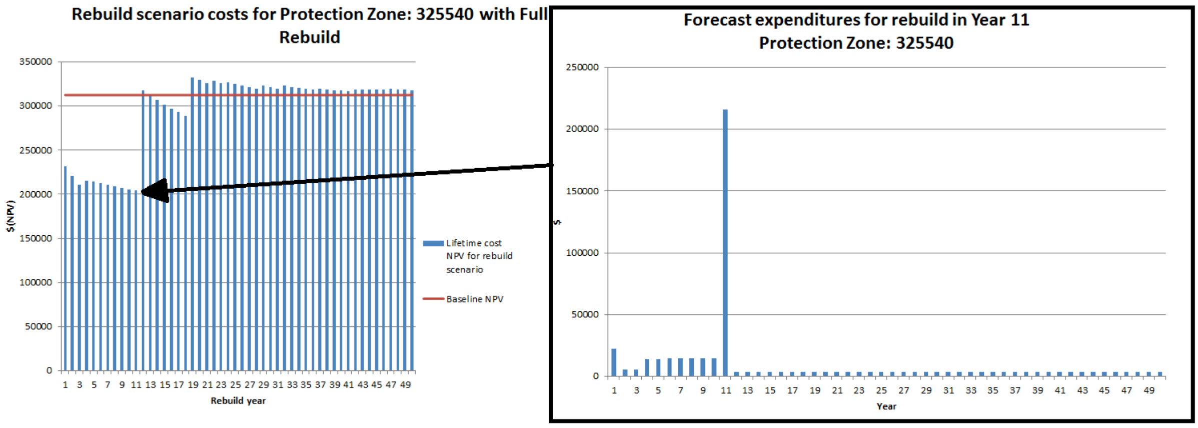

Figure 5 **Example scenario NPV and lowest cost scenario expenditures for one protection zone**

Figure 6 demonstrates the variability in the cost benefit of rebuild for protection zones (PZs) in three different metropolitan suburbs, with each data point representing one PZ. The average age of conductors in Suburb 1 is 10 and 15 years older than those in Suburbs 2 and 3 respectively. This results in the lowest cost rebuild time being earlier, as older assets have higher operating costs and less time until their respective end of service life.

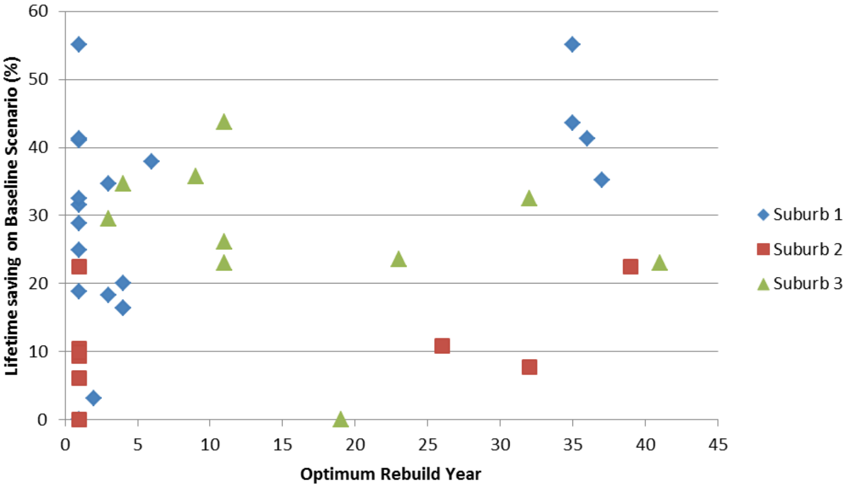

Figure 6 **Percentage discount on discrete asset replacement for Protection Zones in 3 suburbs**

In addition to identifying the network sections with the greatest potential for rebuild cost savings, the model can also be used to maximise cost reduction for a given business or works delivery constraint. Figure 7 shows the optimum rebuild timing and NPV of lifetime cost reduction per kilometre of network (for the lowest cost rebuild schedule compared to baseline) for all 91 Maintenance Zones (MZ) in a West Australian town. Total cost reduction for a given km/year delivery constraint can be maximised by selecting the network zones with highest marginal benefit per kilometre of line rebuilt in a given year.

In this example, rebuild in Year 4 is the lowest cost scenario for four different MZs. Works priority order would be: MZ1, MZ2, MZ3 then MZ4 (i.e. ordered by highest marginal cost saving per km of network rebuilt). The same method can be applied using construction time, material availability or other business constraints.

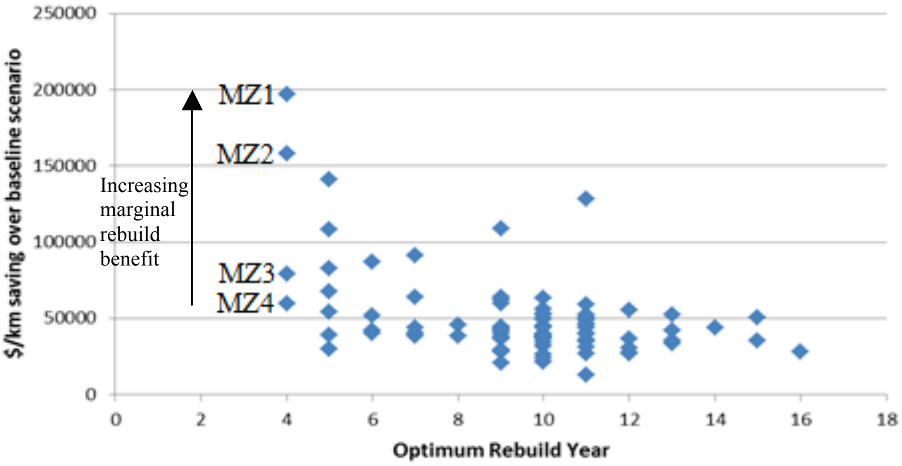

Figure 7 **Lifetime savings per network kilometre for all Maintenance Zones in a town**

4. Conclusions and Future Work

The results of this project indicate that a shift toward a targeted rebuild strategy could result in Western Power reducing long-term capital and operating costs while conforming to existing asset service life limits. It is likely that the modelling concepts and methodology used in this project could be applied to other interdependent asset networks in the wider asset management discipline. The model has also shown promise as a works delivery planning tool, with the ability to calculate and rank the marginal benefits of rebuild within individual zones. The main focus of future work will be to integrate the Western Power risk costing tools into the model to perform the same analysis on aggregated capex, opex and risk costs. The ultimate goal for the proof of concept model is to be scaled to become a business decision making tool that is incorporated into the Western Power strategic planning process.

6. References

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