CP/PAL WOODEN POWER POLES

2019 RCM Study Report

Final Report

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Executive Summary

This document is a report from the large effort known as the 2019 RCM study on the CP/PAL wooden power poles. The main body of work was performed starting in April 2019 and was completed in September 2019. The work was performed by ARMS Reliability, assisted by external experts and by internal CP/PAL asset management team.

This report contains a logical treatment of the work performed with methodology explanations, and provides key results, with equations and appendices supporting the RCM process and the service contract deliverables.

We understand that CitiPower and Powercor (CP/PAL) combine to supply electricity to over 1 million customers in Victoria.

- CitiPower owns and operates an electricity network which serves 330,000 customers in the central business district (CBD) of Melbourne and includes the inner suburbs of Melbourne.
- Powercor covers a wide service area that includes regional and rural areas in central and western Victoria, as well as Melbourne's outer western suburbs, supplying electricity to around 790,000 customers.
- Collectively the wooden power pole population numbers approximately 405,554 poles manufactured from 33 different species of wood, with some in service since 1900. Considerable interest is developing due to the large amount (150,000) of aging durability Class III (3) poles currently in service. These poles are nearing their end of useful life having been originally placed in service during the Victoria state electrification work spanning roughly 1956 to 1967.

In general, there are many challenges that confront the management of wood. CP/PAL has been successful over the recent years in managing these challenges and those specifically associated with an aging wood power pole population. In November 2018, the Australian Energy Regulator (AER) released its annual report ranking CitiPower as the most efficient electricity distribution network in Australia. On the more technical side of wooden poles, Energy Safe Victoria ESV issued a technical report that determined that Powercor's power pole inspection and maintenance process was fit for purpose and there is no immediate systemic risk of pole failures.[1]

Still, CP/PAL is like other utilities globally who are faced with questions about how long a pole lasts once it is placed in the ground and why does that matter? The question gets amplified by the performance of the current aged durability class 3 poles and by an aging population in general, which has seen very few replacements in recent years and now faces perhaps an 8-fold increase over the next 20 years.

There are several other important reasons for paying attention to a pole's remaining useful service life (RUSL). We have approached the answers to several similar questions within this study by using the time proven methodology of Reliability Centered Maintenance (RCM). We have extensively utilized statistical analysis. We have also purposefully aligned the CP/PAL RCM process used with the RCM guidance described in the internationally accepted Dependability Management Standard - IEC 60300.

The alignment rational is simple.

The RCM methodology logically allows for prioritization of the safety of the public and following the international RCM guidance provides a method thought by global asset managers to be prudent for this task.

An unassisted pole failure event places the safety of the public who are present in the immediate area in question. The force of impact of a large pole striking the ground, a car or a person can result in serious injury or death. Of importance are the practicable steps that can be taken to reduce the amount of unassisted pole failures whose rate of failure is thought to increase proportionally with the age of the pole population.

In addition to an un-assisted pole failure[2], the pole or pole top equipment failures that produce fires are equally important and have also been listed as causal elements in destructive bush fires to which Victoria is

[1] Energy Safe Victoria – The Condition of Poles in South West Victoria, Technical report – July 2019

[2] Unassisted pole failure means a pole breaking and falling due to rot, decay or wood-destroying pests, but excludes failures due to outside forces such as fire, vehicle impact, third party or lightning strike

specifically sensitive. Victoria has several designated high-risk bush fire areas (HRBA) where additional maintenance controls are in place to reduce the potential of a bush fire start.

In addition to safety of the public, it is also important to consider economics.

Utilities globally want to maximize their capital dollars and actively seek the longer service life now possible as this over time reduces the need for pole replacements. At CP/PAL with over 405,000 poles in service, the capitalized cost of replacement poles made each year is an important factor in the price reset process. This knowledge must be joined by forward projections of replacement poles to be made in future years in order to accurately determine the total monies that must be reserved.

More recently with global consciousness, utilities have begun to examine their carbon footprint. It is a fact that trees fix or sequester carbon from the atmosphere as they grow, and this carbon remains locked in the wood once the pole is manufactured.

While thousands of tons of carbon are stored in the utility wood pole population, it is still a relatively small portion of a utility's total carbon footprint when contrast to the electric generation, transmission and distribution system, but important nonetheless.

Considering such a broad landscape of drivers with safety, environmental and economic implications, it is important to find a practicable balance. To that end the RCM methodology was designed to review and produce an accurate maintenance strategy thoughtfully composed and designed to counter all reasonably plausible failure modes. When applied again on an existing strategy, the role of the RCM study shifts to confirm the original decisions, perform age exploration and attend to the living program of continuous improvement. Following successful application of RCM in 1997 and 2005 the predominant task encountered during the 2019 RCM study was therefore to reconfirm the condition-based maintenance program in service at CP/PAL since 2005 as technically feasible and worth doing, and noting the areas of consequence for safety, environment, and economics affected highlighting the aging durability class 3 poles.

Any inspection-based program operated by a utility is heavily dependent on the accuracy of field measurements and the establishment of acceptable limits for retirement of a pole from service. CP/PAL confronts this problem using the "pole calculator" algorithm. This is used to assist the asset inspector who inputs measured data, and the algorithm produces a decision on the worthiness and fitness for continued service of the pole inspected.

The pole calculator is not the only avenue to certify a program's worthiness. ESV also recently performed an independent technical review of Powercor's inspection program. This review included destructive proof load testing of poles retired by the pole calculator method which serves to confirm the poles residual strength is accurately estimated, and as a result ESV pronounced the program to be fit for purpose.[3]

The CP/PAL RCM inspection-based program is a good program but also a complex program. When viewed from a continuous improvement lens, RCM is also designed to produce a "living program" that accepts adjustments and improvements determined from in-service data collected as the RCM program operates. This 2019 work in this area is extensive and includes an evaluation of recent tuning changes to the inspection process which were made to add additional "safety factor". In this study the service contract requires the consideration of results prior to the addition of the Woodscan Non-destructive evaluation (NDE) technology which has been in service over the last 18 months.

During the RCM study, recent strategic changes were noted that include;

- An increase in the frequency of its inspection and testing process from 30 months to 12 months for all limited life poles. This results in a more accurate and timely indication of pole condition, minimizing the risk of unanticipated failure
- An increase to the pole residual strength safety factor from 1.25 to 1.40 for all poles on its network. The 25% safety factor was designed to prevent failure prior to replacement has now been increased to 40%. This factor is applicable when a pole is identified for replacement. The 40% safety factor applied at that time ensures the pole is replaced well before it reaches a safety factor score of 1.00.

[3] Energy Safe Victoria – The Condition of Poles in South West Victoria, Technical report – July 2019 Page 5, First paragraph – Poles studied were from Victoria's south west.

- The use of Woodscan technology.

The addition of more safety factor applies when a pole is deemed ready for replacement, and with this new safety factor in service this makes it much less likely a pole will fail while in the Priority 2 - P2 – US (Unserviceable) status.

The increased inspection frequency while in Limited Life (LL) status (now called Added Controls – serviceable (ACS)) pulls a different lever for improved performance in that once a pole is declared to be in (LL) limited life status, it is now much less likely it will fail undetected before the next inspection. This is due to the added inspections now performed once the pole enters (LL) limited life status. This recent change makes it more likely the LL poles will be properly rated into an unacceptable condition and managed within the business "critical path". (See the Critical Path discussion)

Unfortunately, these changes do not seem to make a material difference on the 75% of pole failures that occur from the serviceable state. (See the Critical Path discussion)

By law, ESV holds the distribution business to account by monitoring and enforcing the safety of the Victorian distribution businesses' design, construction, operation, maintenance and decommissioning of electrical transmission and distribution networks. ESV monitors distribution business compliance with their obligations under the Electricity Safety Act 1998 (the Act) to minimize risk "as far as practicable" which is articulated in the distribution business's Electrical Safety Management Scheme (ESMS) and Bushfire Mitigation Plan (BMP) promoted by CP/PAL and accepted by ESV.

"As far as practicable" is therefore the governing limit for an acceptable probability of a pole failure. Intrinsic within the concept of as far as practicable is the acceptance that zero pole failures are not currently achievable.

The challenge with a non-zero target that has no finite value becomes one to consider all sources of information that may contribute to a pole failure or the pole failure rate when measured across a period and then action controls that reduce the number of pole failures to a practicable level.

The 2005 RCM study the risk of pole failure was approached differently, as the level of acceptable risk (of an unassisted pole failure) was provided and assumed to be a level that did not exceed the current (measured) pole failure rate. This can be technically described as a probability point estimate of 20/375,000 (or equivalently 1/18750 for a pole failure rate of 0.000053) in units of pole failures per year. In contrast, when the target is described to be "as far (or low) as practicable", we cannot define an absolute numerical value to describe this acceptable level of pole failure notion, so knowing where the business is currently performing becomes an important benchmark, if only to compare to the past.

Comparatively, the average annual number of unassisted pole failures across Australia is 0.007 per 100 poles with Victoria averaging 0.003 per 100 poles[4] or 0.00003 to 0.00007. The 2019 RCM study used a 10-year study period average where 209 pole failures were recorded between 2009 and 2019 yielding a 0.000021 pole failure rate.

The current CP/PAL failure rate is well below the Victorian and Australian averages. Still the 2019 RCM study strived to understand the limits of "practicable" and ARMS was requested to examine the CP/PAL Business as Usual (BAU) practice in depth probing the RCM derived inspection business process deeply including consideration of the adjustment of inspection frequencies.

To this end the study team at CP/PAL developed what is now called the business "critical path". The "critical path" represents a model which is a term used within the RCM study to describe to a business as usual (BAU) business practice. Under pinning the critical path model technically is a Markovian state diagram which portrays the life of a power pole. This model was developed and utilized during the RCM process to organize the performance of the existing inspection program with SAP derived data. The rationale for doing this was simple. If the business process was under-performing it might be practicable to make small changes to the inspection program "execution" which might lead to a reduction in the pole failure rate.

For this reason, the individual pole status transitions were examined. The pole status changes in SAP as a result of an inspection. This data was analysed extensively to identify patterns and collect statistics. This

[4] ESV Report noted in 3 - Sourced from the Australian Energy Regulator's Regulatory Information Notice data submitted by: Victorian DNSPs 2011 to 2018; other DNSPs 2016 to 2018

analysis was essential as it was driven by the need to identify additional practical levers of control that might be possible.

On the critical path we found what are now referred to as the "β1" transitions could be considered a forward predictor of pole failures. The predicted failures themselves are likely to be observed on the "η6" direct transition from the serviceable state to failed pole state. These are thought to be β1 transitions that ran out of safety margin.

In a different body of work, the service contract required we project the next 20 years of replacement pole performance. This analysis then shows the number of poles that will become candidates for the β1, η6 and η7 transitions are expected to increase perhaps as high as 8-fold higher occurring over the next 20 years. The combined study team made this projection two ways – with one method being more conservative. Both methods of projection show an increase in pressure on the inspection program and this makes it likely pole failures will increase in the future, with only the latest controls representing a changed condition that might be able to arrest this increase. (Again - See Critical Path discussion).

While there remain some unknowns as the future unfolds, the active monitoring of the critical path transitions should serve as a predictor of future pole failures. Active management of the inspection process and possible adjustments to existing safety buffers should allow the increased pressure to be absorbed.

While the report does not provide an exhaustive treatment of every methodology that was utilized during this study, we do go into some detail to support service contractual requirements. We do provide supporting calculations, with charts and references for the interested reader. This additional effort serves to educate the reader on the very complex topic that on the surface must seem like a simple piece of wood.

Our conclusion after 4 months of work, including the analysis of several hundred data sets, is that the RCM process has succeeded in providing a new level of information to the business from which data informed decisions have been made.

It would be a serious oversight if we did not thank the entire CP/PAL team, their retiree's, and the international expertise that joined the RCM study and made this study such a success.

A very special thanks for keeping the ARMS team safe while we worked on a very interesting challenge.

Disclaimer

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Revision History

Rev	Date	Section/Page No	Description of change
1	28/10/2019	All	First issue

Contents

Scope Boundary

Services to be performed by ARMS Reliability:

- Plan and facilitate an RCM study on CP/PAL's timber distribution poles
- Undertake a planning session with CP/PAL lines asset strategy team members
- Providing guidance on the data content and format requirements to support the data collation by CP/PAL lines asset strategy team.
- Facilitating RCM workshop/s including nominated subject matter experts (CP/PAL and external/industry)
- Multiple scenarios within the RCM study on timber distribution poles are being sought as follows:

1. Validation of existing business as usual (BAU) practices and maintaining existing inspection frequency.
    i. BAU practices shall incorporate recent policy changes associated with 'serviceable – added control' timber poles.
    ii. Scenario should consider significance of network location on failure rates, and a population projection for timber poles under BAU.

2. Validation of inspection frequency required to maintain current pole failure rates.

3. Recommendations of required inspection/assessment methods for failure mode performance to reduce the current failure rate to within CP/PAL management expectations.
    i. Consideration should be made of the developments associated with CP/PAL's parallel investigation into NDI methods for timber poles.
        - RCM study is not to extend to scenarios that would breach regulated minimum inspection frequencies.
        - Provide a recommendation for a monitoring regime for the factors influencing the outcome of the RCM study, with due consideration of utilizing CP/PAL's existing asset management system (SAP).
    ii. Deliverables of this service include:
        - A clear and detailed written report that documents the outcomes and recommendations of each RCM study, including detailed basis of all decisions and assumptions made during each RCM scenario.
        - Supporting documents used/produced in the RCM study, including all calculations with corresponding formulas in electronic CP/PAL agreed format
        - All documentation is required to be submitted in printed form and in addition, as electronic files. The electronic versions of files shall be in commonly used formats such as MS Word, MS Excel, MS PowerPoint or PDF.

Project Background

The use of wooden poles to support electrical overhead lines and the knowledge of their state of conservation becomes crucial for decision making by companies in the electricity sector which use these structures.

It is the consensus among electricity distribution businesses globally that the extension of the in-service life of wooden poles represents an important factor on cost accounting. Various approaches to re-investment planning have been considered by many authors since the early 1900's. At CP/PAL with an aging population exceeding 400,000 poles, the extension of in-service life is not only economically important, but equally important, and perhaps more import is the need to manage this population safely and increase the ability to plan for the age-out of the poles currently in service, as age extension does not last forever.

The RCM approach to the program of maintenance and the subsequent replacement of poles can be decisive in the economic impact of these structures have on power distribution systems. Thus, these programs should be accompanied by a probabilistic approach that allows reduction and optimization of costs with the prediction of future retirements. Since wood is a renewable resource, there is also an environmental gain, but even this must consider the supply of the Australian renewable timber resources available in future years for energy network applications.[5]

For this RCM project a contract for the supply of services, CP/PAL Order No. 7024011 was issued on the 26th day of April 2019 between Powercor Australia LTD and ARMS Reliability. The core work was structured to facilitate an RCM centric study and additional work to evaluate the suitability and capability of various aspects of the wooden power pole maintenance strategies with other deliverables and forward-looking predictions of future pole failure rates that might be expected.

When viewed at a high level, the project was a risk management project which utilized RCM coupled with statistical analysis to inform decisions culminating in a workshop that was guided by the Reliability Centered Maintenance (RCM) methodology. The 2019 RCM work, as noted, follows prior work in 2005[6] and the RCM work that was initially first actioned in 1997. The 2019 RCM work was specifically guided by the IEC 60300 dependability standard.

The RCM process used in 1997 and 2005 were a bit different. These studies used historical data from the assets coupled with the experience of people in the business as well as suppliers of material for the purpose of building a picture to allow management processes to be put in place to manage the risk posed by the asset. During this time frame the durability class 3 poles posed few performance issues as they were in their "honeymoon period" of sorts and presented few problems. We have concluded the experience-based approach used in 2005 would have been largely then built on the functional failure experience of the then durability class 1 poles.

The 2019 study is different in now it considers the aging durability class 3 poles and further expands the practicable boundaries using applied statistical analysis of the pole sub-populations derived using SAP captured data of pole performance. Using data to inform business decisions is important. On the surface the SAP data is ideally attributed many ways, allowing a variety of unique scenario analysis options to be prepared. The attributed data did allow the RCM team and CP/PAL management to make more data informed decisions than those that have been possible in past RCM studies, but this was only possible after a multitude of data errors were suppressed.

The challenges with data integrity were many.

To make the data usable considerable work was needed to cleanse the data extensively. It would take a large part of 4 months' work before a reasonably clean working database emerged. Unfortunately, the data cleanse was not complete before the scheduled RCM workshop, so as more data became available, rework was needed to utilize the latest data in the analysis programs. The data cleanse work as noted, progressed steadily over 4 months and was required to be supported by expert recollection and knowledge which was invaluable as some data governance changes were made over the last 20 years, and knowing when the data fields were used for what purpose was essential.

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[5] Australian Timber Pole resources for Energy Networks – L. Francis and J. Norton, Innovative Forestry Products, Horticulture and Forestry Science, Department of Primary Industries & Fisheries, Queensland Government and ENA – Energy Network Association, October 2006
[6] Powercor report: 2005 RCM Review on Powercor's Asset Inspection cycle

As an example of the challenges encountered, five (5) different incrementally improved data sets were issued in 4 months just to represent the in-service population. This data set is simply an inventory of poles that are in service. The last data set of this kind was issued after the RCM workshop. The reason for this was during the RCM workshop several challenges to the data integrity were presented and found to be justifiably made. This challenge process highlighted a problem with data integrity but also resulted in improved data which was welcome because of its increased clarity and accuracy. The new data was use but where automatic updates were not possible between analysis packages, the analysis had to then be manually updated and as a result, work was performed several times before it was finally complete.

Even as this report was being compiled, better data was being delivered and it was sorely needed to provide even better scenario analysis and views of performance. The last data set was transmitted on September 13th, 2019.

It should be noted this was a very agile effort with many changes.

Better data allows a more informed view.

From a practical and improved view point we can share, the power poles on the Powercor network vary in material type, site, location and environmental conditions. In the past it was not seen possible to manage the individual pole as a stand-alone item. For this reason, in prior RCM studies the poles were grouped to a level which was considered manageable based on the known data considerations whilst maintaining a level of risk which was acceptable to the business at an acceptable cost to the consumer. The groupings were not always aligned with the changes in data.

Data analysed for the 2019 study suggests there is clear performance differences that vary predictably between species, treatment type (if used), old forest or plantation grown wood, and there is a noticeable but a smaller than expected regional environmental correlation which is consistent with low correlation to environmental conditions observed by other researchers [7].

The practicable challenge in this RCM Study was to consider all sources of individual pole information with the poles sub-population statistical performance as a group and with the impact of a pole failures observed to allow one to arrive at a strategic program that is both manageable and practicable. Practicable means " able to be done or put into practice successfully".

Scaling the 2005 target pole failure rate expectation up to the current 405,544 poles in service suggests a rate of 21 to 22 pole failures per year would be "acceptable" if we were using these older criteria. The current data confirms a 0.000021 failure rate. The criteria contained within the 1998 Electrical Safety Act however clearly shifts the obligation from that of a defined failure rate to one that is "as low as practicable" which is a change from the 2005 RCM analysis which as a result makes some calculations more difficult.

The RCM team looked at what might be practicable.

First, we looked more closely at the actual pole failures and examined poles that also almost failed.

To consider poles that almost failed the data was grouped using a more stringent pole failure definition. This effort used a definition that was more stringent than the reportable failure definition used to report pole failures to ESV. As a result, for some analysis considerations we included the near miss (P1 ranking) events over the past 10 years. With this very conservative inclusion to pole failure events CP/PAL have recorded a rate of 37.8 pole failures or poles that came dangerously close to failing or failed on average per year from a population of 405,554 wooden power poles.

As noted, this is a conservative analysis of the business-critical path, but this also revealed that some poles were not progressing from "Serviceable" to "Unserviceable" in a controlled way through the LL state as prescribed by the RCM inspection process.

This was a very important finding.

Upon learning this, the RCM study focus was then placed on what levers of change could CP/PAL action to control more of the pole's end of life journey in a proactively managed fashion? To answer this question, we

[7] Predicting Rejection Rates of Electric Distribution Wood Pole Assets, Boyan Lyubomirov Kelchev
University of San Diego, 2009.

performed various scenario analysis, and population projections were re-operated on the post workshop data to understand the near-term increase in the pool of pole failure candidates that fed the pole failure group.

Noting that strategic changes had already been made to the CP/PAL inspection process safety buffers, and that there were some other changes under consideration, the BAU critical path was further examined incorporate the various changes. In order to fully understand this complex discussion, those changes still under consideration should be reviewed in conjunction with the BAU critical path discussions contained herein and coupled with the population projections and the current RCM tasks to determine if as the population of candidates for pole failures increases, whether or not more practicable controls might be required in the near future.

The RCM workshops detailed several action items that were captured each day during discussions, including those topics surrounding the large effort needed to stabilize the existing data. CP/PAL should consider further actions that add to their ability to capture meaningful consistent data that has additional predictive power. This new data collection should start soon, and CP/PAL should collect data for the next 5 years and perform another RCM analysis.

The next RCM workshop should occur in about 5 years, and thoughtfully operate on this next level of data captured to adjust the “RCM living program” even further and to review if additional measures might be required to combat the increased loading from pole replacements expected, thereby keeping the pole failure rate as low as practicable.

The Reliability Centered Maintenance (RCM) Methodology

This section provides a high-level introduction of the IEC 60300 RCM methodology used during the 2019 RCM study. It follows similar sections found in the 1997 and 2005 RCM reports detailing their study methodologies.

Reliability Centered Maintenance (RCM) is a structured methodology used to identify and select wooden power pole failure management policies. When applied, RCM derived maintenance policies will efficiently and effectively achieve the required safety, availability and economy of operation of each wooden power pole in service.

Wooden power pole failure management policies derived from the RCM processing can include preventative maintenance or inspection activities, operational changes, design modifications or other actions needed in order to mitigate the consequences of a catastrophic pole failure.

The RCM methodology was initially developed within the commercial aviation industry in the late 1960s, culminating in the publication of ATA-MGS-3[8]. “RCM” per se, is the industrialized version of “MSG-3”. RCM is also an acronym for a methodology that has been popular for almost 41 years after it was first coined by Nowlan and Heap[9] in 1978. Since its introduction the RCM method continues to be the proven, prudent, and accepted methodology that operates to prepare critical assets world-wide.

The RCM process itself is important. RCM provides a structured decision-making process used to identify applicable and effective wooden power pole preventive maintenance actions and validate the inspection requirements and frequencies which CP/PAL uses. RCM operates in accordance with the safety, operational and economic consequences of identifiable pole failures whilst considering the degradation mechanisms (rot, termites, fungal fruiting, etc.) that are largely responsible for causing those failures.

The RCM process can be visualized as provided in IEC 913/09 which is shown using the process flowchart found in Figure 1.

The RCM process also asks seven (7) questions;

1. What are the functions and associated performance standards of the wooden power pole in its current operating context?
2. In what way(s) does a power pole fail to fulfil its function? (a.k.a. – functional failure)
3. What causes each functional failure?
4. What happens when each pole functional failure occurs?
5. In what way does each pole functional failure matter?
6. What can be done to predict of prevent each pole functional failure?
7. What should be done if a suitable proactive task cannot be found?

In asking these seven questions about a pole functional failure we are structurally exploring its core failure mode which can be described in general terms as when the pole drops below a predetermined specification of performance. The specifications of performance include a minimum bending resistance strength and a minimal amount of sound wood thickness which when below relate to the RCM concept of a functional failure. A functional failure is meant to refer to an event where the pole in service functionally fails or its strength or sound wood drops below an established specification for performance but is still within its designed program safety margin and is still physically standing.

A catastrophically failed pole or an ESV reportable pole failure is a pole that stayed in service far beyond the point of a functional failure designated as (F) and either breaks, splits or falls to the ground. The data group of total pole failures can be further reduced by classification into either an “assisted pole failure” or an “un-assisted pole failure”. Excluding assisted pole failures allows for RCM consideration that excludes random

[8] ATA-MGS-3:2003, Operator/Manufacturer Scheduled Maintenance Development
[9] NOWLAN, F.S. and HEAP, H.F. (1978). Reliability-Centered Maintenance. Report AD/A066-579, National Technical Information Service, US Department of Commerce, Springfield, Virginia. (UAL-DOD)

events like vehicle strikes, lightning, and extreme weather events. This additional classification allows focus on the aging process normal to a pole.

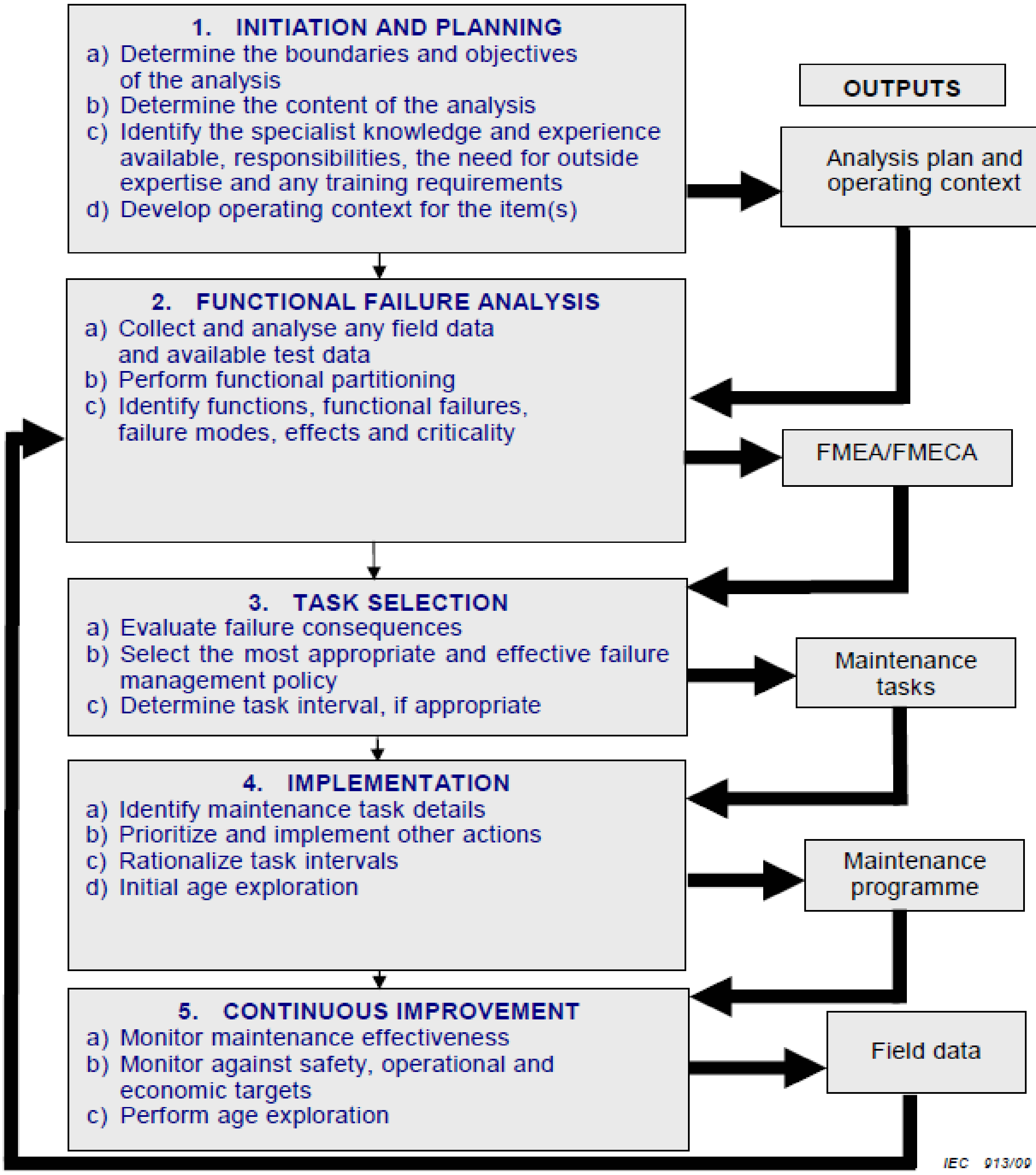

Figure 1 - RCM Process Overview IEC 913/09

The result obtained by working through the RCM process culminates with a judgement that is made as to the necessity of performing a maintenance or inspection task, or a design change or perhaps other alternatives to effect improvements. In our study, this maintenance task judgement has been previously rendered in RCM studies in 1997 and 2005 and so our task in 2019 was to reconfirm or validate these decisions.

In 2019 decisions were also requested to be evaluated more closely for the purpose to determine the optimal frequency of inspections given the available safety margins that have been designed into the inspection program, tempered by the wide variability of the current aging power pole population.

Where data existed, it was possible to suggest the frequency of inspection influenced by actual measured PF interval and calculated from guidance found in the MIL-2173 RCM standard on RCM.

The basic steps of an RCM study are as follows:

a) Initiation and planning;

b) Functional failure analysis;

c) Task selection;

d) Implementation;

e) Continuous improvement.

Steps (a) through (d) where completed initially in 1997 prior to an initial data load of the asset management system utilizing SAP PM. The 1997 RCM study states it was also "focused on the inspection cycles for distribution power poles whist maintaining the current level of risk and to determine the feasibility of the alignment of Powercor's inspection cycle to CitiPower's inspection cycle."[10]

The 2005 RCM study reviewed the function and functional failures of each asset and calculated the level of inspection required based on the level of risk acceptable to the business.[11] In 2005 the wooden power pole primary function statement was adjusted, and several secondary functions of the wooden power pole were added to ensure completeness of analysis.

The RCM methodology and additional terminology we have used in 2019 has been defined in the international standard IEC 60300 – Dependability Management. The international standard thereby grounds the 2019 RCM process with the best and most current international guidance for RCM.

The specifics of Dependability Management and the RCM process can be found in IEC 60300 part 3.11 – the Application Guide – Reliability Centered Maintenance.

As noted, the 2005 RCM study also sought guidance for specific inspection frequency calculations, related to the maximum acceptable probability of failure of the inspection process. This guidance was taken from the US Military RCM Standard MIL-2173 (AS) MILITARY STANDARD: RELIABILITY-CENTERED MAINTENANCE REQUIREMENTS FOR NAVAL AIRCRAFT, WEAPONS SYSTEMS AND SUPPORT EQUIPMENT (21 JAN 1986) [S/S BY MIL-HDBK-2173]. [12] The military standard for RCM provides the best explanation and provided worked examples for how to properly utilize the provided technical equations. This area was explored closely before data on the PF interval was analysed using Kaplan Meier Survival Analysis suggesting an alternate approach.

For historical consistency, we thought it was very important to maintain alignment with prior RCM studies especially where RCM is used within existing CP/PAL policies.

For these reasons the 2019 RCM study maintained the form and function of the 2005 study decision worksheet. This format is known within industry as the RCM II format. The RCM continuous improvement evolution process has been followed since 1997. This is consistent with repeat applications of the RCM methodology as generally provided in IEC 914/00 and the diagram below to augment the "RCM living program" after an initial maintenance program has been established using maintenance data as shown in Figure 2.

[10] Powercor Australia LTD - 2005 RCM Review on Powercor's Asset Inspection Cycle report, Page 7 of 51, section 2
[11] Powercor Australia LTD - 2005 RCM Review on Powercor's Asset Inspection Cycle report, Page 7 of 51, section 3
[12] Guidelines for the Naval Aviation Reliability-Centred Maintenance Process, Navair 00-25

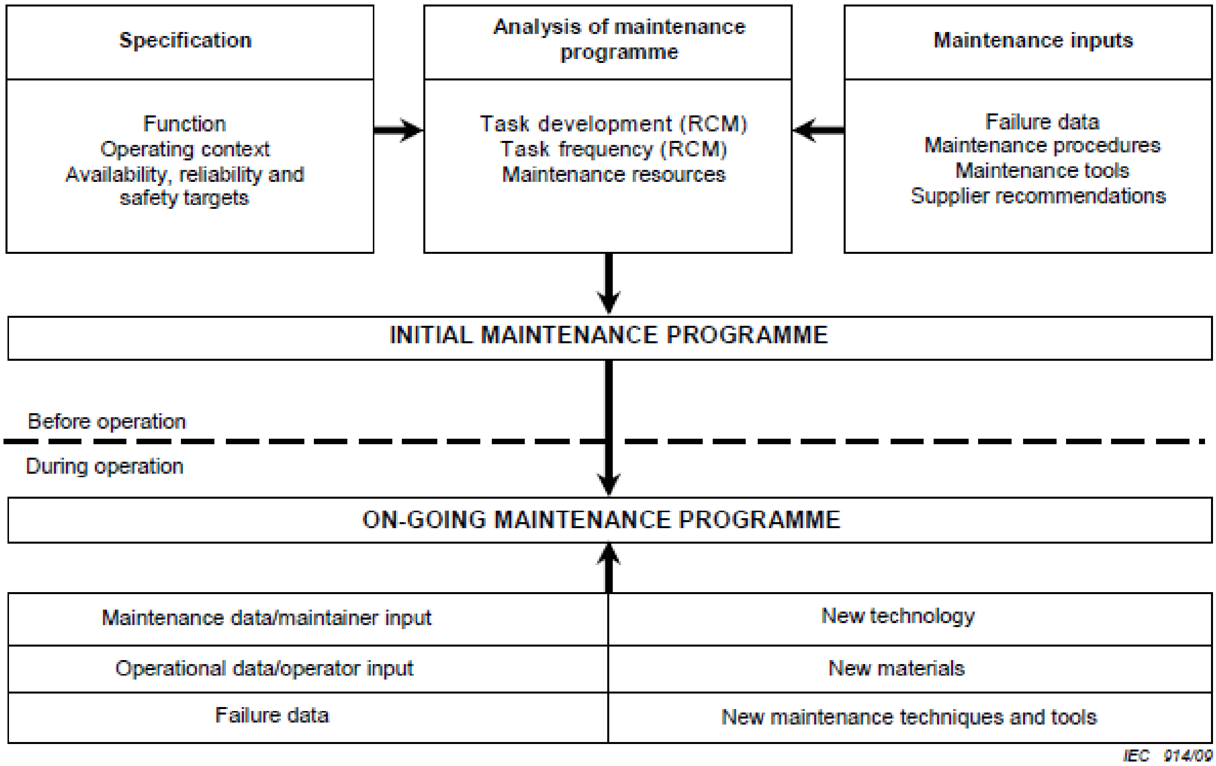

Figure 2 - Evolution of an RCM Program - IEC 914/09

Successful repeated application of RCM also requires a good understanding of the asset under consideration and that understanding is informed over many years by inspection monitoring and consistent data capture.

To this end data in 2019 has driven us to realize that the wooden power pole species and timber structures generally, as well as the operational environment, operating context and the associated systems combine to create differing performance trends that can be advantaged. These items must be considered together with the possible failure modes and their consequences so all relevant considerations are made which must be considered holistically to achieve the highest safety and lowest possible and practicable level of risk.

To be capable of making such a broadly informed decision the membership of the RCM team was very carefully considered.

The 2019 RCM workshops we were fortunate to have a cross functional team of Australian and International experts in the CP/PAL offices in Melbourne in August 2019.

The workshop work agenda included of course work to re-evaluate the primary and secondary functions of a wooden power poles derived from the 2005 RCM study. Perhaps a more dominate focus was the enablement of data informed decisions to support the RCM process. The 2019 study boundary was set to focus on the wooden power pole only, so items like cross arms, some metal and insulating items were not considered in 2019.

The 2019 review focus was on;

- The function of the wooden power pole
- Functional Failures that may occur
- The failure mode (or way in which it fails)
- The effects of the failure.

The 2005 RCM primary function of a pole was ***"to be capable of supporting at the specified height and lateral clearances, under specified loading conditions, overhead conductors, and other line components."***

In 2019 this function was split to consider the load supporting capability separate from the clearance/vertical alignment function to allow more precise consideration.

The secondary functions included but were not limited to;

- To be capable of being disposed of in a manner that reduces the impact on the environment at the end of useful life of the pole.
- To be capable of being electrically safe.
- To be capable of preventing unauthorized personnel accessing the pole top.
- To be capable of being identified.
- To be capable of accepting chemical treatment applied at the pole site.
- To be capable of preventing insects/animals inhabiting the pole.

During the workshop the RCM II logic was applied using the RCM process resulting in a maintenance strategy decision for each failure mode of consequence.

The resulting RCM decisions (Found in Appendix M) form the balance of the 2019 RCM study and are almost entirely on-condition recommendations which have been technically feasible since 1997. These actions still require a periodic inspection of the wooden power pole for certain defects and to be practicable, they are grouped into a cyclic regime.

The program adjustments needed are/were to safety margins applicable at decision points on the critical path.

The inspections recommended need to be performed at a periodic interval, with effective program safety margins at the functional failure point (F) to be fully effective. Why is this important? Over time, we are expecting the candidate pool of pole failure candidates to increase by perhaps as much as 8X, so it is vital the safety margins be monitored and if needed further adjusted to counter the variability of wood, the effectiveness of inspection and to use the emergent technologies that might become available in the future.

The 2019 RCM process took guidance from the RCM II decision logic diagram shown in Figure 3 to confirm the inspection-based program as technically feasible, worth doing and applicable.

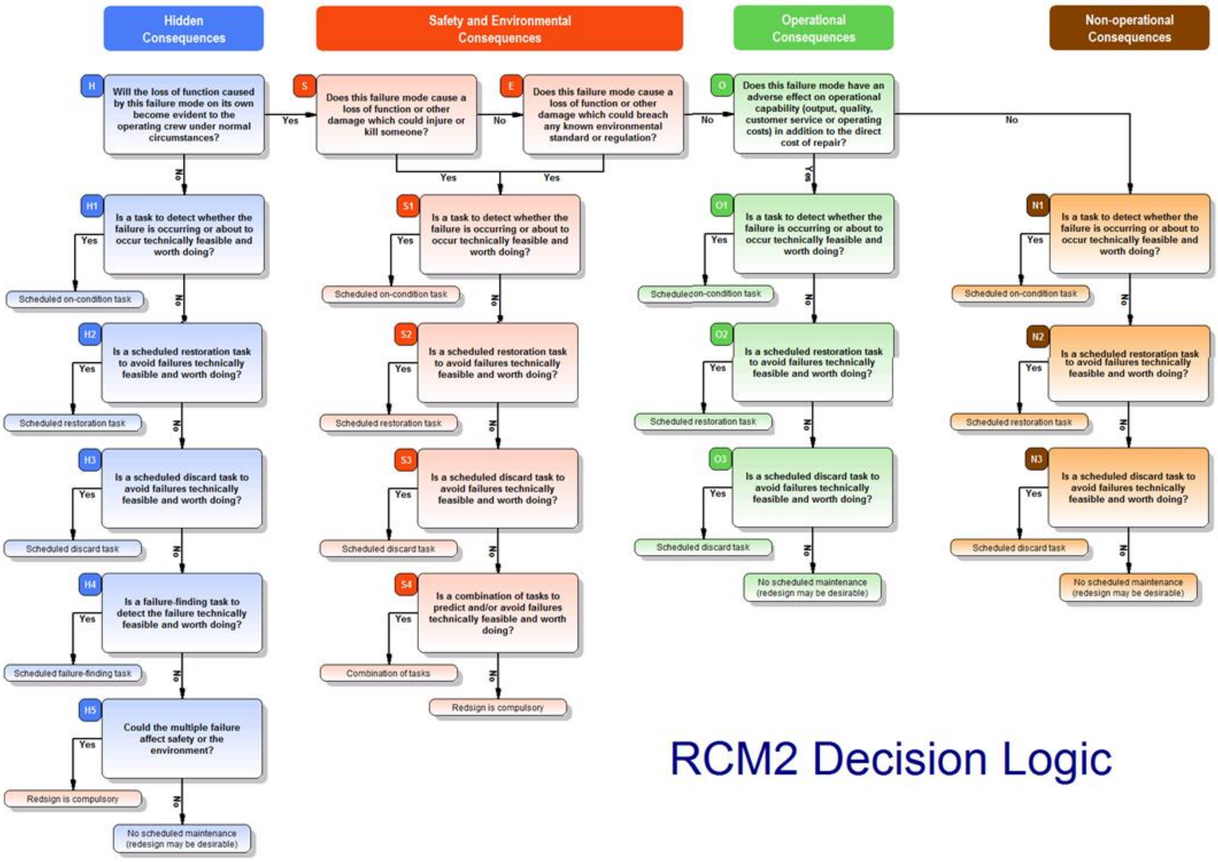

Figure 3 - RCM II Decision Logic

The resulting tasks were designed to offset the array of failure modes.

They are recommended to remain grouped together, so the SAP executed inspection process is efficient.

While “inspection” in this sentence is defined loosely, it is meant to reference an activity whereby one inspects each pole for each relevant failure mode at a frequency that best suits the reduction in pole failures. (See CP/PAL Inspection Process Section)

This decision logic chart should be worked with the RCMII worksheets to fully inform the reader as to the RCM process followed.

RCM Team and RCM Preparations

As with almost any project that spans several months, preliminary work was required to prepare for the RCM process and statistical analysis.

The data preparation and RCM planning began in May 2019 and extended through mid-September 2019.

The additional but vitally important up-front activities included assembling an appropriate cross-functional team, making sure that all members of the analysis team understand and accept the ground rules and conditions of the analysis (e.g., scope of the analysis, definition of "failure," etc.), gathering and reviewing relevant documentation, etc.

CP/PAL management determined the make-up of the cross functional team seeding it with several industry experts who proved invaluable.

The quality of the RCM decision process was positively influenced by the strength of the RCM team, their contributions and the combined teamwork. It is an understatement to convey in words that the RCM team exhibited excellent teamwork as each expert contributed at a very high level of intensity as each of the various topics were explored in depth, and this was infused with current and leading-edge research which was also considered during the RCM evaluation process.

Several members of the team needed a few days to recover from the intensity of the RCM workshop.

The RCM Team included;

- Philip Sage – Principle Reliability Engineer – CRL CMRP -RCM Facilitator - ARMS Reliability
- Peter Livingston – CP/PAL – Asset Management
- Michael Powell – Australian Timber Expert/Fungi Expert – Biotica
- Nathan Spencer – Australian Wooden Timber Structural Integrity Expert – REVO Group
- Tim Gowland – Renewal and Regulatory Expert – CP/PAL
- Amy Boyd – Data Scientist – Asset Lines CP/PAL
- Dennis Clancy – Wooden Power Pole Expertise in Victoria – Biotica
- Glenn Trew – Wooden Power Pole Inspection Expertise – Electrix

RCM Study Additional Comments

The 2005 RCM Study recommended the addition of several measurement points into SAP PM to be made on the wooden power pole during the inspection work[13] with the forward view that future RCM studies could leverage data collected to make data informed decisions.

This data is messy and does not contain enough predictive power in its raw form, and so more improvements are needed to deliver a ready data set with considerable predictive power a modern utility should possess.

This is needed for on-going monitoring and for future RCM studies.

The data clean-up steps made to the current SAP PM database are partially listed in Appendix E and F for transparency but at this writing in mid-September those listed are recognized to be a subset of a larger list now maintained by CP/PAL.

We have still included these as a reminder of the importance to take a big step in this direction.

When we did arrive at reasonably good data, we found the pole performance to be considerably varied and affected by many variables. Each species acted differently, and the probable length of service was also a highly correlated function to the treatment type applied during manufacture.

The “dots” in Figure 4 represent an individual poles age at replacement, as analysed by a Weibullian approach to illustrate the varied performance of each species. Each line of dots of the same colour is related to a single species. If all species performed the same, all the dots would coincide. They do not, and the wide differences manifest in the average year a species requires replacement with a varied deviation around that average.

The legend uses the Australian standard AS3818.1 species brand 2 letter abbreviation, BI is Iron Bark, and so on.

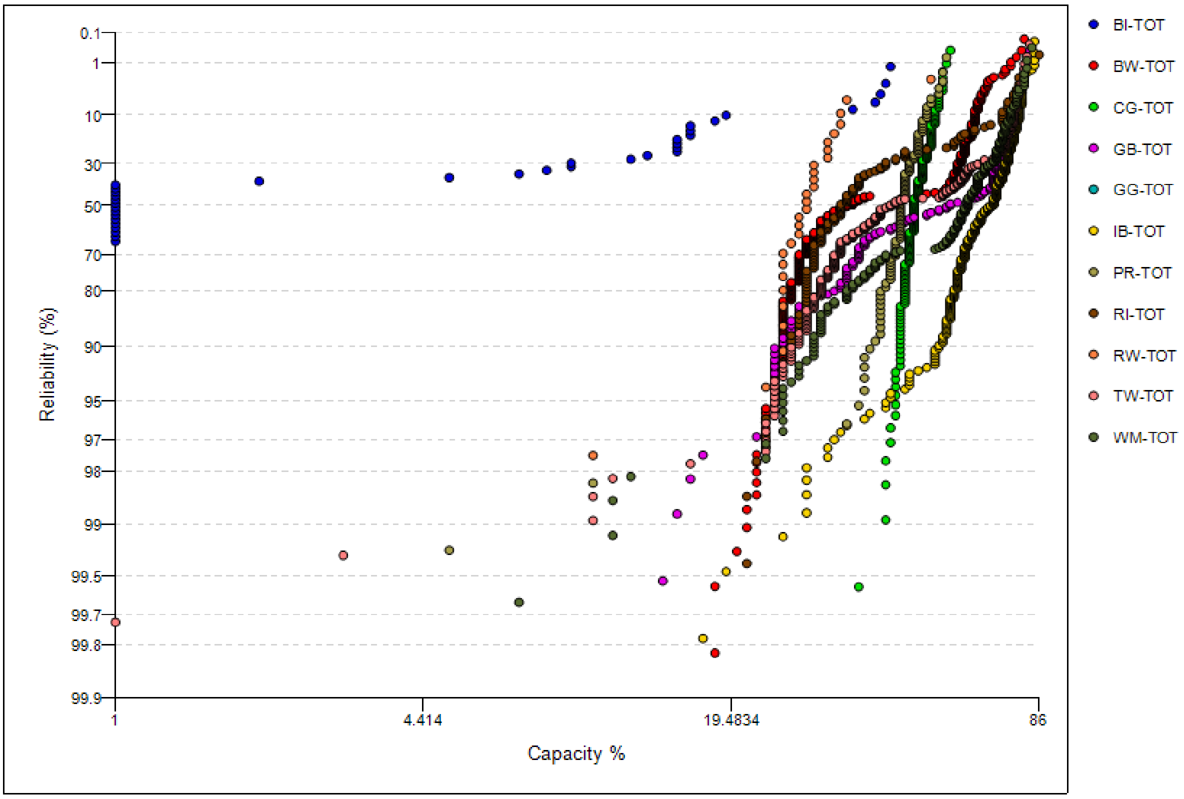

Figure 4 - Pole performance by selected species[14]

[13] IEC 60300-3-2, Dependability management – Part 3-2: Application guide – Collection of dependability data from the field
[14] Chart from Timber service life design – Design guide for durability, revised version Oct 2013 LEICIESTER, R. Wang, C. et all., Technical Design Guide issued by Forest and Wood Products Australia

SAP data has many attributes, but some very important events are not tracked or could not easily be surfaced for the RCM investigations.

What is not tracked or measured is the performance (or lack thereof) of the chemical treatment applied during each inspection.

The chemical is known by its trade name of “pole saver” and is a boron and fluoride treatment that is thought to arrest several types of common rot. During the RCM workshop it was concluded the pole calculator input was over-riding the “as found” condition with default data making it impossible to utilize records stating that “no pole saver found”.

This should be corrected and the inspector should input if no pole saver was found indicating differently if (depleted or never installed).

For poles that pole saver is known to fall into the rot cavity where it is thought to be in-effective, the data should clearly mark this event.

Review of SAP Reported - RCM Functional Failure Causes

The reported cause of a pole replacement (Functional Failure) was compared with the primary RCM functional failures during the RCM workshop to determine if the selection of primary functional failures was complete.

We used the SAP data to determine if a functional failure affected a critical mass of the pole population. The data presented is classified by the functional failure cause code assigned to each pole removed from service from 2009 to 2019.

Fire	2%
Footing Failure	0%
Fungal Fruiting Body	10%
Incorrect installation	0%
Inspection Holes	0%
Lightning	1%
Rot/decay external	8%
Rot/decay internal	36%
Rot/decay internal & external	19%
Termites Glyptotermes	2%
Termites subterranean	12%
Third party	2%
Vehicle impact	1%
(blank)	8%
Grand Total	100%

Table 1 - Functional Failure Causes

Combining classifications to align to RCM functional failures we have;

- 63% of retirements were due to Rot or Decay.
- 14% of retirements were caused by termites.
- 10% of retirements were caused by Fungal Fruiting Body.
- 2% of retirements were caused by a Fire
- 2% of retirements were caused by Lightning or Car strikes.

87% of the functional failures were recorded due to functional failures attributed to rot, decay, and termites or independently caused by a fruiting fungal body being observed on a pole above 2 meters.

Cause codes from random sources like Lightning, third party, or Vehicle Impact are not controllable per se, but were discussed as secondary functions of the pole during the RCM workshop. These do not have critical mass and account for a low amount of pole replacements. (4%)

The largest area for improvement resides with the data integrity where 8% are blank “cause records”. The blank data could not be considered in the RCM workshop due to its incompleteness and this should be corrected to ensure all pole replacements have an accurate pole replacement cause code.

There is no cause code currently available to designate the emergent condition of soft rot.

Survey of Existing RCM Tasks

The following task list and policies exist for the CP/PAL RCM program to clarify the RCM tasks and define the specific status and conditions.

Task List	
No.	Description
1	Address poles that are classified as Unserviceable as per the Network Asset Maintenance Policy for Management of Unserviceable Poles (05-C001.D-392)
2	Reinspect limited life poles every 2½ years ± one month
3	Poles identified with termites shall be addressed as per the Network Asset Maintenance Policy for Termite Management (05-C001.D-394)
4	Poles identified as leaning shall be addressed as per the Network Asset Maintenance Policy for Management of Leaning Assets (05-C001.D-393)
5	Poles identified as being located in hazardous situations shall be addressed as per the Network Asset Maintenance Policy for Management of Hazardous Structures to Traffic (05-C001.D-399)

Table 2 - RCM Tasks and policies in service during the 2019 RCM study

The existing task list should be worked in conjunction with the RCM worksheets found in Appendix M.

The Overall State of Wooden Power Poles

This section provides an overview of the challenges encountered whist trying to evaluate the current inspection performance and determine whether the program was fully effective under the business as usual (BAU) scenario.

There are five million timber power poles currently in-service throughout Australia. Roughly speaking about 1/11th of those poles are operated by CP/PAL.

Wooden poles have been commonly used to support electrical lines throughout Victoria being produced from a range of species cultivated in the country. Older poles operated by CP/PAL are native hardwood forest species that have suitable structural characteristics and are highly resilient to rot.

Newer poles are quite likely to be plantation grown.

In Victoria, 74% of all poles in-service are timber poles, and at least 50% of them were installed over 40 years ago[15].

To classify the poles resistance to the elements, the Australian Standard AS 5604 provides a durability classification system for untreated wood and is based on test samples.

The CP/PAL poles in service are durability classes 1, 2, 3 and 4 species, with most of the durability class 3 poles of concern being utilized in western Victoria and installed as part of the state's electrification program during the years 1953 to 1967. Class 3 and 4 poles require pressure treatment to be used in HBRA applications. [12]

The older poles were treated with creosote or creosote derivatives which is referenced in data and found on some chart legends as (WCI) for "wood creosote impregnated".

The newer poles are green in colour and are treated with a 1.2% solution of Copper – Chromium – Arsenate (CCA) which in data is referenced by its salt nature as (SAL) poles.

These both are pressure treated poles.

There are also untreated de-sapped dressed poles designated as (WUD) in data or untreated round poles (WUR).

Under careful analysis, we find the useful service life performance of the power poles varies by species, durability classification of the untreated wood, the type of treatment applied, periodic chemical application (pole saver or Blue-7), and possibly local environmental conditions.

In Figure 5 - the most popular species in-service today has their age at replacement charted as a histogram with yearly bins, fit with a normal curve. One performance model or size does not fit all poles.

[15] Australian Timber Pole Resources for Energy Networks Report
http://era.daf.qld.gov.au/id/eprint/3071/2/dpiandena_timber_pole_review06-sec.pdf

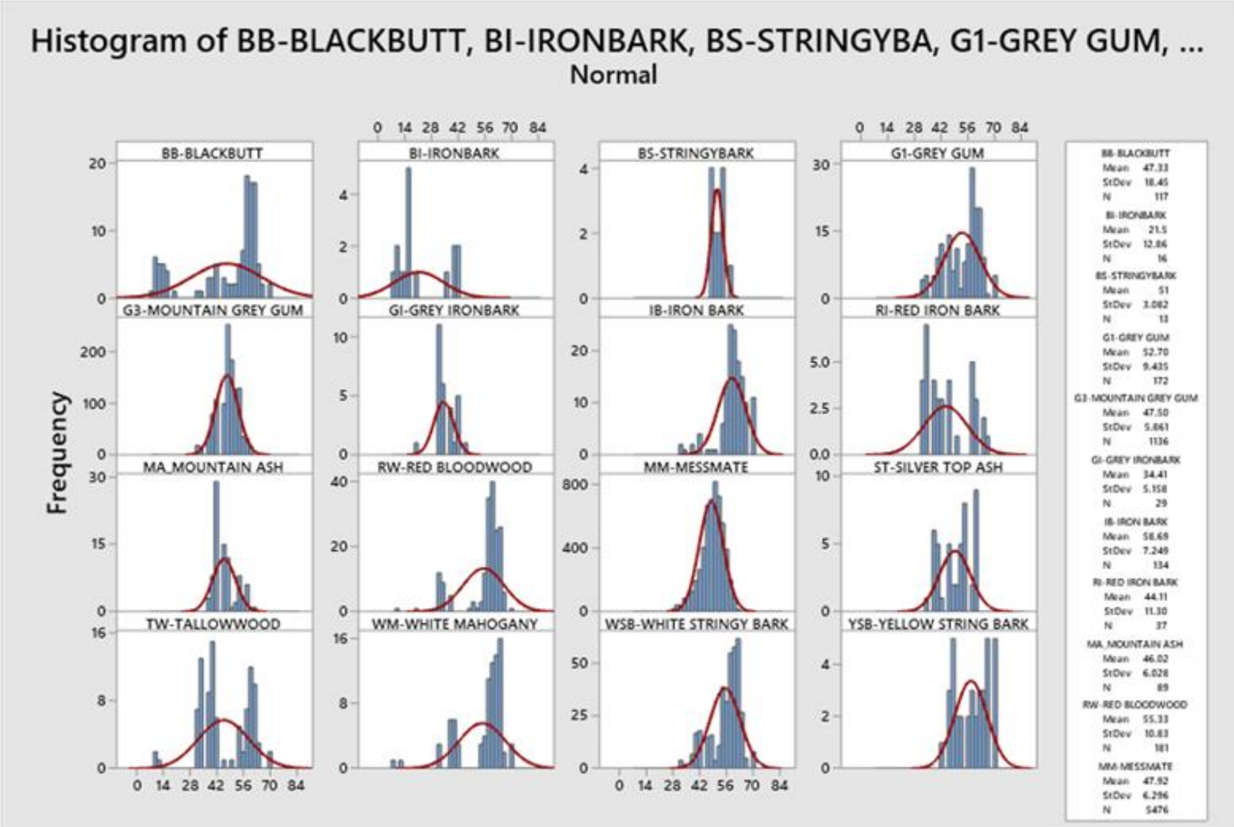

Figure 5 - Age at Replacement for the top 16 Species of Timber

Our analysis shows that older, premium-quality untreated durability class 1 poles that were either de-sapped or at least have been de-sapped around their ground line have exceptional in-service longevity.

There are a relatively small number of *Pinus Radiata* poles which have been treated with CCA to a suitable level to meet H5 bush fire area applications[16][17].

As noted, the most employed pressure treatment today is the one with a water-based chromated copper arsenate preservative (CCA) which is applied under pressure, since the use of the pentachlorophenol and creosote are now forbidden. While forbidden to use on new poles, the Powercor population has a large amount of older creosote treated poles in service and a smaller amount of pentachlorophenol treated poles designated (PEN) in data that become hazardous waste when they functionally fail.

In the RCM study the abbreviations of WCI and PEN are used to designate the wood creosote impregnated and pentachlorophenol impregnated pole data. These abbreviations are used in the data analysis titles and the abbreviations are used also in some graphical titles found throughout the report.

The pole life of all CP/PAL wooden poles today is extended by chemical treatment to retard decay with a boron/fluoride preservative used in the retreatment of in-service poles.

The Preschem product is called "pole-saver" and it is applied during inspection. It has been chosen due to its high efficiency and lower toxicity for humans and the environment. This chemical is applied into a drilled hole near the ground line. The Boron and Fluoride composition used in the pole saver product is thought to retard Brown and White rot effectively but does not seem to affect the failure mode introduced by soft rot.

Historically speaking, the pole saver was first used in 1991 and reportedly by the end of 1993's inspection cycle, the entire population had received its initial application. Prior to 1991 a product known as Blue-7 was

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[16] Australian Standard AS 1604.1 (2005) states traditional preservatives for hazard class five (H5) are copper chromium arsenate (CCA) type C: 1.20% m/m (% Cu + %Cr + %As) for hardwoods and 1.20% m/m (%Cu + %Cr + %As) for softwoods OR Creosote 13.0% m/m for hardwoods and 24.5% m/m for softwoods.

[17] Clancy – 2006 per communications as denoted in Australian Timber Pole Resources for Energy Report by Energy Network Association of Australia (ENA) page 39, 3rd paragraph.

used on some poles but was not reportedly applied to all poles in service. The pole-saver product must be in contact with sound wood and acquire moisture in order to be able to diffuse into the timber.

From a life analysis perspective, the introduction of both chemicals alters the life performance of the population by an un-measured amount making a forward prediction of the end if useful service life very difficult because the life extension amount is unknown.

The resulting increase in the in-service lifetime of poles is important cost deferral but we must also look at the total life cycle costs which in part are due to the costs associated with a pole replacement, and incur additional costs because the treated wood when taken out of service is considered a hazardous waste which must be adequately disposed of.

So, there are many factors which affect the end of life estimate. To sort out the population CP/PAL has loosely applied AS 5604-2005 to the CP/PAL SAP data. In the Australian Standard AS 5604-2005 lists approximately 80 species of timber which are classified by strength group and with a durability class rating, i.e. class 1, 2, 3 and 4 [18] as an attribute we have utilized to group scenario analysis. This durability rating is for native wood free from preservatives and thus only forms a starting point for evaluation.

Wood of course is subject to deterioration, which can occur due to the action of physical, chemical and biological agents and attack by termites[19]. Biological agents are the most important decay factor, and wooden poles can be attacked by bacteria, insects, fungi and marine drills.

The attack of wood decaying fungi can be rapid and can result in dramatic loss of pole strength.

Thus, complicating the estimate of pole life, the lifetime of the in-service pole could be shortened due to un-arrested decay or termite attack.

When performing a statistical analysis of the replacement of functionally failed poles, it is important to consider the cause of failure which has been recorded in SAP. This is the only record of these variations.

Decay is therefore a normal process for a wooden power pole. The decay rate arrested by pressure treatment and field chemicals is not attributable, making it difficult to fully identify the underlying species pattern.

Decay or as it is sometimes called, “Rot” mostly occurs within a region extending from about 0.5 m above to 0.5 m below ground line, where the presence of oxygen and moisture % enables metabolic activity and growth of aerobic micro-organisms such as fungi. There are many insecticides and fungicides used in wood treatment, but the efficiency obtained in the application of these wood preservatives varies greatly.

White rot and Brown rot are the most common failure modes within the decay category, but there is an emergent failure mode associated with CCA treated poles. CCA treatment is thought to effectively arrest white and brown rot, but there is emerging evidence the CCA treatment is not effective at arresting soft rot.[20]

Of the 80 species classified in AS 2205, CP/PAL uses 33 different species which in some cases have been arranged in RCM classification groupings and then were utilized to support the RCM Study.[21]

15% of the CP/PAL poles currently are listed as species ZZ-UNKNOWN. A reason for such a large amount of unknown species was offered during the RCM workshop.

That reason is, power poles are identified by a metal tag at 2 meters above nominal ground line. This is called the “pole disc”. When the pole disc identification is missing or possibly was subject to vandalism, the inspector is trained to enter the species as ZZ-UNKNOWN, which overwrites the SAP equipment record model number field, which is the field that contains the species ID.

While this is unfortunate, the loss of pole discs has been reported by other Distribution Business (DB) operators to be as high as 58%.[22] The problem is therefore not as severe at CP/PAL, but it is noticeable.

For this reason, the RCM study considered the ZZ UNKNOWN group of poles to be an unknown mixture of data, from which reliable conclusions could not be drawn. CP/PAL did discuss an effort to remedy the problem

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[18] Australian Standard AS 5604-2005 Timber - Natural durability ratings
[19] Powercor Network asset Maintenance Policy for Termite Management document (05-C001.D-394)
[20] Australian Timber Poles Resources, I. Francis and J. Norton, Queensland Government and ENA, October 2006 Page 95.
[21] See Appendix G – Species Listing used for the 2019 RCM Study.
[22] Inspection of Wooden Poles in Electrical Power - Distribution Networks in Southern Brazil, Flávio L. R. Vidor et all, IEEE Transactions on Power Delivery, February 2010, IEEE Xplore

by looking closely at SAP PM records to recover the last known species of wood from data, where the pole disc is now missing, and the pole has not been replaced. This data was not made available during the study.

Given these exclusions, there was still ample data to work with often resulting in very tight 95% statistical confidence intervals for several groupings.

With good data the analysis found that there is considerable life performance variance observed between the differing species of wood, as illustrated in Figure 6. In this exhibit several species with critical mass were analysed using their functional failures and the results of four different analysis methods overlaid onto a common result to enable the evaluation.

As an example, the study found that there are clear differences that exist in the life expectancy and performance when the poles are grouped in several scenario groupings, as viewed in Figure 6. The x-axis is years of service on all four graphs

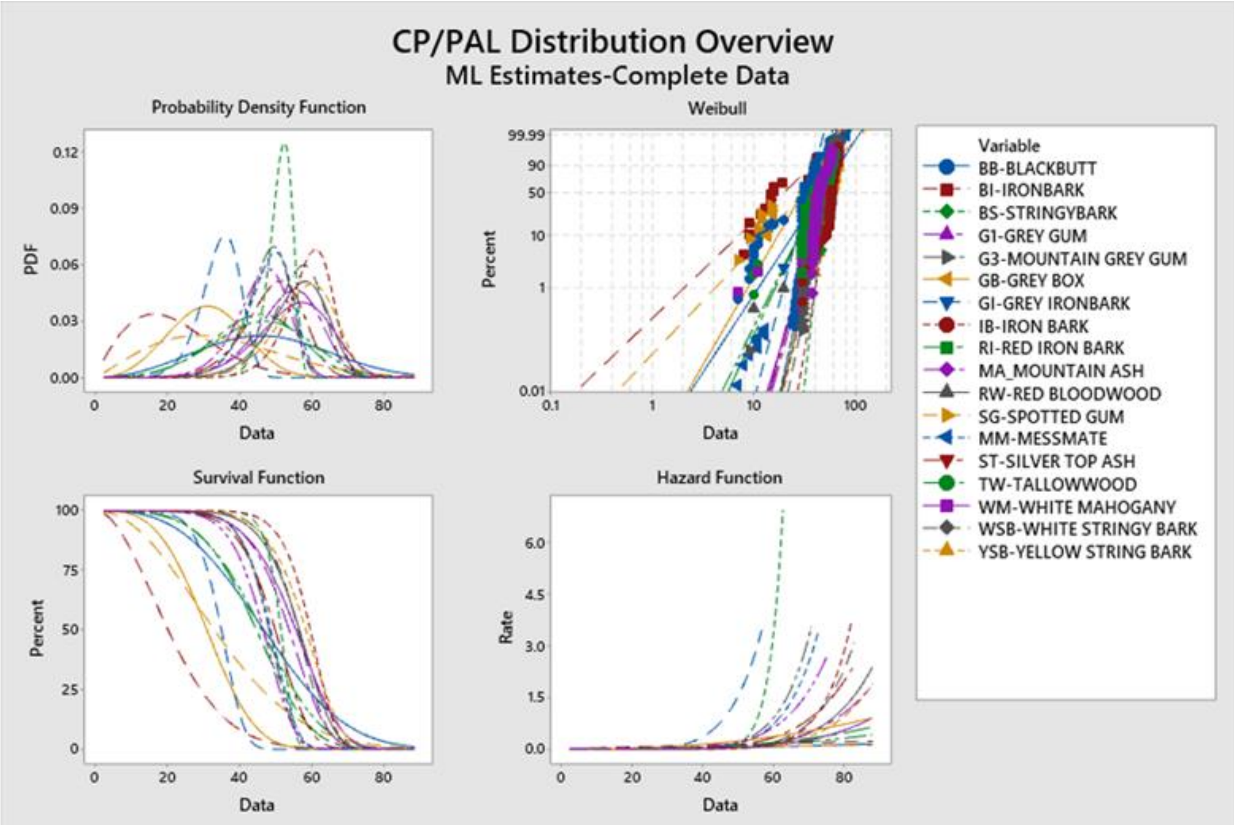

Figure 6 - Species Life Variance

The species life variance exhibit has 4 graphs on the same panel;

1. The Probability Density Function (Upper Left) is the probability density of end of service life replacements from the period 2009 to 2019 showing the differences between peak probability density for replacement.
2. The Survival Function (Bottom Left) starts with 100% of the replaced poles in service and ends when 0% of the poles of a species have all been replaced. Data used is the 2009 to 2019 replacement data. The survival function shows the distinct variation between species and their in-service life before replacement.
3. The Weibull (Upper Right) shows the in-service life of the poles that have been replaced and includes the 95% statistical confidence limits (dotted lines). The poles, species dependent, begin to go out of service for replacement as early as 40 years and some as late as 80 years of service life.
4. The Hazard Rate (Bottom Right) shows the age dependent failure rate for each species of wood. The differing curves indicate that the age dependent functional failure rates are species and age dependent.

During the RCM study there was an interest in consolidating data into durability group ratings.

The national timber pole standard[23] states that only durability class 1 and 2 can be used for power poles without preservative treatment[24].

We also performed this same analysis separated by durability group and found there are clear differenced broadly displayed by analysing the durability groups used in SAP, showing the durability class 1 and 2 poles are more durable than class 3 or 4.

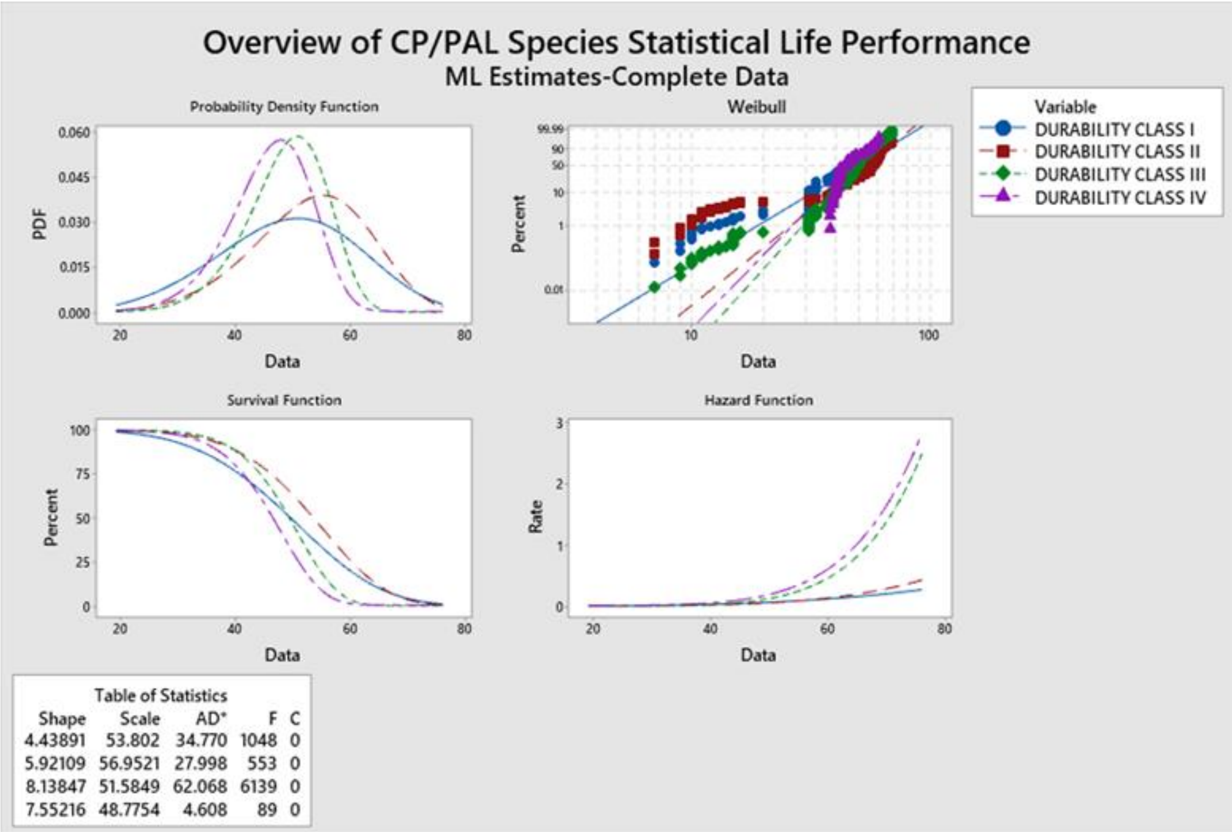

Figure 7 - Overview of CP/PAL Species Statistical Life Performance by AS 5604 2005 - Durability Rating

Older wooden power poles are Durability Class I and II species, but during the Victorian State Electrification project, many Durability class III Messmate poles were installed (approximately 150,000). These poles of concern were pressure treated with primarily wood creosote impregnation (designated WCI in the RCM data analysis).

[23] Australian Standard AS 2209-1994 'Timber - Poles for overhead lines'.
[24] Australian Standard AS 1604.1:2012 'Specification for preservative treatment Sawn and round timber'

The durability life performance overview variance exhibit shown in Figure 8 has 4 graphs on the same panel;

1. The Probability Density Function (Upper Left) is the probability density of end of service life replacements from the period 2009 to 2019 showing the differences between peak probability density for replacement for each durability classification.
2. The Survival Function (Bottom Left) starts with 100% of the replaced poles in service and ends when 0% of the poles of a species have all been replaced. Data used is the 2009 to 2019 replacement data. The survival function shows the distinct variation between durability classifications and their in-service life before replacement.
3. The Weibull (Upper Right) shows the in-service life of the poles that have been replaced and includes the 95% statistical confidence limits. The poles, also durability dependent, begin to go out of service for replacement as early as 40 years and some as late as 80 years of service life.
4. The Hazard Rate (Bottom Right) shows the age dependent failure rate for each durability classification of wood. The differing curves indicate that the age dependent failure rates are durability and age dependent. Durability Class III and IV experience higher age dependent failure rates starting earlier in Age at about 40 years of in-service life than Durability Class I and II poles which show a marked increase in age related failure starting at about 60 years of service.

We also noted discernible differences in poles classified with a Durability rating Class 1 if they were pressure treated (PT) or untreated (NPT) as shown in Figure 8.

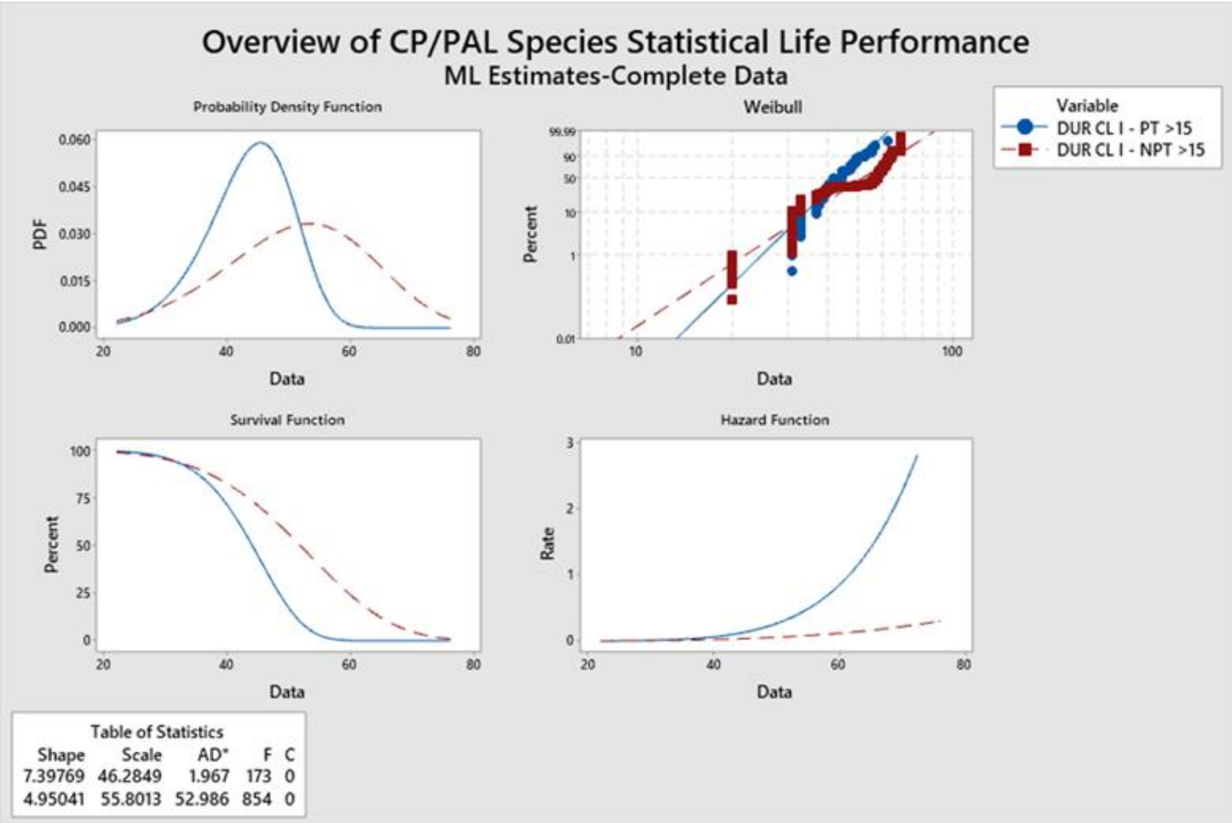

Figure 8 - Differences in Life Performance of Durability Class I rated poles

The data was analysed by excluding in-service ages less than 15 years from the data set for 2009 to 2019 replacement poles to use the portion of the data we had confidence in early on. We did this to focus on the older performance within the data set where most of the differences exist. In the graphs of Figure 8 and Figure 9, "PT" refers to the wood has been subject to one of three available pressure treatment types listed below.

Within Durability Class I, records were selected for pressure treated timber which resulted in data for 173 replacements;

Pressure Treated Wood

- Wood Creosote Impregnated (WCI)
- SALT (CCA – Green) (SAL)
- Penta (PEN)

Untreated wood classified as Durability class I isolated 854 replacements;

- Wood Untreated Round (WUR)
- Wood Untreated – Dressed (WUD)

The characteristic life when 63% of the poles sampled will be replaced is an age of;

- Pressure Treated = 46 years
- Non-Pressure Treated = 55 Years
- The RCM data was organized in a way that several unique groupings could be examined to determine if a unique characteristic could be isolated. It was noted that several characteristic profiles emerged that varied by the species, treatment type, location of the functional failure, durability, and region.

In Figure 9, the analysis examined the performance differences between Durability class 2 pressure treated timber vs. non-pressure treated.

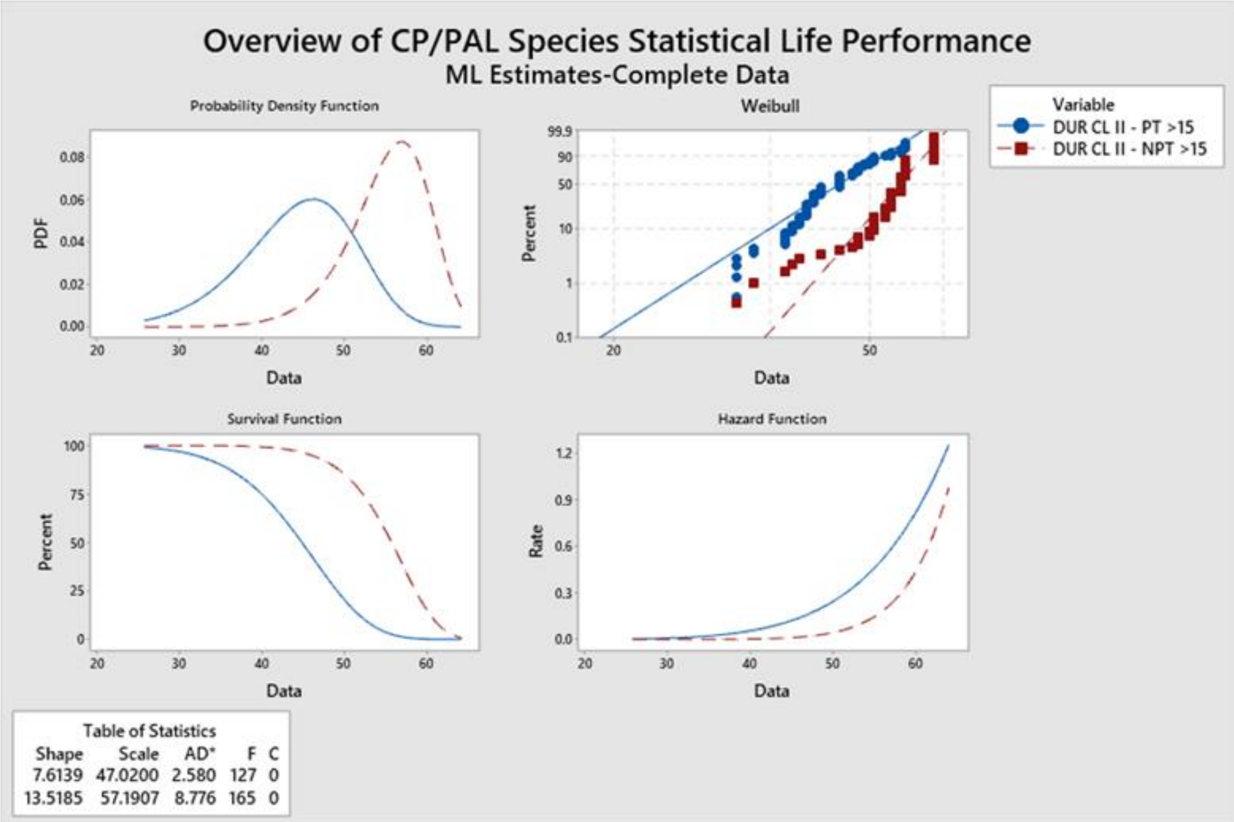

Figure 9 - Differences in Life Performance of Durability Class II rated poles

The data was again analysed by excluding in-service ages less than 15 years from the data set for 2009 to 2019 replacement poles.

The data was filtered on Class II, then records were selected for pressure treated included 127 replacements;

- Wood Creosote Impregnated (WCI)

Untreated wood classified as durability class I included 165 replacements;

- Wood Untreated Round (WUR)
- Wood Untreated – Dressed (WUD)

The characteristic life when 63% of the poles sampled will be replaced is an age of;

- Pressure Treated = 47 years
- Non-Pressure Treated = 57 Years

Of the untreated pole population at CP/PAL there are two distinct classifications in use. There are many older high-quality wood untreated round poles (WUR) and Wood untreated Dressed (WUD) poles.

For current replacement poles, Powercor, like all other electricity distribution businesses, now uses a mix of concrete, steel and copper chrome arsenate (CCA) treated timber poles in accordance with the overhead line design standard[25]. CCA, the current standard industry wide preservative for power poles, will gradually replace hardwood poles and last at least 40-plus years.

The most used species by CP/PAL today seems to be BB-BLACKBUTT species which has been treated with reportedly 1.2% CCA.

Also, important to note that all CCA is not the same. The SME report that older CCA treatments suffered a quality issue and previously were at differing chemical mixtures and concentrations, so one must temper life expectancy data for older CCA treated poles accordingly.

These poles are rated to withstand winds of up to 180km/h.

[25] Australian Standard AS 1604.1:2012 ‘Specification for preservative treatment Sawn and round timber’

RCM Failure Mode – Rot and Decay

The largest failure mode measured by data is of decay or rot and causes a combined 63% of pole replacements over the last 10 years.

Understanding the failure mode more completely allowed the RCM team to determine the appropriate counter measures and evaluate the appropriateness of the current inspection-based maintenance policy.

Decay or rot is caused by prolonged fungal attack over time that ultimately eats enough sound wood to weaken the pole.

Typically, with White or Brown rot - the timber pole is eaten from the inside out, and the presence of rot fungi is not a functional failure itself, rather it is only when the pole reaches a minimum specification for performance (like 30 mm of sound wood remaining) that a functional failure is declared.

The loss of sound wood caused by rot or decay can also affect the residual strength of the pole, and so loss of strength is an independent functional failure to that of a reduction of sound wood.

Understanding how a fungal attack occurs helps formulate the RCM countermeasures. Timber will not be subjected to fungal attack unless four conditions are satisfied: [26]

• The correct moisture level must exist in the wood:

0-20% Moisture Content – Fungal attack will not occur (The wood is too dry),

20-60% – enough moisture for attack to occur exists,

>60% it is too wet resulting in insufficient oxygen for fungal attack to occur.

The RCM workshop conclusion was quite simply that at most pole locations enough moisture does exist for rot to occur and the moisture (rainfall) was not controllable.

• Next we considered that Oxygen must be present for fungi to survive.

Timber that is completely submerged or very saturated timber is rarely attacked and timber 600 mm or more below ground is rarely attacked due to lack of available oxygen at that depth in the ground.

Nearer the ground line, oxygen is available, especially where drilled holes and cracks in the timber extend into the rot cavity. This is the primary section of interest.

The RCM process determined that the formation of a rot cavity was a normal part of the pole evolution and the general thought is with a chemical retardant like pole saver applied near the ground line, the boron and fluoride chemicals will diffuse into and then protect the wood most susceptible to weakening of the pole resulting in an extension of its remaining useful life (RUSL).

• Temperature must be in the range of 5-40ºC;

25ºC to 40ºC is ideal for fungal attack, suggesting seasonal patterns to the rate of fungal attack.

At lower temperatures, fungal attack is retarded.

At higher temperatures, the fungus will not survive.

While there are some regional temperature variations across Victoria, the temperature likely to exist at or just below the ground line is within the 5-40 ºC range often and was determined to be something that was not controllable by an RCM task.

• Food in the form of nutrients (carbohydrates, nitrogen, minerals, etc.,) must be present.

- Using a species that has a durability appropriate to the application or by using species (containing limited untreatable heartwood) that have been preservative treated (i.e. the nutritional aspects are undesirable to the fungi) would result in a longer life in service.

26 Adapted from Timber service life design – Design guide for durability, revised version Oct 2013 LEICIESTER, R. Wang, C. et all., Technical Design Guide issued by Forest and Wood Products Australia

- Future work could be considered to preference at procurement certain species and treatment configurations based on life experience data now available.

Food for fungi is usually provided by the timber itself, particularly sapwood, which is normally high in sugars and carbohydrates that are preferred by some fungi. For this reason, older timber was presumably de-sapped by removing the sap wood layers and data suggests for certain species this is quite effective.

Removal of any one of these four conditions will prevent fungal attack but in practical consideration the following controls are plausible choices;

The RCM workshop determined that treating the timber with preservatives at manufacture or repeat application of diffusive chemicals known to control or retard fungal attack was technically feasible and applicable.

- The current maintenance procedure is to replenish and apply 3 new pole saver rods at each inspection should be maintained as a maintenance action. [27] The practice is to drill 3 or 4 16 mm holes downward at an angle of 30 degrees to the vertical and at an angle of approximately 20 degrees. Then apply Preschem "Pole-Saver" at each full inspection visit to a pole (every 5 years) was confirmed as the prudent approach but notes were made about its suspected effectiveness.

The current practice leaves the pole untreated from the period of installation until the first full inspection. This practice may not be fully desirable, and some consideration should be given to installing pole saver rods at the same time as the pole is constructed to further reduce the amount of decay and retard its development.

The current practice of pole saver application is also varied by the CP/PAL durability rating.

For example;

Class 1 durability timbers can be treated progressively with the application of one treatment hole per inspection if no internal decay is identified during the first treatment.

All other timbers are to be treated fully from the first inspection.[28]

So, this means D1 poles do not always receive three-hole patterns until their 15th year in service completing the pole saver protection.

This type of treatment is applied at or near the ground line and if the drilled holes are correctly positioned, the treatment will reach approximately 300 mm below nominal ground line up to 150 mm above the ground line. When applied correctly it is thought to protect the wood fibres most susceptible to decay near the ground line.

It is additionally suggested that chemical testing be performed on selected test case poles to examine the penetration depth of the boron and fluoride to confirm the chemicals are reaching the desired target wood fibres at a chemical strength required to adequately protect them from rot or decay.

[27] CP/PAL Training Reference Manual for Inspection of Poles – Document No. 05-M450 Issue No. 3.0 Appendix F – ppg 67-68.
[28] CP/PAL Asset Inspection Manual

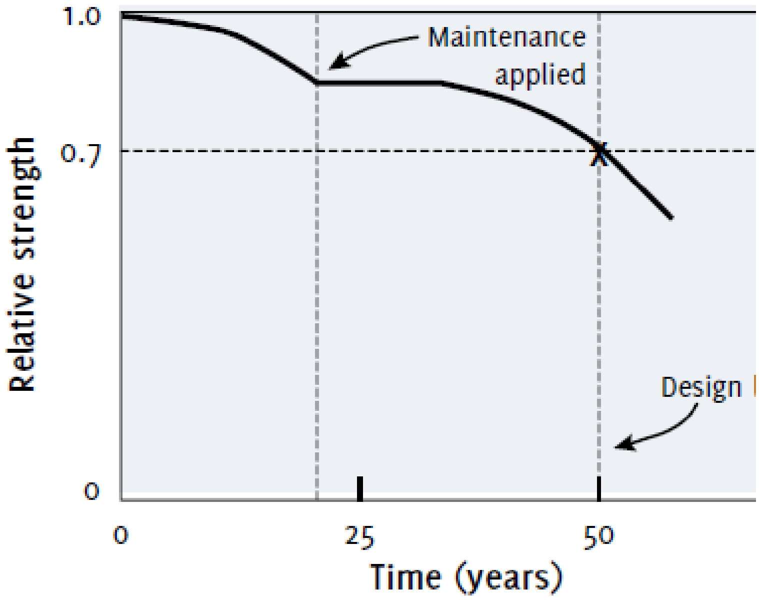

Figure 10 - The effect of a maintenance action extending pole life expectancy

The potential for extra pole service life due to the use of internal diffusing chemicals tends to vary with the type of pole and is greater for hardwood than for softwood poles[29] , but no data exists in SAP to support this type of variation analysis.

The chemical treatment and rot performance need to be tempered by the known start of the pole saver program which inherited a varied population of rot and decay in progress.

At CP/PAL the Preschem treatment began in 1991 with complete population coverage achieved a few years later, however as noted this was applied on the existing population which it is reasonable to suggest had already experienced a wide range of decay before receiving their first treatment.

Therefore, the effectiveness of a life extension due to preventative maintenance and application of a chemical must be considered within the context that the poles to which it was applied already were in service and thus covered the range of possible decay states.

See additional comments made in the section: The Overall State of Wooden Power Poles and the comments about Blue-7.

- The RCM workshop recommendation was to continue using CCA treated poles and to continue applying pole saver at the current frequency.
- It is recommended to investigate applying pole saver to newly installed poles vs. wait 5 years for the first full inspection to apply pole saver.
- It is recommended consideration be given for applying full pole saver treatment to D1 poles sooner.
- It is recommended some poles being replaced should be tested to learn how effective the treatment is.

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[29] Adapted from - Timber service life design – Design guide for durability, revised version Oct 2013 LEICIESTER, R. Wang, C. et all., Technical Design Guide issued by Forest and Wood Products Australia

RCM Failure Mode - Fruiting Fungal Bodies

This section discusses the failure mode caused by a mushroom called a fruiting fungal body which typically occurs on an older pole above 2 meters above the ground line.

- Data suggests non-pressure treated wood of certain species are particularly susceptible.

There is no additional maintenance or chemical applied to the top section of the pole to retard or prevent fungal attack. SAP data records indicate in the period from 2009 until 2019 – 100% of fruiting fungal bodies were recorded to be above 2 meters above the ground line and occurred on just twelve (12) different species of wood from 33 total species.

Victoria is in Zone B and C as shown in the above ground hazard map in Figure 11. Untreated wood (de-sapped) or untreated round poles are thought to be at higher risk than poles that have been pressure treated above 2 meters (Creosote or CCA).

A fruiting fungal body is known to eat wood into the pole creating a pocket which will weaken the pole placing it at risk of pole snap failure. This rot occurs and is not within the zone of the pole treated by the Preschem boron and fluoride treatment.

The current RCM inspection of this upper portion of the power pole is subject to visual inspection only and the pole is condemned if a fruiting fungal body is sighted.

10% of all poles (503 qty) replaced between 2009 and 2019 were caused by the presence of fruiting fungal bodies. 40% of the poles replaced for fruiting fungal bodies were between 26 and 30 years in service and associated with untreated dressed wood (WUD). Relatively few (38) of those so afflicted were treated with creosote whose characteristic life was measured at 50.88 years, with the balance (473) being untreated wood. Untreated round wood (WUR = 126 qty) has the best performance against fruiting fungal bodies with a characteristic life of 59.47 years.

- Therefore, we conclude that untreated dressed wood is most likely to develop fruiting fungal bodies above 2 meters where the boron and fluoride chemicals are not thought to reach, and the occurrence suggests an age range where a visual inspection seems prudent should start after 25 years of service.

The RCM study did not analyse or look for a correlation by the hazard rating zone.

The RCM maintenance strategy for the fruiting fungal body is therefore designed as a run until functional failure and replace the pole when a fruiting fungal body is sighted during inspection visits.

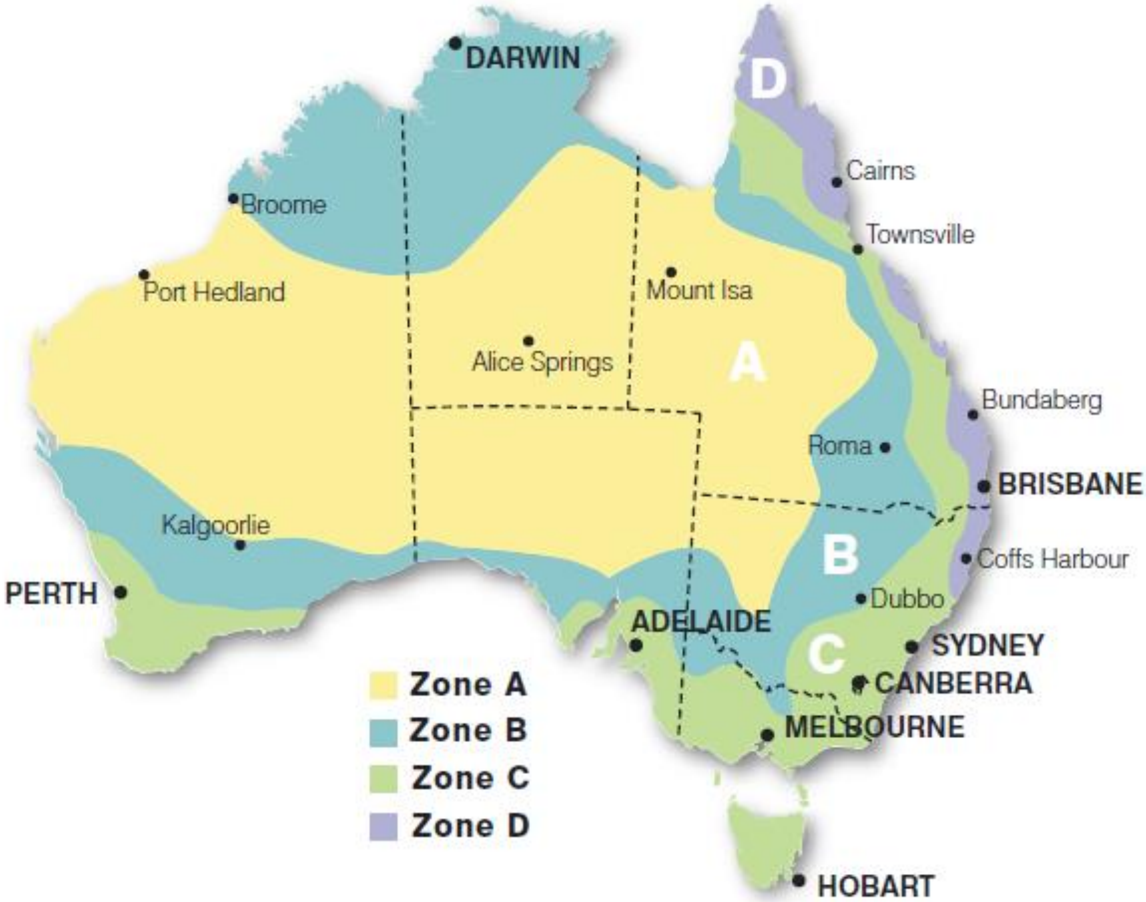

Figure 11 – Above Ground Decay Hazard zones for Australia.[30]

[30] Chart from Timber service life design – Design guide for durability, revised version Oct 2013 LEICIESTER, R. Wang, C. et all., Technical Design Guide issued by Forest and Wood Products Australia

RCM Failure Mode - Insect Attack

This section discusses the functional failure modes caused by insects and whether there is evidence to support a zonal maintenance strategy based on the termite hazard zone. Termites that attack timber can be classified into two types, subterranean (wet) and dry wood.

Victoria is largely in Hazard zone B, with some north western cities like Mildura in Zone C having higher incidence of infestation by termites as reported by SME.

Subterranean termites pose by far the most risk in Australia and when observed they are immediate grounds for pole replacement as SME reported no known effective treatment that can counter a pole failure when this type of insect is detected other than a pole replacement. In the period from 2009 to 2019 termites accounted for roughly 14% of the total power poles replaced by CP/PAL.

Termites Glyptotermes	2%
Termites subterranean	12%

Table 3 - 2009 to 2019 power pole replacement causes coded in SAP data

As noted, termites were reported to be more prevalent in areas like Mildura than for example in the South West of Victoria.

A regional influence was expected but data analysis and correlation could not be performed during the RCM study.

Rather an approach considering an on-event inspection response and secondary action to replace the pole was decided applicable.

The Australian Termite hazard zones are shown below in Figure 12 with Victoria's North West rated as Zone C, and the rest of Victoria rated as Zone B. D has the highest hazard rating on this chart.

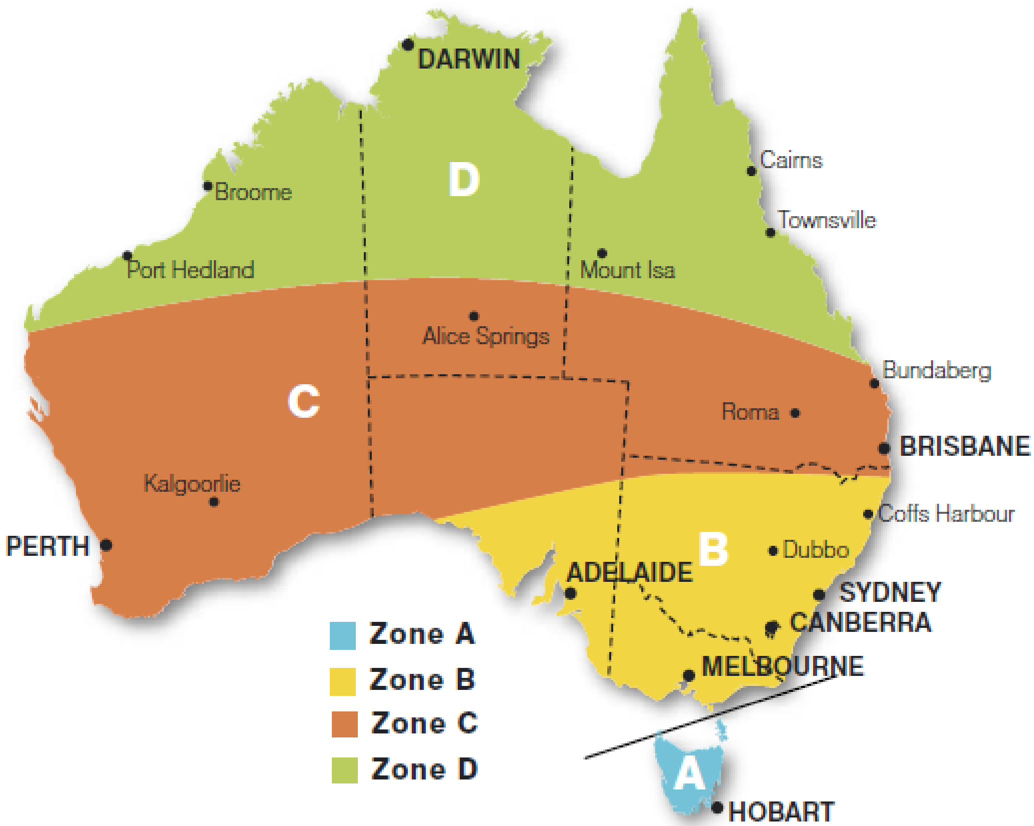

Figure 12 - Termite Hazard Map for Australia

The inspection recommendation was made in the 2019 RCM workshop. It is important noting the 2005 RCM study which did also recommend the adoption of a preventative termite treatment to be applied in known termite prone areas. This recommendation was set aside in 2019 as the inspection approach is working and this recommendation was reportedly not actioned following the 2005 study.

Absent a preventative action - the current maintenance program relies on the periodic application of an inspection to detect the presence of termites and follows up with an on-condition task to apply a termite treatment or replace the pole.

The counter measures for this functional failure seem practicable.

Durability Considerations

This section does a bit of a deep dive into the subject of wood durability to support and inform decisions on inspection optimization and prediction parameters chosen by durability classification. The reason is the species durability is used often within the RCM study to classify performance and less durable wood may need differing RCM recommendations due to the differing heartwood life expectancies.

This section should be worked with the scenario analysis by durability presented above.

In the search for incremental improvement it was essential to understand the differences each durability group of species supports. There are 4 durability classifications which apply to the wood itself in an untreated state. Preservatives and treatments like pressure creosote and CCA extend the life by altering the base wood and within the SAP database there is a durability rating that is generally aligned to the Australian standard, but exceptions exist where a wood preservative combination seems to work as well as a higher classed wood.

As defined in the ISO 15686-1:2000(E), durability is: "(the) capability to perform the required function over a specified period under the influence of the agents anticipated in service.

" Service life is defined as: "(The) period of time after installation during which a pole meets or exceeds the performance requirements."

In RCM terminology a "Functional Failure" occurs when the pole drops below its stated performance requirements and may be thought of as the end of useful service life.

The AS 1604 series gives preservative treatment specifications for a range of decay and insect hazards, but they do not account for varying levels of hazard due to macro or micro climatic conditions, etc. AS 5604 provides natural durability classifications but they are actually for untreated timber rating decay in and above ground, lyctus susceptibility, termite resistance and marine borer resistance. The "natural: durability ratings of a species of wood as provided for in AS 5604 and represent the natural wood durability and its resistance to decay and termites in an untreated state. In SAP poles are classified by their durability rating in general alignment with AS 5604 with some differences were noted where treatment favourably extends life.

Natural durability class	Probable heartwood life expectancy (years)		
	Fully protected from the weather and termites	Above ground exposed to the weather but protected from termites	In-ground contact and exposed to termites
Class 1 Highly Durable	50+	40+	25+
Class 2 Durable	50+	15 to 40	15 to 25
Class 3 Moderately Durable	50+	7 to 15	5 to 15
Class 4 Non-durable	50+	0 to 7	0 to 5

Table 4- Life expectancy of un-treated wood by AS 5604 Durability Classification[31]

CP/PAL operates wooden power poles of Durability class 1, 2, 3, and 4 in decay hazard zone B.

The Class 3 and 4 poles are pressure treated which changes their probable heartwood life expectancy.

The Class 4 poles are pressure treated softwood treated to H5 rating suitable for HRBA service and have a typical service life expectancy rated at 100 years of more. Class 4 poles were not installed until more recently.

As noted above, the CP/PAL database generally follows the AS 5604 durability classification designation but does in some cases the SAP rating upgrades the in-ground durability of certain species and treatment combinations in recognition of their superior performance in the field for CP/PAL.

[31] Timber service life design – Design guide for durability, revised version Oct 2013 LEICIESTER, R. Wang, C. et all., Technical Design Guide issued by Forest and Wood Products Australia

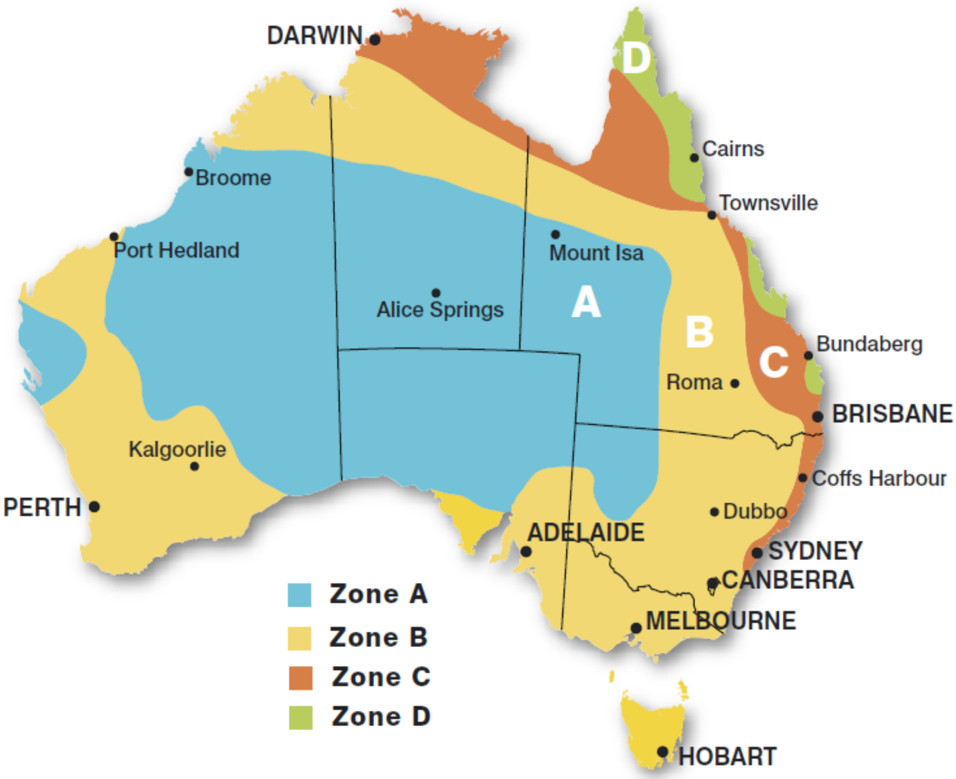

Figure 13 - In ground decay hazard zones for Australia[32]

The typical service life of round poles with various preservative treatments is provided below;

Timber type	In-ground durability class(1)	Treatment(2)	Typical service life (years)		
			Pole diameter 200 mm	Pole diameter 300 mm	Pole diameter 400 mm
Treated softwood	4	H4	60	80	100
		H5	100	>100	>100
Treated hardwood	1	H4	50	80	90
		H5	80	>100	>100
	2	H4	50	70	70
		H5	80	100	>100
	3	H4	40	45	60
		H5	50	60	70
	4	H4	30	35	45
		H5	40	45	50
Untreated hard-wood(3)	1	—	45	60	80
	2	—	25	30	40

Notes:
1. See Table 4.1.
2. As per AS 1604.1. for CCA and creosote.
3. De-sapped poles.

Table 5 - Typical In-service life for poles of various durability ratings installed at CP/PAL[33]

[32] Chart from Timber service life design – Design guide for durability, revised version Oct 2013 LEICIESTER, R. Wang, C. et all., Technical Design Guide issued by Forest and Wood Products Australia
33 Timber service life design – Design guide for durability, revised version Oct 2013 LEICIESTER, R. Wang, C. et all., Technical Design Guide issued by Forest and Wood Products Australia

Pole Failure Rates

The main safety concern of the RCM study was centralized with a pole failure event.

The criteria for the program performance are to meet a low level that is practicable. In order to comply with the RCM service contract requirement, the pole failure rate was examined intently.

Over the last 10 years CP/PAL has recorded pole failures with the annual average of wood pole failures rising to and exceeding (in recent years) the management expectation of 20 pole failures per year.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of Pole Failures	6	15	9	5	30	38	23	21	21	11	21	10

Table 6 – Number of pole failures by year

For the 2019 RCM study CP/PAL selected 209 pole failure records[2] as a total for the critical pole failures that their maintenance program should be configured to manage. This equates for a 10-year critical failure rate average of 20.9 pole failures per year. A wooden power pole catastrophic failure is defined as when the pole top snaps or the pole falls to the ground and is a reportable pole failure to ESV. This differs from near miss events which are distinguishable by their P1 un-serviceable status.

Additionally, the RCM pole failure was refined to be an "un-assisted" catastrophic failure if its causes of failure are not related to a vehicle strike, lightning, or a high wind event.

As noted, the 2019 RCM study considered P1 pole replacement as near miss events, because a rating of P1 is a failure of the condition-based inspection process, and from an RCM perspective it is a critical failure to adequately control the condition-based inspection process. As noted, before, this is a more conservative approach in that poles which are still standing (barely) are also counted as a failure event.

This is a different definition for pole failure than is used in other forms of reporting, including reporting sent to ESV. In practice, the totals of pole failure volumes are captured in a common database and then reported under several different definitions for a pole failure, with the most visible reports being those to the regulatory bodies the AER and ESV.

Under the ESV reportable definitions, in the last 10 years under the ESV definition a total of 209 poles have catastrophically failed.

Currently the average annual number of unassisted pole failures across Australia is 0.007 per 100 poles with Victoria averaging 0.003 un-assisted catastrophic failures per 100 poles, or a failure per population of 0.00003[34] per year.

With 405,554 wooden power poles in service at CP/PAL this equates to 405,554 * 0.00003 failures per annum or 12.15 pole failures per year when the statistic is referenced to the CP/PAL total population.

An upper benchmark was gleaned using the Victorian average or 0.00007*405,000 = 28.75 pole failures per year when the Australian average is utilized, which indicates the CP/PAL performance is better than the Australian average catastrophic failure rate.

The current CP/PAL management expectation is a failure rate of 20 poles per year – referenced to a population of 375,000 which is 0.000053 failures/year. When extrapolated to the 405,554 poles in service equates to a failure rate of 21.6 pole failures per year as defined in the ESV definition. Next the pole failures were analysed to try and detect species or age-related characteristics that would be useful in informing decisions.

[2] As provided by Powercor – in file Copy of RCM Failed poles - maintenance history final (002).xlsx containing 384 unique pole failure records from 2009 to 2019

[34] Sourced from the Australian Energy Regulator's Regulatory Information Notice data submitted by: Victorian DNSPs 2011 to 2018; other DNSPs 2016 to 2018 as provided in the ESV document "The condition of Power Poles in South West Victoria – Technical Investigation Report – July 2019

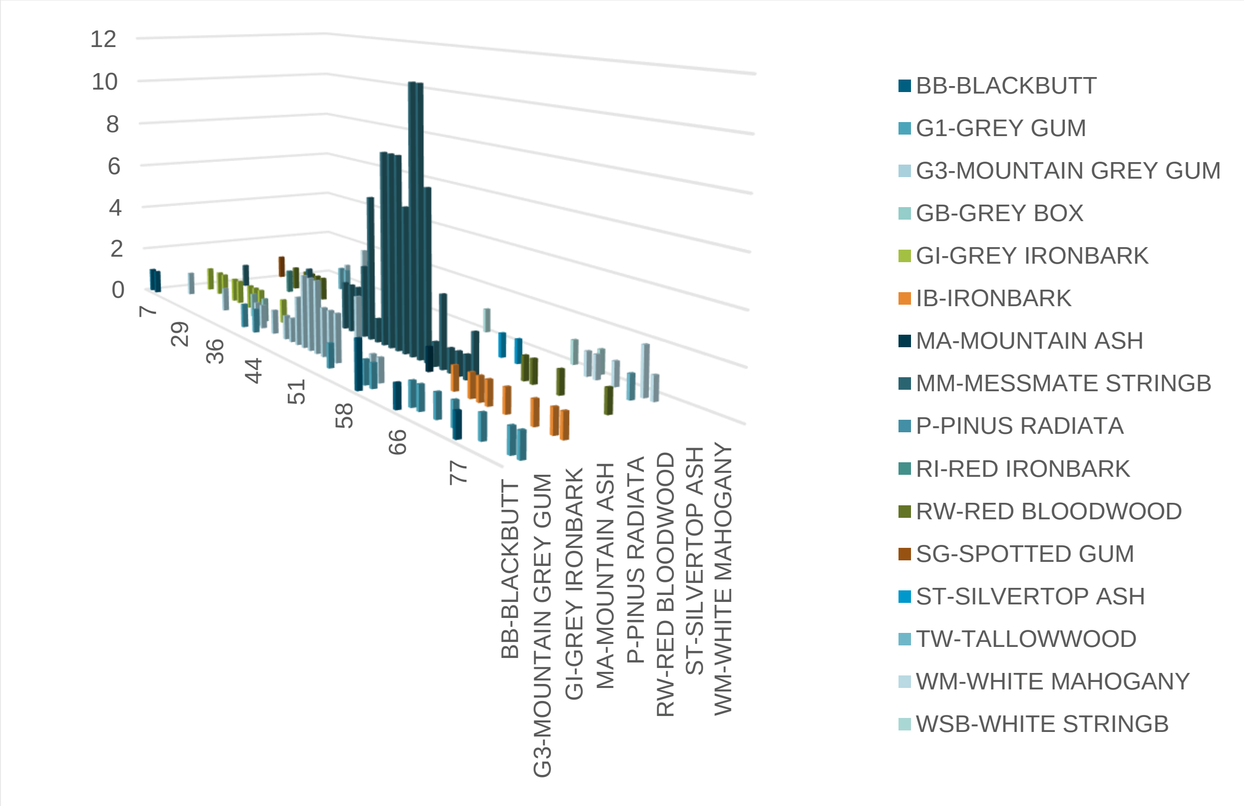

Figure 14 - Failed Wooden Power Pole Age Dependency Analysis Results

The analysis in Figure 14 shows ESV reportable failures by age in service at failure and species involved.

From the small amount of reportable failure data collected over the last 10 years, Messmate and Mountain Grey Gum show age dependence, whereas all other reportable pole failures, when grouped by species do not show an apparent age characteristic.

These two species are candidates for increased inspection frequency when they become 50 years old.

The failed pole with P1 near miss events included indicate the inspection process is not adequately detecting or managing a condition-based problem a small but important portion of the time.

Serviceable Poles that Subsequently Fail in Service	252
Limited Life Poles that Subsequently Fail in Service	43
Un-serviceable Poles that fail while still in Service	83
Total Pole Failures – 2009 to 2019	381

Table 7 – Pole failure statistics, 2008-2018

This information should be worked with the transition information contained in the section titled “The Critical Path” which discusses BAU and with the projections of replacement populations provided to fully understand the P1 near miss contribution to pole failures.

Failure Performance of Poles

The failed pole data was analysed for dependency by durability classification as used in SAP.

As was expected the aging Durability class 3 poles are the most populous portion of the pole failure data set. This is shown in Figure 15 which depicts pole failures over the last 10 years, by durability group by age in service before failure.

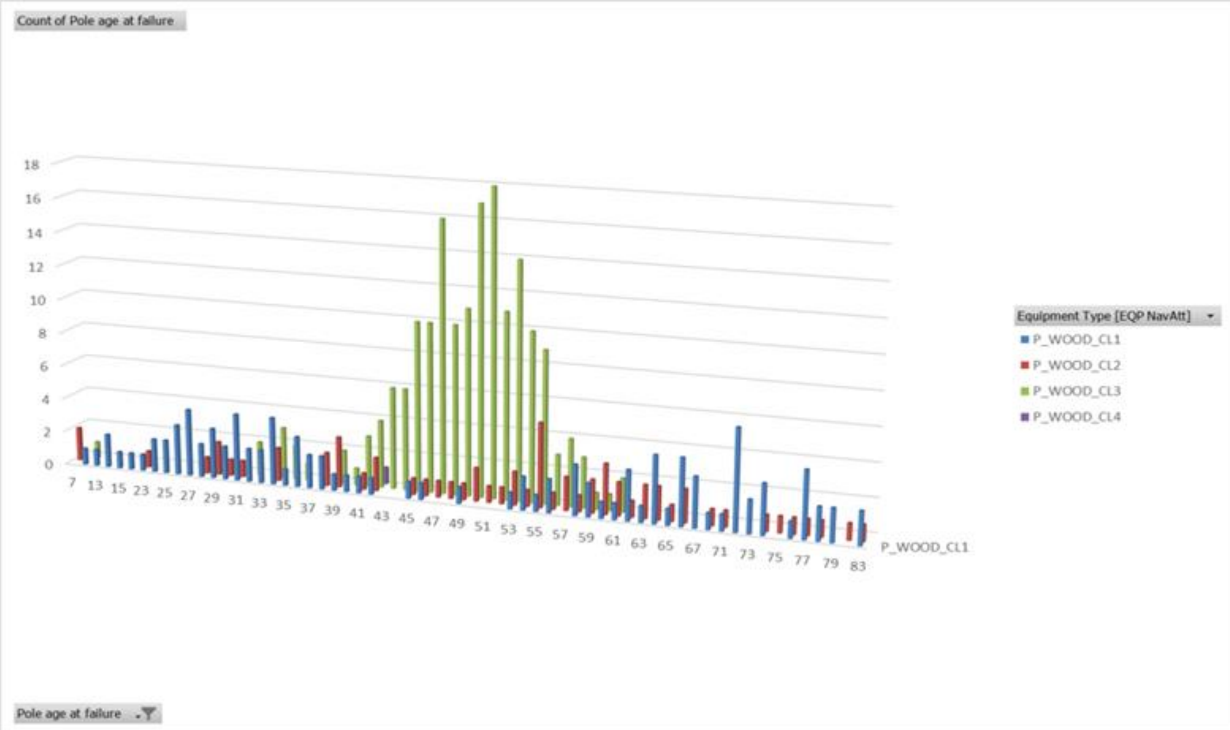

Figure 15 - Pole failures by Durability Classification

The MM-Messmate species drives the durability class 3 failure performance.

Most of the Messmate pole failures were recorded between years 50 and 60 in service.

Mountain Grey Gum, also durability class 3 wood, is the second most likely pole failure species.

The SAP database does not track pole information by a regional grouping so one was created during the RCM workshop as suggested by Dennis Clancy of CP/PAL.

By assigning feeder designations which are attributed in SAP with high accuracy to a regional group the data could be viewed from a regional experience-based viewpoint. The number of poles in each group is shown in the table 8 below.

The regional feeder assignment is found in Appendix J as this data feature does not exist in SAP.

The central group includes zones 3, 4 and 5 as shown in Table 8 allowing a crude regional influence to be considered to determine if an augmented inspection frequency was beneficial in the south of Victoria.

Count of Geo split (North/South/Central)	
Row Labels	**Grand Total**
Central	114212
North	145904
South	144437
Grand Total	**404553**

Table 8- Pole population by Region Grouping (Ad hoc)

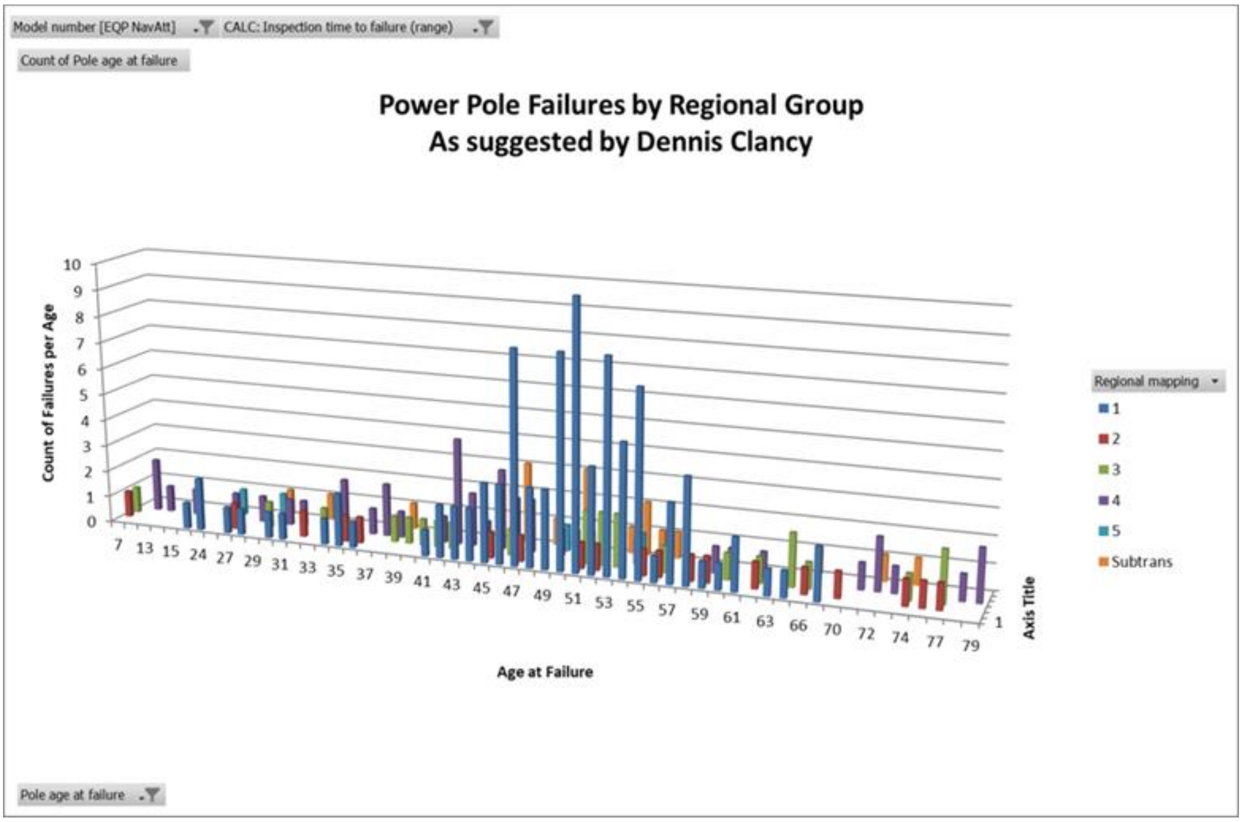

Figure 16 - Pole failures by Regional Group Number

In Figure 16 the pole failures were then analysed by regional group number as correlated in Table 9 below showing some clear regional influences, but these must also be tempered with knowledge of where the Messmates are installed.

There are more failures in the north region of Messmates, but there are also more Messmate poles installed in the north group at an age susceptible to failure. The 62741 Messmate poles installed in the North group represents 15% of the total CP/PAL power pole population. Messmates in total represent 33.4% of the total CP/PAL population and account for 87 recorded pole failures over the last 10 years.

Count of Geo split (North/South/Central)	
Row Labels	**MM-MESSMATE STRINGB**
Central	30187
North	62741
South	42196
Grand Total	**135124**

Table 9- MM - Messmate In-Service Population by Regional Grouping as of August 2019

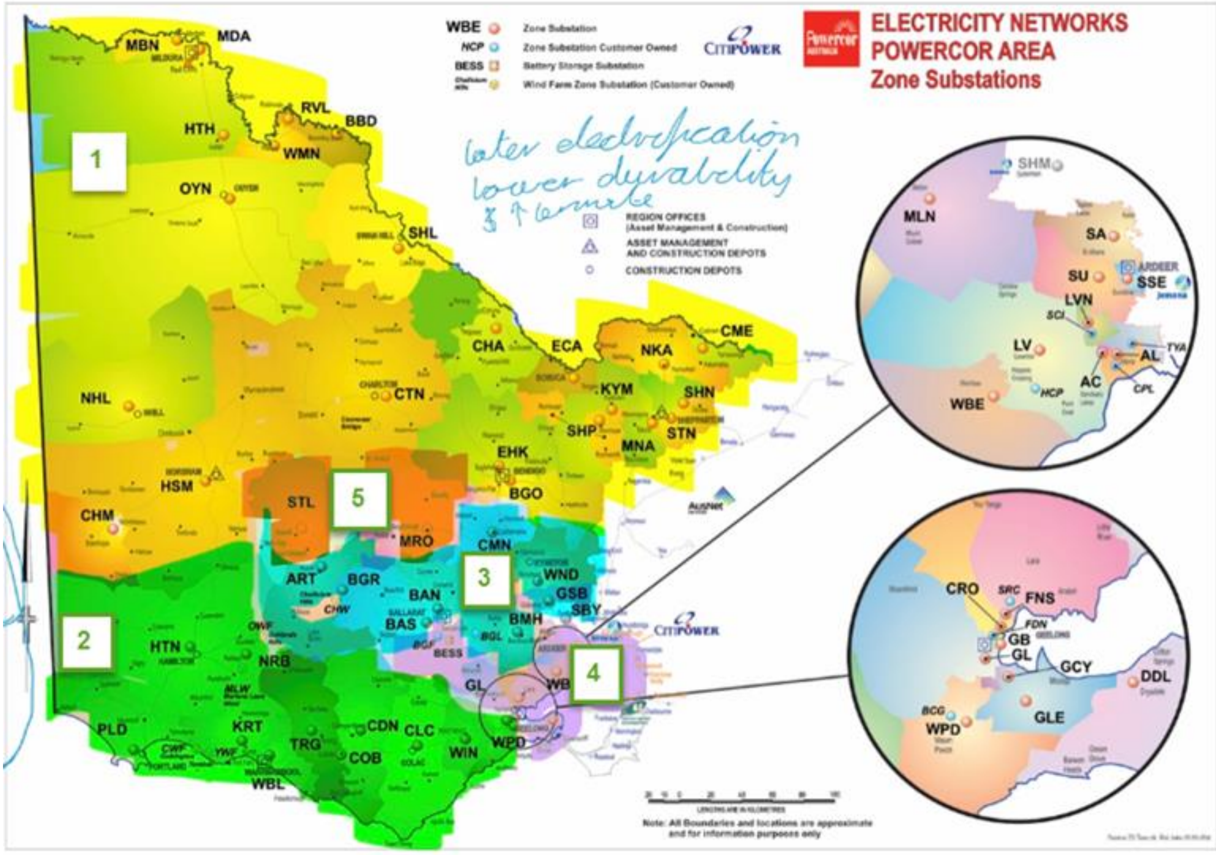

Figure 17 – Legend for Regional Group number associated to geographical area by feeder designator

Pole Failures by Year

The pole failures per year was analysed by year by species involved. [35]

Count of Failure Year	Column Labels												
Row Labels	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Grand Total**
G1-GREY GUM			1		3	3	1	2	3	1			14
G3-MOUNTAIN GREY GUM	1	2	1	3	4	9	1	4	3	2	3	3	36
GI-GREY IRONBARK		2	1		6	5	2	1		1	2		20
MM-MESSMATE STRINGB	3	7	2	1	10	11	11	10	11	4	14	3	87
ST-SILVERTOP ASH					1		1						2
SG-SPOTTED GUM							1						1
BB-BLACKBUTT					1	2	1					2	6
RI-RED IRONBARK			1										1
RW-RED BLOODWOOD	2	1	1			2	1		2				9
WM-WHITE MAHOGANY			1	1	1	1		1		2			7
IB-IRONBARK		1			1		2	1				1	6
GB-GREY BOX		1			2		1		1			1	6
WSB-WHITE STRINGB			1			1		2			1		5
TW-TALLOWWOOD						2			1	1			4
P-PINUS RADIATA		1					1				1		3
YSB-YELLOW STRINGB						1							1
RM-RED MAHOGANY						1							1
MA-MOUNTAIN ASH					1								1
Grand Total	**6**	**15**	**9**	**5**	**30**	**38**	**23**	**21**	**21**	**11**	**21**	**10**	**210**

Table 10 - Pole Failure by Year by Species

The pole failure trend chart in Figure 18 shows a slight increase trend over the last 10 years but is below 20 pole failures/year. Note: The year 2019 is a partial year as the data set was taken during the RCM project before September 2019.

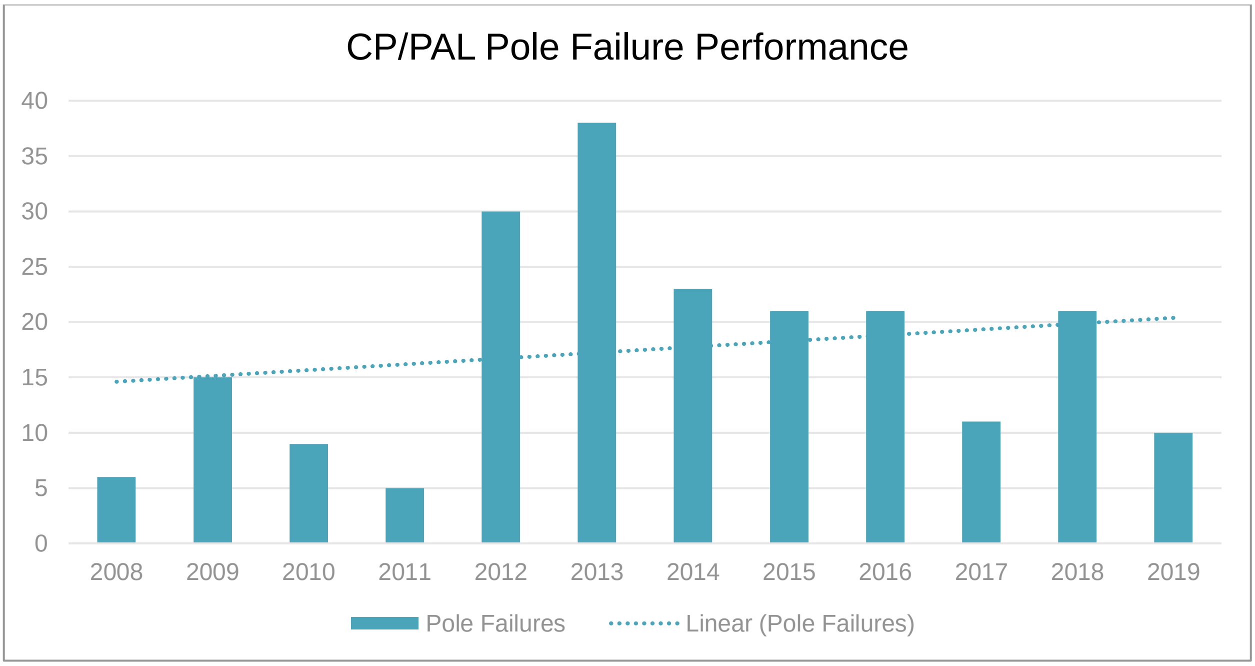

Figure 18 - Pole Failures recorded by Year by Species

[35] File: RCM Failed Pole Analysis 2008 to 2019 (various viewpoints).xlsx – Analysis excludes Model number ZZ – WOOD UNKNOWN and failures recorded at inspection or #N/A.

Periods between Inspection

Row Labels	Count of Failure Year
<12 months	67
<24 months	51
<36 months	80
> 48 months	42
48 months	20
At inspection	118
Grand Total	378

Table 11- Time since last pole inspection

Table 11 provides information regarding the time before a pole failure since last inspection.

In this table the P1 technical failures are included and a data set in this case was an earlier data set with 378 failures of near misses (vs 380 or 384) that was used. The data is left uncorrected by better data sets as the data is not materially impacted.

With many poles being condemned at inspection; the probable limit of the inspection program safety margin is exposed.

The information in Table 11 needs to be worked with the Kaplan Meier survivor estimates for the PF interval which is clearly suggesting some poles transit the PF interval very quickly in an un-managed process and with the β1 and η6 transitions on the critical path. (See Critical Path Analysis)

The pole failures at inspection become Priority P1 scheduled replacements and most do not actually fail. The quantity of ESV reportable failures in this data set was 210 pole failures.

Also, important to note is this data is largely from the period where inspections were carried out on a five (5) year cycle with poles in HBRA being inspected at 2.5 yearly intervals. The data needs to be tempered with the recent changes as detailed in the section on the CP/PAL Inspection program which recently changed to 12 monthly inspections of ACS (LL) status poles.

The inspection frequency intervals and program should remain as is found in service today. KPI monitoring of the β1 and η6 transition should be developed and management should have high visibility of this metric to monitor the on-going predictor for pole failures.

Future Pole Functional Failure Rate

Estimating the amount of future pole failures that are likely to occur within a future year was a topic of great importance to the 2019 RCM study as when it is worked with the BAU critical path model, it informs about future pole failure expectations and is a service contract deliverable.

The population composition is changing daily, and each pole is aging.

Complicating matters, many poles are thought to be subject to less than perfect decay controls, differing environmental considerations, differing treatments, initial durability's, and so on. Thus, in order to answer the question of whether the RCM derived controls are practicable and effective, one must seek to understand what they will be applied upon where weakness might be exposed.

Of practical interest is a service contract deliverable to answer the question will the number of pole failures increase, stay the same or decrease?

To answer this type of question, one must first accurately estimate the future population of candidates for a pole failure and then apply against the pool of candidates an estimate the effectiveness of the existing RCM derived controls and analyse both the strategic and execution performances.

The reason for doing so is some more aggressive estimates suggest the size of the pool of pole failure candidates is expected to increase as high as 8-fold the current size, which if unabated, would suggest the proportional number of pole failures may reach over 100 pole failures a year in the foreseeable future.

Over the last several years only about 1000 poles per year have been replaced. Orange dots in Figure 19 represent quantities of poles replaced each year between 2009 to 2019. From this limited data we can make a conservative estimate using the pole functional failure rate method.

The projected Required Pole Replacement Rate (per Year) is calculated from the 10 year averaged age based replacement rate observed between 2009 and 2019, then applied to the current age of the total population, and processed until all in-service poles were exhausted, resulting in the typical renewal pattern shown in Figure 19

This averaged approach is then curve fit with two versions of curve fit (exponential and cubic projection) which was applied to the 10-year windowed data of functional failures extending out 100 years. The lower left corner of Figure 19 "orange dots" are affected by the Woodscan technology over the last 18 months which effectively "un-retires" several poles and restores them to either serviceable or limited life (ACS) status.

The real interest is in the height of the first peak, which on average reaches approximately 7.5 times the current pole replacement rate. The chart in Figure 19 cannot cater to the extremes, nor account for the contributions from sub-populations not observed within the 10 year window and so a conservative estimate of a 7.5 fold increase over the next twenty years is suggested as the possible peak increase in the number of poles reaching functional failure that could reach a catastrophic failure if not controlled by the RCM program. A more aggressive estimate is provided in later sections that shows the peak occurring slightly sooner.

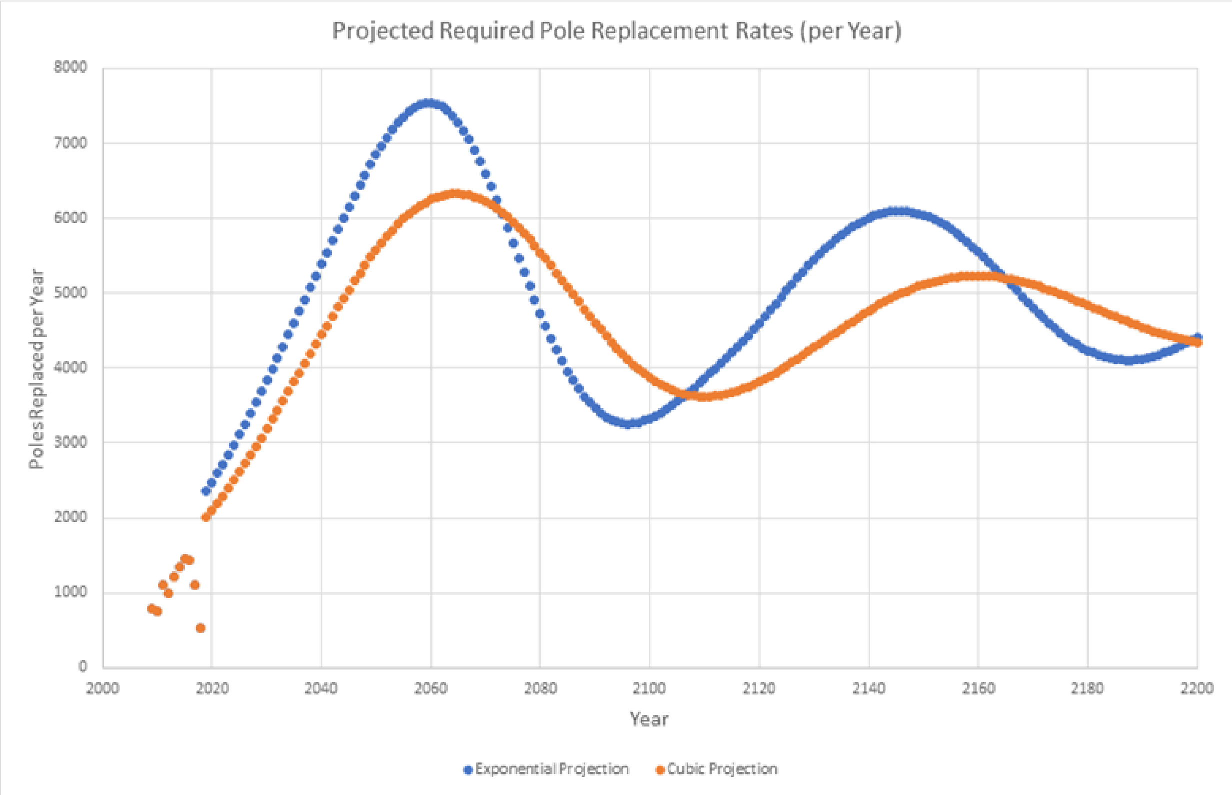

Figure 19 - A Conservative Estimate of Future Year Pole Replacement Quantities

Precise Pole Prediction Methodology

To understand the service contracts scenario analysis of the BAU business process with the critical path analysis (presented shortly), it was required to estimate and inform the volume of likely transitions. It was therefore necessary to reasonably project the expected peak amount of pole replacements each forward year for the next twenty years, but add precision by accounting for the varied sub-population tendencies, including individual failure rates extrema and in some cases longevity not possible by an averaged approach. This projection was approached more aggressively using statistical inference.

In recent years reliability has been formulated as the science of predicting, estimating or optimizing the probability of survival, or more generally the life distribution, or the mean life of a power pole. Interest in reliability has been manifest by mathematicians, engineers, scientists, economists and those concerned with environmental and life studies. Such developments and interest have been focused on the interplay between reliability and statistics.

Thus, the theory of statistical inference plays an important role in life monitoring and reliability problems.

In this RCM study we are interested in both the functional failure of a pole as a predictor of the catastrophic pole failure event. Because the actual number of pole failures average per year is a small number (around 20) drawing matters of statistical inference from small samples are subject to concerns surrounded by the confidence that can be attached to results obtained from relatively small sample sizes. This is a form of Resnikofs conundrum; for the most important failures we have the least amount of statistical data (approximately 209 failures have occurred over 10 years).

We chose to work with the functional failure data as a pathway to infer the likely pressure it would place on the future pole failure rates. We balanced this inference with knowledge from other researchers.

Wooden poles have been subject to many studies, some records exist dating back into the 1800's tracking the life expectancy of a pole, which varied then as it does today by species of wood, the soil into which it was set, the treatment applied and the environmental factors.

Life Expectancy of a wooden power pole is therefore a challenging multi-variate exercise that has been attempted by many researchers.[36] To support this RCM study service contract, several methods needed to be evaluated in search to find the best method that would allow successful predictions to be made over the next 20-year requirement. We did study various methodologies, including historical methods of expectancy, the use of Monte Carlo simulations, and we also considered the advanced concepts tabled during the RCM workshop like machine learning that have been recently trialled by others.[37]

As noted, the challenges were not so much in which methodology to apply, but rather, given the data sets that were available, which methodology was capable of technically rendering a reasonably accurate 20 year forward prediction of the extremes likely to be observed.

Also, important to note for renewal theory application in support of this service contract requirement we were not to consider replacements of replacement poles. This simplifies the analysis considerably as one must only predict the replacement of the current in-service pole, not future generations or probable combinations of future species that might be selected for installation at a location.

The remaining challenges were confounded by the mixture of failure modes within each species that either are statistically classified as sub-populations with mixed failure modes or could qualify for treatment as a mixture of competing risk failure modes.

In use of the pole retirement data we applied the RCM concept of a functional failure and not a total failure (see critical path PF interval leading to pole failure). Because we had available the construction year, we were able to work with a complete life record and avoid censoring. It was possible in most cases to develop the set of replaced poles that were replaced between the year 2009 until 2019 as statistically complete data, by reflecting to the construction year to establish the start of service date.

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[36]] S. V. Datla and M. D. Pandey, "Estimation of life expectancy of wood poles in electrical distribution networks," Structural Safety, vol. 28, pp. 304–319, Oct. 2005
[37] KELCHEV, B. L. - Predicting Rejection Rates of Electric Distribution Wood Pole Assets, MIT Sloan School of Management, 2009

This is perhaps questionable data as some pole service records extend back 80 years in-service or more, unfortunately there is no way to re-validate this data. In the absence of better data, we used the available data and have assumed it to be correct, knowing that this data if accurate, it had to begin its life on paper records and then over time has transitioned through a few computer systems.

The attraction of a functional failure data in the RCM study is there are 10,000 functional failure events within the 10-year window and many attribute combinations return a relatively high level of confidence that we understand the underlying performance from the data sampled.

Thus, we can suggest we can use the functional failure of a pole to inform the future failure event, noting however that as we do, the strategic safety buffers of the critical path are being adjusted by the business, which we anticipate will have a small effect on the point of functional failure declaration of the life data used in 2019 and the future RCM studies.

So, with all the disclaimers in place, in this RCM study the topic of interest is two-fold.

There is a common interest in predicting the amount of pole failures is close coupled with assessing the steps needed to reduce future pole failures to a practicable level. This combined topic should be worked with the critical path BAU discussions as those discussions portray how a pole failure occurs relative to the modern inspection program which is designed to prevent it.

Secondly, there is a need to strategically set safety margins for the specification of a pole functional failure so as to influence the former matter to a lower total number noting that the population is not at a stable replacement performance level and the population of poles which gives support to a pole failure is expected to increase by as much as 8X over the next twenty years.

This should be worked with in addition to those topics nominated, and with the replacement projections and the inspection effectiveness discussions to fully become informed.

As noted with many pole studies various authors have tried many differing approaches and in some cases with only limited success to achieve correlations and draw statistical inference to inform. Spencer[38] and Elder recently applied an adaptation of abridged life tables created by calculating among other variables the force of mortality by calculating Greville tables to extract the parameters of interest after a battle with bad data that made upon a population of 1.3 million power poles in NSW. In doing so the evaluation and use of Weibull parameterization was set aside citing too many data issues existed in the study data set to be successful.

As noted earlier the CP/PAL data had similar problems to those cited by Spencer before cleansing. On the other end of advancement, as tabled during the RCM workshop Kelchev used a logistic regression model with machine learning to estimate the probability of replacement of each pole in a US based study. While the probabilities calculated by this advanced method were not accurate at the individual pole level, averaging them across a subpopulation of poles reportedly yielded a reasonable estimate of the overall replacement rate for that subpopulation which is of the same order of magnitude as our results for pole failure rates.

The specific challenge presented to this RCM study was that of the fragmentation and incompleteness of the data coupled with a very narrow observation period made joining the data sets problematic. As Kelchev found, the predictive power of the data collected by a utility is poor. At minimum, CP/PAL pole data seems to be data that is muddied by the multiple data errors and omissions or has been otherwise altered by period specific data governance changes that allowed data fields to be utilized for differing purposes.

Complicating life expectancy matters, field chemicals have been installed in a uniform manner since 1993 (see Preschem discussion) but earlier chemical treatments applied in the field were applied inconsistently or not at all, and no data record exists other than retiree memory exist to inform us on the use of a different chemical prior to 1991 (Blue – 7). So equipped, we are powerless to evaluate the total effect of field chemical life extension properly. This is an important maintenance action to thwart rot and decay which is the top functional failure cause.

This dataset also has a large data gap in that 15% of the species of wood are listed as unknown which are impossible to classify. A separate attempt to correct the unknown data was discussed during the RCM study but its results were not available, so wood classified as Species ZZ-UNKNOWN have not generally been included in the RCM study.

[38] SPENCER, N, ELDER L. Pole Service Life – An Analysis of Country Energy Data- Koppers CLTD - Australia

After uniqueness reduction was made on the SAP equipment number (only replace a pole once) this data set yields about 10,000 unique pole replacements that were made during the interval starting in 2009 and ending in 2019. We discarded approximately 4000 records after the data was pronounced clean to work the later portions of the study with this reduced data set.

The good news is this resulting data set has statistically unique features that inform, and a combinatorial approach produced approximately 347 unique statistical sub-groups when separated by species, manufacturing treatment or lack thereof, and then the recorded functional failure location. The problem was the in-service population was not equally attributed, so we were faced with apportioning the population or as we ultimately did, treating the analysis at higher levels where alignment of data was clearly attributed.

At a high level we can report we still observed differences between species, species and treatment, species-treatment type. The variation in lower level data makes us question the durability group uniqueness and usefulness for analysis, given the many different patterns observed in each sub population within a durability group.

Thus, we decided to work from a species and treatment applied at pole manufacture level to perform a projection.

Final Data Used for Analysis

The final data we have used for this analysis was as noted originally derived from the SAP PM database but has been cleansed extensively.

Age in service data from periods prior to SAP PM utilization has either been imported from earlier database systems or paper-based records and is calculated from the year 2019 using the pole construction year currently available in SAP and are assumed correct.

The resulting performance can be categorized into four main data sets;

- In Service poles in 2019 – 404,544 qty
- Replaced Poles 2009 to 2019 – 10,000 qty
- Pole failures 2008 to 2019 – 384 qty
- Pole status transitions 2009 to 2019 – ~50,000 qty

The replaced pole data set was extracted from SAP by the work order task to replace the pole. In this data set, records with a replacement year 2019 are for poles that have either already been replaced or have been designated to be replaced in 2019. The early data set was organized by species, treatment type and then failure location. Each sub-population was overlaid on the same chart to glean the similarities or lack thereof between various species, durability classifications, treatment type effects and end of life replacement failure location.

Other data improvements were made to the data records resulting in what was 90% accuracy by the subject matter experts who attended the RCM workshop. The pursuit of data perfection is perhaps academic, and while it may be considered desirable to some, the view of pole performance can be ascertained from the data in this condition, and noting the effort expended, this is the data that has been subject to 4 months of cleansing activities.

In the early data shown in Figure 20 for reference (each pole is a dot – 405,554 poles) one can clearly see a large amount of replacements erroneously recorded at an in-service age of 0 to 10 years.

Individual pole historical analysis has shown that several of these outlier data points could be corrected and were caused by the incorrect re-use of the old pole equipment record in SAP. The approved process is the correct procedure of creating a new equipment record in the SAP PM database and setting the replaced pole to be marked for deletion.

The un-corrected data can be visualized and has been coined “the blob” chart. This visualization contains all 405,554 in service pole ages, separated by species and treatment type on a common graph.

After data repair the blob is still a blob but has much less early and end of life failures.

Drilling down into the blob reveals clear differences in performance.

Despite some data errors, we noted some very interesting trends that vary between 20 years and 80 years of in-service life, and distinct differences exist between species, treatment types, failure causes, failure location with regional location when the blob of data is dissected more precisely.

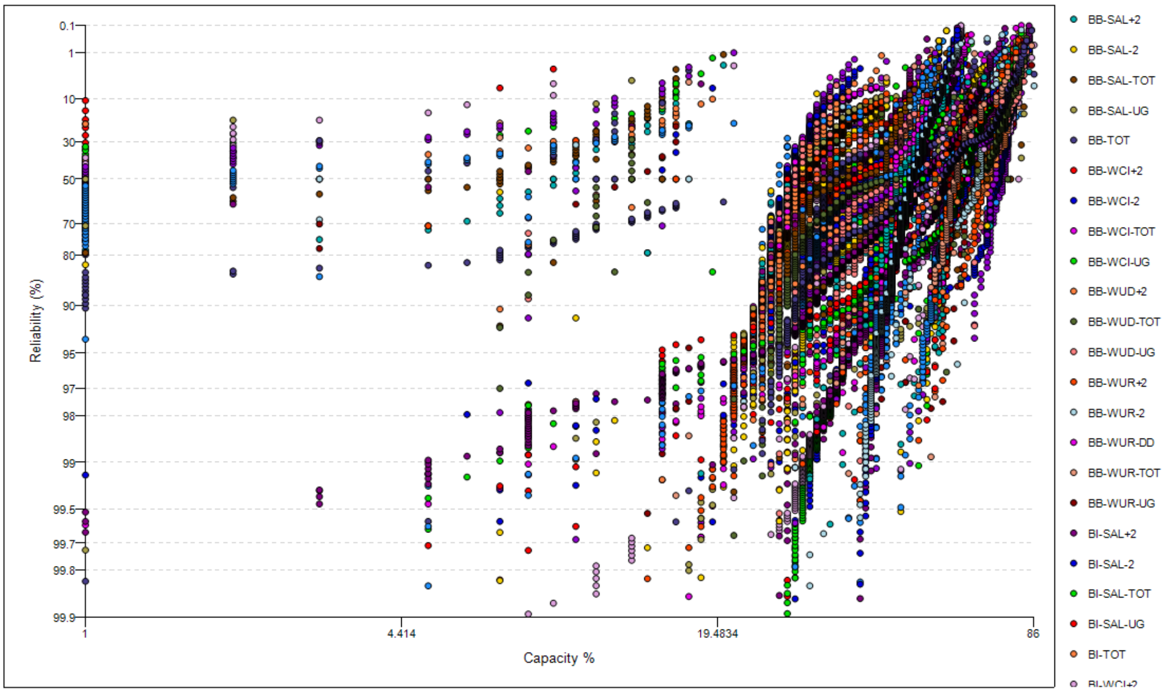

Figure 20 - Replacement Poles organized by Species, Treatment, Location before data clean up (Multiple sources of error exist in the original SAP PM data set – x-axis starts at 1 year of service and extended to 86 years of service – several errors exist in the form of data under 7.5 years of in-service life)

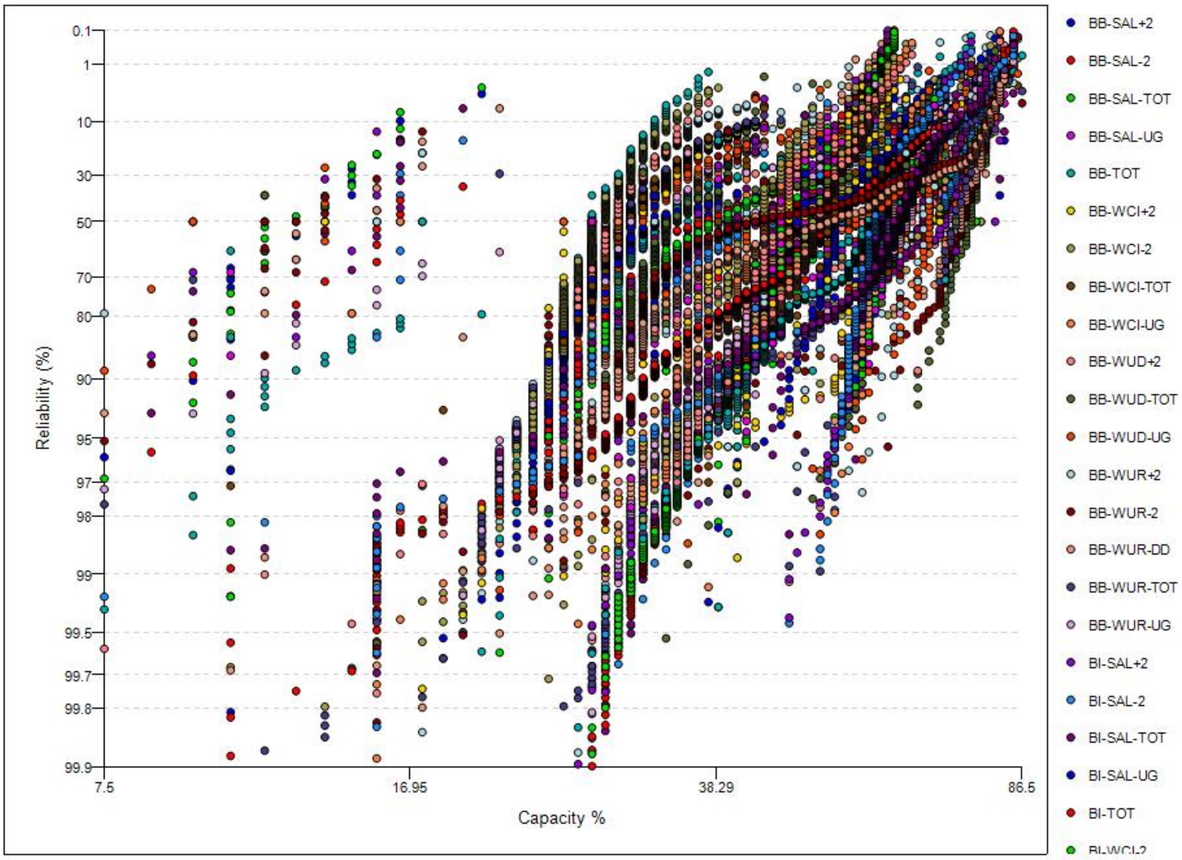

Figure 21 - Replacement Poles organized by Species, Treatment, and Location after data clean-up to 95% accuracy (no errors exist below 7.5 years in service – x-axis starts at 7.5 years to 86.5 years)

The second data problem exists caused by the relatively small window that 10 years of replacement pole data provides a very limited view into the life timeline of a 109-year-old pole population. The resulting view this data provides is skewed.

The rank ordered data is what we have coined as “insertion censored”. This is caused by the dates the poles were introduced into the population and their life expectancy performance which combine to yield few and in some cases no data of value within this 10-year window of observation from which the pole failure performance has been observed and can reliably be ascertained.

Other data sub-sets presented a different challenge from projections.

In some cases, the in-service pole population of a sub-group exceeds the functional failure distribution’s oldest age as observed by a pole functional failure. This means the poles in service exceed the age of a specific functional failure distribution and suggests there is at least one more functional failure mode to be observed.

This presents a serious problem for any algorithm attempting to utilize past performance to predict the future performance because the future has not yet arrived. This forced us to treat some data sets as mixed sub-populations in lieu of treatment as mixed competing risk models. In doing so we have followed guidance as prescribed by Nelson[39] and Al-Hussaini[40] and the probable portion of mixing has been estimated using the available data.

As Nelson points out “life data with a mix of failure modes requires the use of special methods. It is clearly wrong to use data from one failure mode to estimate the life of another failure mode”. This also applies to the notion of censoring of data applied against any specific failure mode.

Where a mixture of sub-populations presented itself as the driving underlying force, we fit the distribution to the data using Maximum Likelihood Estimates (MLE) as prescribed by Nelson using Minitab MLE processing. When the data was clearly statistically independent, we used the underlying theoretical model for these cases to be the series system model for independent competing failure modes.

The series-system model for the functional failure life of independent competing failure modes assumes;

1. Each unit has M potential times to failure, one from each mode, and the times are statistically independent.
2. The time to functional failure is the smallest of M potential times.

To avoid left censoring we used the pole’s construction year as the date a pole entered service. By calculating the insertion date, we thereby worked the study from complete data records for pole service life and eliminating the need to treat left censored data.

For transition analysis data used in the BAU critical path modelling this data was dug out of SAP to take the oldest transition back to its origin to avoid left censored data by calculating the age in a status back to its insertion. The later comment is specific to the treatment of transition analysis as provided in the critical path BAU discussion.

The application of mixed sub-populations largely eliminates the need for right censored data treatment with some data as it is clearly wrong to include as right censored data if the failure modes do not compete or if the future failure mode has not yet been observed. Testing confirmed the inclusion of certain censored data “biased” the mean life to such an extent (more than 30 years in some testing) so much so that the original population of functional failures could not be recovered when re-simulated.

The bias culprit appears to be the Mean Order Number (MON) algorithm treatment of right censored items whose various combinatorial possibilities are undetermined, but the algorithm calculates the mean or average rank order, which is a guess of sorts as to which rank is correct to assign to a censored item.

To avoid these problems, we have treated many populations as mixed sub-populations using the observed functional failure events.

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[39] NELSON, W. Applied Life Data Analysis, Wiley Series in Probability and Mathematics – 1982 John Wiley & Sons – Canada pg. 347, pg. 364.
[40] AL-Hussani and Khalaf S. Reliability and Hazard Based on Finite Mixture models, Handbook of Statistics, Vol 20 2001 Elsevier Science. (2.18 et al)

For poles, we also had to consider the effect of “interval data” generated by the inspection program itself. We did this because there are clear patterns of functional failure concentrations at the inspection intervals the program operates on within the data.

The functional failure (F) is also only found upon inspection which occurs at a prescribed interval (See section on the CP/PAL inspection program). From this we only really know the functional failure has occurred during the time between the current inspection and the last inspection. Estimating the time in service must be considered.

In doing so, we have treated the intervals as small intervals by assuming a nominal 100-year life expectancy and approximated the failure time to the nearest year (vs. Midpoint of the interval).

Data has therefore been analysed using the resulting year and based upon the availability of accurate construction year data this data has been treated as complete data. The compression to year of installation was provided by CP/PAL and any error introduced by this treatment is considered small or nil.

Because no poles of a certain attribute combination/classification were installed during ranges of years or have not come of age within the 10-year window of observed functional failures, there is no data from which to process their functional failure performance or relate this to the pole failure prediction. When this occurs, an estimate is used.

If the window of observation was perhaps wider, (like 50 years) the performance answer probably changes with more data, so we have used care when “insertion censored” data is possible. The 10-year window unfortunately was constrained due to a known SAP data issue with 2005 era data. 2008 or 2009 data was an inspection cycle clear of this data issue and offered the most homogeneous data possible, hence the start in 2008 or 2009 for the noted data sets.

The topic of insertion censoring (for lack of a better term) is interesting and does not occur often but it does affect the statistical analysis approaches because it eliminates certain functional failure times from being possible to be observed. This affects the rank order calculated for a specific sub-population group if not all the data are possible to be observed. If data is missing from any data set the estimated parameters regressed would be incorrectly calculated if the missing data is not accounted for.

In a nutshell, for a 60-year-old pole to functionally fail, there must be a 60-year-old pole installed that can fail. If no poles of a certain species or combination were installed 60 years ago, then it becomes impossible to observe a failure at this age within the observable window. If the study window is 10 years, then we need to augment the prior sentence to include 50 to 60-year-old poles.

If we use Blackbutt as an example of insertion censoring, we can observe the effect readily by observing the last 20 years of CCA poles installed as shown in Figure 22. If we fast forward 35 years into the future and hypothetically perform another RCM study and analyse a 10 year window of functional failures from 0 to 10 years prior we will have at risk of functional failure poles whose minimum age is 35 years and a maximum of 55 years old, but we will have no poles older than 56 years old because they were not installed or inserted into the population 56 years ago.

Because of the 10-year window restriction, we “insertion censor” functional failures which would affect a parameter estimate obtained by normal regression techniques and affect the estimate of pole failures and pole replacements because we have limited the poles that can be observed.

When we estimate the future poles to be replaced within any year by the average failure rate method, another problem arises. When we have only a small number of poles installed during any given year – the number of functional failures observed will be somewhat proportional to the number inserted during any given year. If we perform a ranked regression, the lower number of absolute functional failures will adjust the resultant rank obtained. Where we have used the resulting point estimates of the conditional failure rate obtained for any age, we have then used the mean (average) normalized failure rate to perform a de-convolution process to estimate the renewal cycle projections.

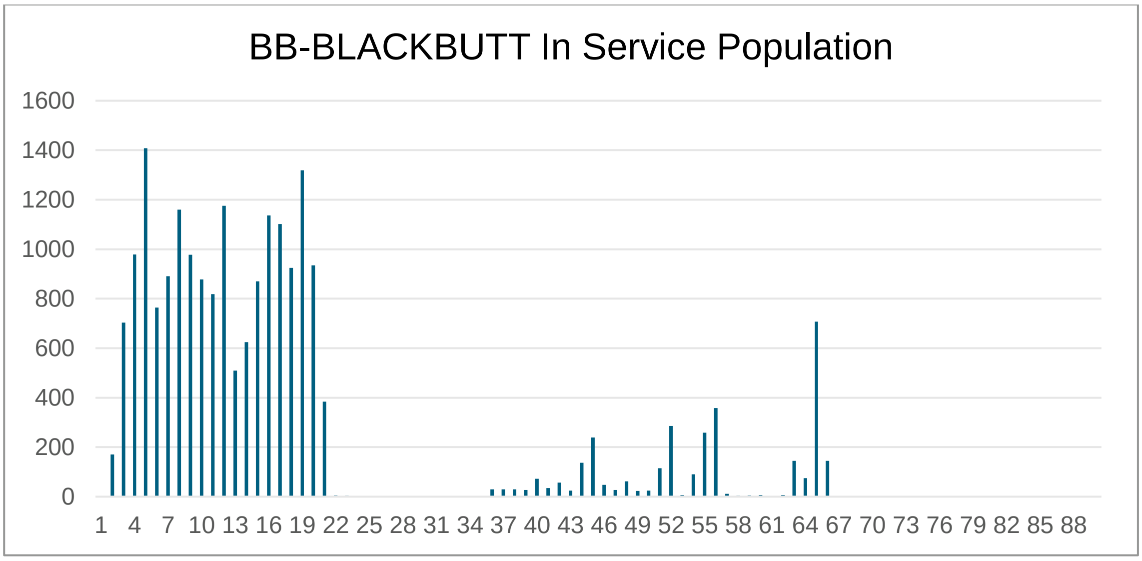

Figure 22 - Blackbutt In Service Population is insertion censored during the years no new poles were inserted.

So, given all the data challenges we have strived to treat the data we have with care and processed from the functional failures a set of parameter estimates.

These were initially regressed to the equation of best fit, either Weibull, normal, log-normal, exponential using ordinary least squares rank regression on x (OLS). As a test for mixed sub-populations when we encountered mixed sub-populations often a bi-Weibull provided the best fit. In the end we settled on treating the mixed sub-populations by separating them and then fitting them to a standard 3 parameter Weibull equation using Maximum Likelihood Estimation (MLE), often setting the failure free period to zero.

The population projections are made using a parameterized Weibull approach calculating the conditional survival function and resulting probability density from the initial age of the in-service population functional failures, noting the differing approaches needed for mixed sub-populations and competing risk conditions.[41] This is an RCM Centric approach. The RCM process was founded upon the conditional probability of failure whose six (6) distinct curve shapes show cased the need to approach maintenance policies differently.[42]

In this study we have calculated the conditional survival function using a 2 parameter Weibull parameterized approach given the condition that a pole has survived up to the start of the interval (year), the chance of survival until the end of the year was then the quantity of interest.

$$R(t|T) = \frac{e^{-((T+t)/\eta)^\wedge\beta}}{e^{-(\frac{T}{\eta})^\wedge\beta}}$$

This reduces to the familiar 2 parameter Weibull equation when a new pole is inserted at T=0 as the denominator reduces to R(0)=1 and the numerator reduces to $R(t) = e^{-((t)/\eta)^\wedge\beta}$.

From the number of failures tabulated in a given year it is a simple subtraction from the in-service population to capture the expected number of functional failures at any future age.

Where Monte Carlo estimates were used, the in-service age indicates the age (in years) a pole has survived to start a new year is referred to as the “initial age” as used in the Isograph Availability Workbench software. This is the current age of a pole in the in-service data set. The quantity of poles that are currently at that age for the sub-population are then subjected to the results.

[41] AL-Hussani and Khalaf S. Reliability and Hazard Based on Finite Mixture models, Handbook of Statistics, Vol 20 2001 Elsevier Science. (Equations 2.1 to 2.18 et al)
[42] NOWLAN, HEAP, Reliability Centered Maintenance, United States Department of Defense 1978

If the confidence interval for a parameter estimates was poor, an estimate of the likely parameter was substituted, based on input from Subject Matter Experts (SME) or the durability ranking. The values used accompany each sub-population.

The exclusion to projected data is where a subpopulation or species in total is not of a critical mass, they have been excluded from the projection process because their non-inclusion introduces only a small error when balanced against 405,554 poles in service. We have also not included unknown wood – Type ZZ.

Figure 23 (shown below in the next chapter) showcases the complexity we have worked with.

Population Profiles

A 20-year population profile projection was an RCM study service contract deliverable. In order to accomplish this projection, we also needed to understand the practicable effects of this large aging population and when 99% of a species was expected to go out of service. We calculated the B1, B50 and B99 projections for the 1%, 50% and 99% out of service for each combination to learn the window of functional failures that were to be expected to be within. The aging population sub-grouping is presented below showing the clear differences that needed to be accounted for, grouped by species and treatment applied at manufacture of the pole. Note the clear population sub-groups exist by age and treatment as shown in Figure 23.

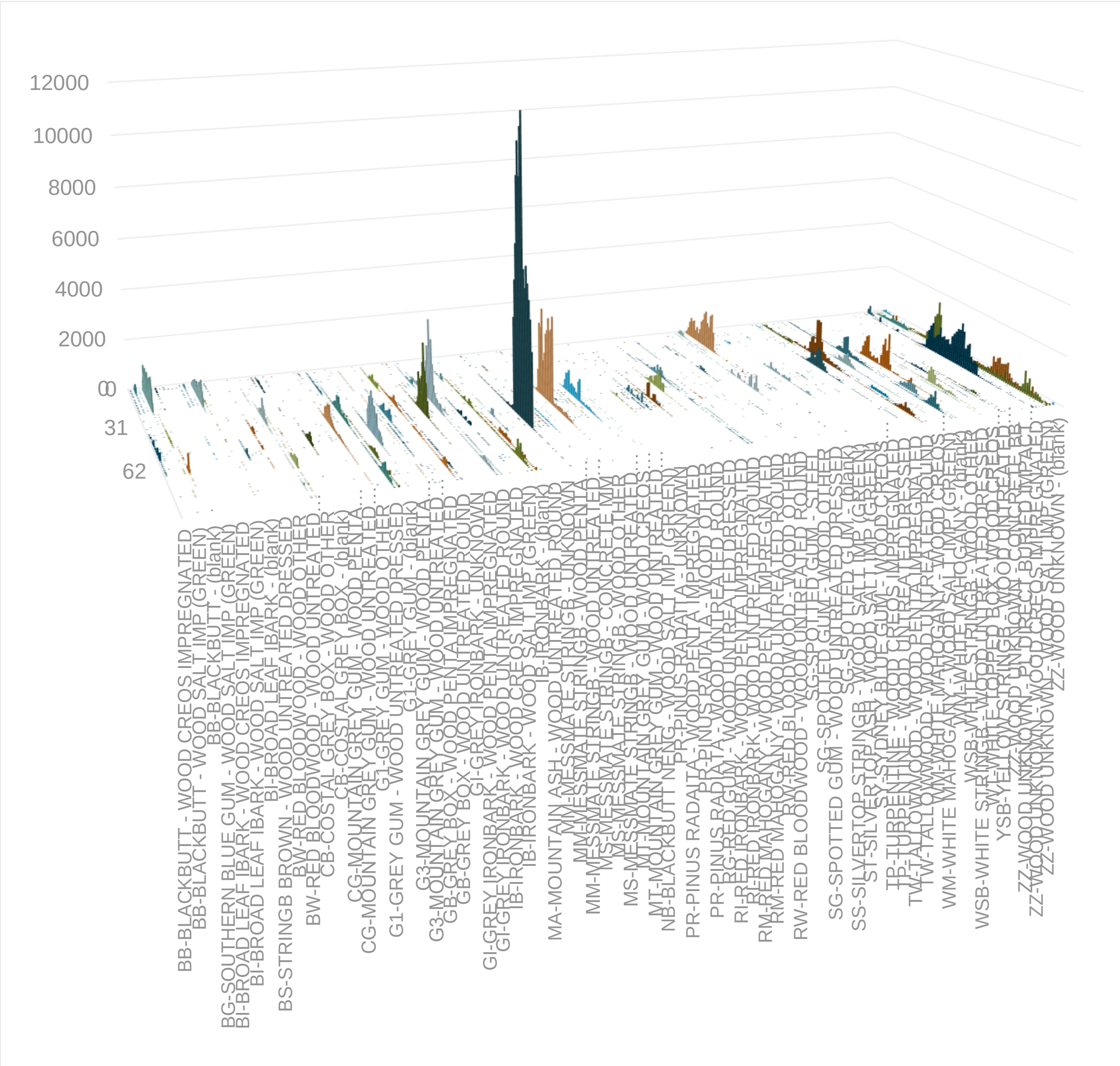

Figure 23 - Current in-service age by species and treatment classification

Kaplan Meier Non Parametric Analysis

To gain an understanding of the challenges illustrated by 4, the functional failure survivor performance was calculated using Kaplan Meier (KM) estimator method first by applying a non-parametric analysis to the functionally failed species groupings.

The KM view resulted in Figure 24 to produce a suite distinctly different in survival performances that varied by species and treatment type and yielded some interesting observations. There were also distinctly different hazard rates that vary by age, but all species analysed indicate in RCM mantra they are subject to age or wear out performance as shown in Figure 24 for the main species populations.

The KM analysis was operated also with confidence limits set at 95% to give us an understanding of the suitability of the statistical data.

We found most functional failure survivor curves terminate after about 70 years. This is contrast by in-service population that has a few poles that currently are listed as exceeding 109 years in service. Thus, there is a bit of a paradox. Some poles are in-service longer then the observed end of life. We resolved this paradox by assuming in most cases that these poles where outperforming outliers would be replaced in the next few years.

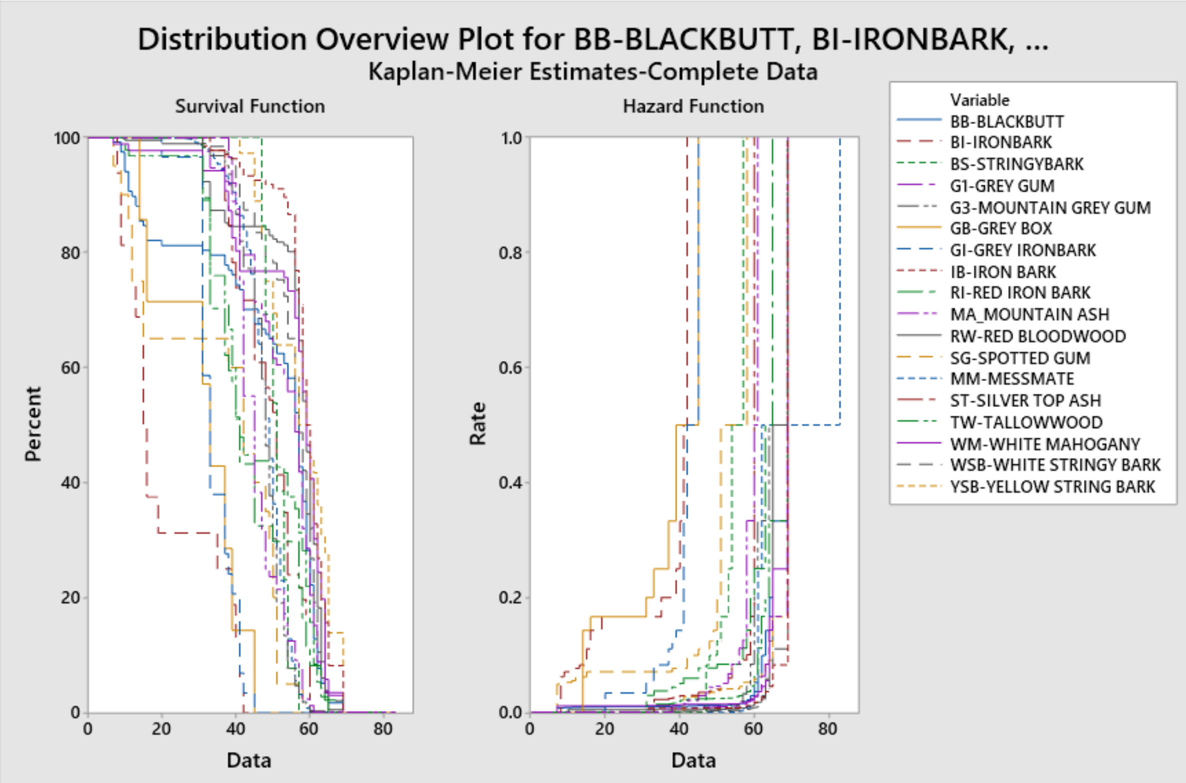

Figure 24 - KM Statistics for each Species of Timber

Where age paradox presented a situation of critical mass where the functional failures observed end before the age of the existing in-service population, SMEs have suggested this occurs on populations of wood that are considered by the SMEs to be premium timber from old forest growths and not newer timber from plantation growths whose life expectancy is yet to be revealed.

While this may be true, it does complicate the forward projection of future replacements when wood exists for which there is no observable end and it requires that additional care be taken to separate the old premium timber from newer timber.

We observed the practical end of service life as calculated by KM for most timber is about 70 years in service.

On sub populations of wood that currently exhibit extreme long life, were noted, we have used other estimates of the probable replacement age of this sub-population, as detailed within the species projection text, because of the age paradox, there is no observed functional failures that give rise to a parameter regression.

Histogram Analysis

Analysis by histogram fitted to a normal curve was performed to see if the wear out was normally distributed. Additional parameterized analysis was performed in the Availability Workbench Weibull module by curve fitting to normal, log normal, 2 parameter Weibull, 3 parameter Weibull, Bi-Weibull, tri Weibull and exponential equations.

The results shown in Figure 25 display considerable varied performance, including bi-modal performance and for some species tri or quad non-normal functional failure performance. The results led us to conclude that many species contained a mixture of sub-populations of different performance poles and could not be treated just at the species level.

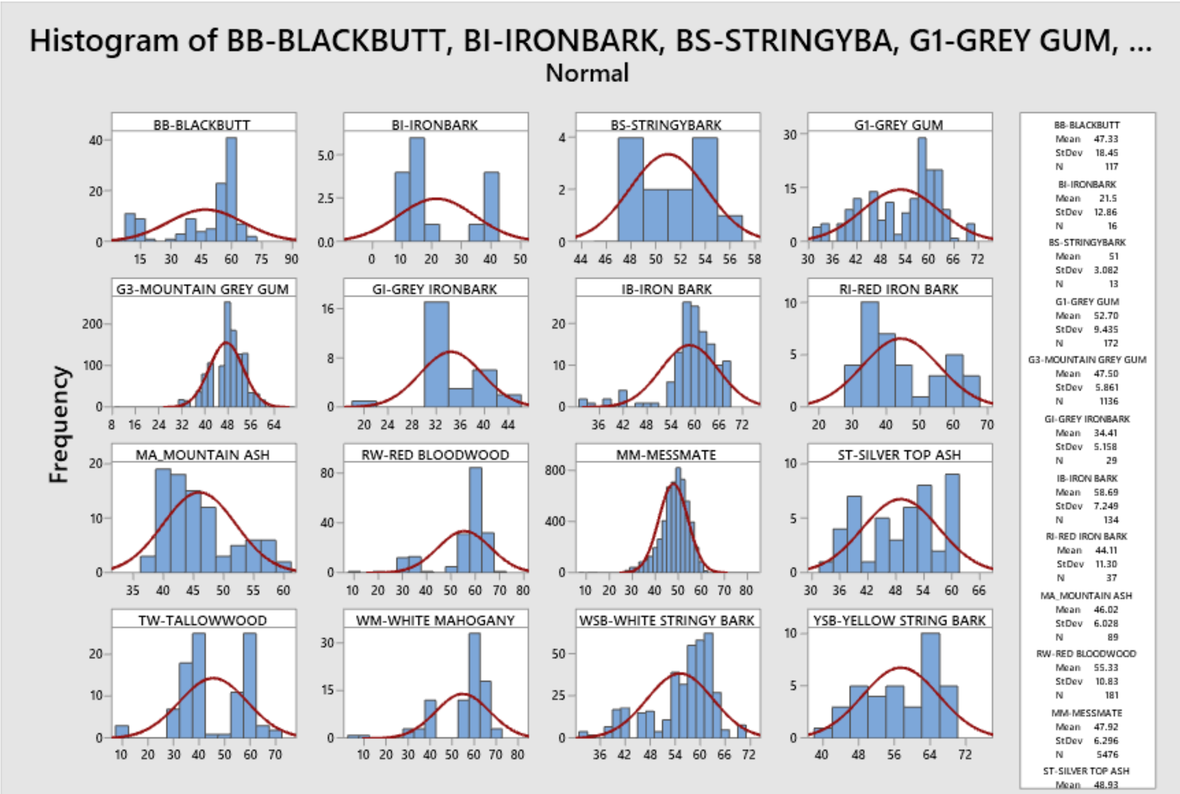

Figure 25 - Histogram Analysis on Main Species Groupings

The exception to non-normalcy is the Messmate Functional Failures which present very normally distributed performance of some 5400 functional failures.

Because the projection method (And the Monte Carlo method) was reliant on parameters regressed from data, the fit to a parameterized equation was tested three ways; Goodness of Fit, Correlation Coefficient, and Anderson-Darling (AD) Indicator calculations. The Goodness of Fit and Correlation Coefficient were calculated in Isographs Availability Workbench – Weibull Module.

The AD indicator was a product of Minitab calculations.

Goodness of Fit [43] (ε) tests the relative fit of the functional failure age data to a parameterized curve.

The Correlation Coefficient (ρ) determines how well the data correlates to the resulting parameterized equation.

[43] SBTNTVASAN, R. (1970). An approach to testing the goodness of fit of incompletely specified distributions. Biometrika 57, 605-11.

The Anderson-Darling (AD) test (Stephens, 1974) is used to test if a sample of data came from a population with a specific distribution. It is a modification of the Kolmogorov-Smirnov (K-S) test and gives more weight to the tails than does the K-S test. The K-S test is distribution free in the sense that the critical values do not depend on the specific distribution being tested (note that this is true only for a fully specified distribution, i.e. the parameters are known).

All three were used in the evaluation to select the most likely parameters.

Appendix Q contains results for selected sub-populations as tested by the AWB software. Minitab results display the AD* number in the legend of various charts.

Expectancy and Forward Projection

As noted, one of the many service contract requirements was to project a forward-looking view of pole replacements.

This was limited to be over the next 20 years, but data provided is for a longer period as it also contains information of value and was needed to confirm the projection within the 20-year window was accurate.

This knowledge will inform the failure rate and pole failure discussion as the increase in the pool of possible failure candidates will likely to occur over the next 20 years and this will pressure the pole failure rate. This analysis by species and sub-population has been accomplished and the results are presented in the charts that follow.

This full projection is grouped by durability classification to showcase the problems expected with the aging D3 population. This projection is built upon the summation of the species within each durability class based on Appendix F grouping. This projection does not include the unknown timber – code ZZ. The projection is as expected a little bit more aggressive than the projection derived by average failure rate because it considers the extremes of sub populations instead of the average obtained by the failure rate method.

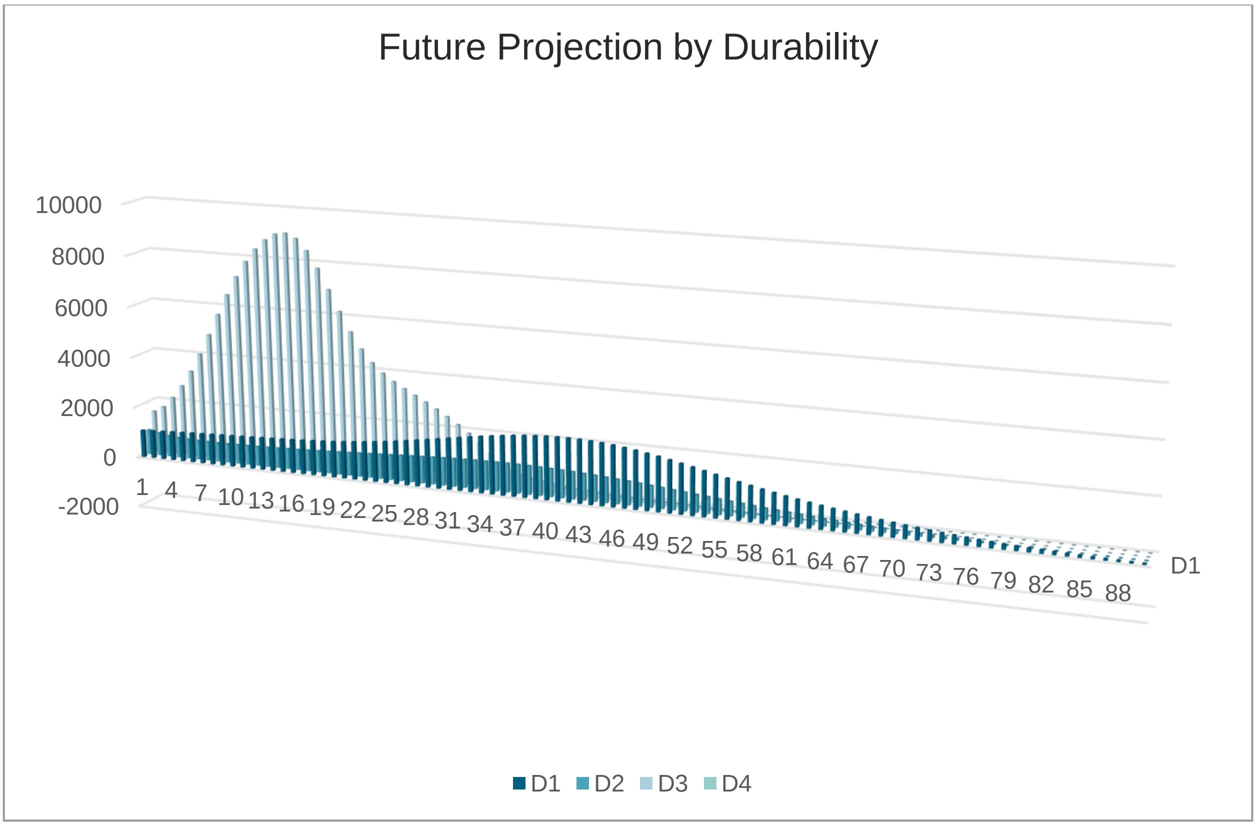

Figure 26 - Forward projection of replacement poles by durability class.

The visualization of the life expectancy forward prediction plots needs some explanation, so the reader understands the information plotted. This combined plot was necessary to see issues with competing risk models, and insertion censoring. The main sub-group has been taken at a species level, but the treatment of the projection is varied by the type of challenge the data presents.

In the projection plot there are several sets of data plotted on a common x-axis. This data includes the existing in-service population, the data by year of service at replacement for the actual replacements made during the years 2009 to 2019, and supported by the explanation in the text in some cases the outline of the Weibull shape regressed by Maximum Likelihood Estimation of the functionally failed replacement poles is overlaid upon the replacement data to allow evaluation of the rough or close fit.

In each of the following species projections, Age is found along the x-axis and serves to indicate four different values.

1. The current age in years of the in-service population. (Initial Age)
2. The in-service age at replacement of all functionally failed poles. (F)
3. The age in future years from this year replacement poles are projected to be retired as functionally failed poles. (Projected F)
4. The age used by the predictor function.

Confidence in the prediction[44] in the form of Confidence Intervals (CI) for the regressed parameters used in the forward prediction models have been evaluated by calculation of the two-sided 95% confidence limits as per Nelson using MLE processing. As noted elsewhere, in several cases the amount of data available does not yield a high level of confidence in the resulting parameters which we believe has been offset by SME input. In other cases, the amount of functionally failed poles is enough to render a high level of confidence within the intervals that are not “insertion censored”.

Therefore - for each species results and some commentary is provided to explain and qualify the projection along with a treatment classified in-service population from which the prediction was operated to confirm the initial age or the substitution of mixed sub population apportionment. Other charts are identified in the text for the species.

The species are summated to produce the full projection by durability found in Figure 26 which is the service contract deliverable.

[44] KANOFSKY, P. (1968a). Parametric confidence bands on cumulative distribution functions. Sankhya A 30, 369-78. KANOFSKY, P. (1968b). Derivation of simultaneous confidence intervals for parametric functions from a parametric confidence region. Sankhya A 30, 379-86.

BB – BlackButt Forward Projection

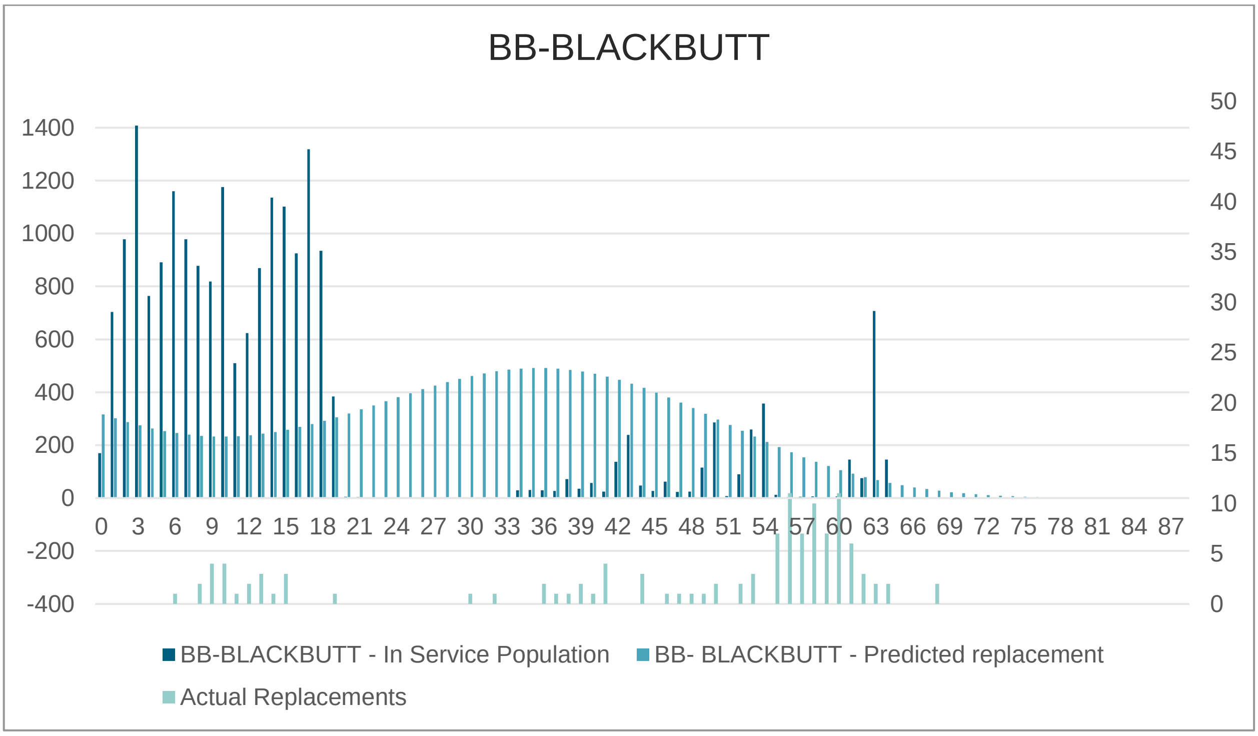

Figure 27 - BB - Blackbutt Prediction

The total number of Blackbutt poles in service is approximately 20581 with the majority being installed within the last 20 years. There is a smaller amount of older premium timber.

The prediction of future functional failures per year is approximate due to low numbers of actual functional failures that have occurred over the last 10 years (only 117), as a result confidence in MLE regressed parameters must be considered with a check to inform the choice made by review of KM analysis in an attempt to improve the projection.

The final projection is conservative and was ultimately made using a 2 parameter Weibull shape factor of 4 and a characteristic life of 52 years. These parameters were derived from a Maximum Likelihood estimate. The 95% confidence limits calculated suggest the characteristic life could range between 49.5 and 56.1 years and the shape parameter could be as low as 2.5.

Because of the low numbers of functional failures available and the projection of the next 20 years being of importance, an attempt was not made to better fit a prediction model against the possible three functional failure modes that might be speculated.

There is an influence on the near-term future year replacements from the current population that has reached an in-service age of 62 years. The older in-service poles are premium timber from old forest growth, and many are Creosote impregnated.

The newer installed population is largely CCA treated and may exhibit soft rot functional failures before an in-service age of 15 years.[45] Other wood treatments were not considered to be of critical mass and were excluded due to their low numbers in-service and/or their low numbers of functional failures.

[45] Analysis from CP/PAL data provided in file: Poles replacements_-_timber_ (2009-2019) _final (002).xlsx

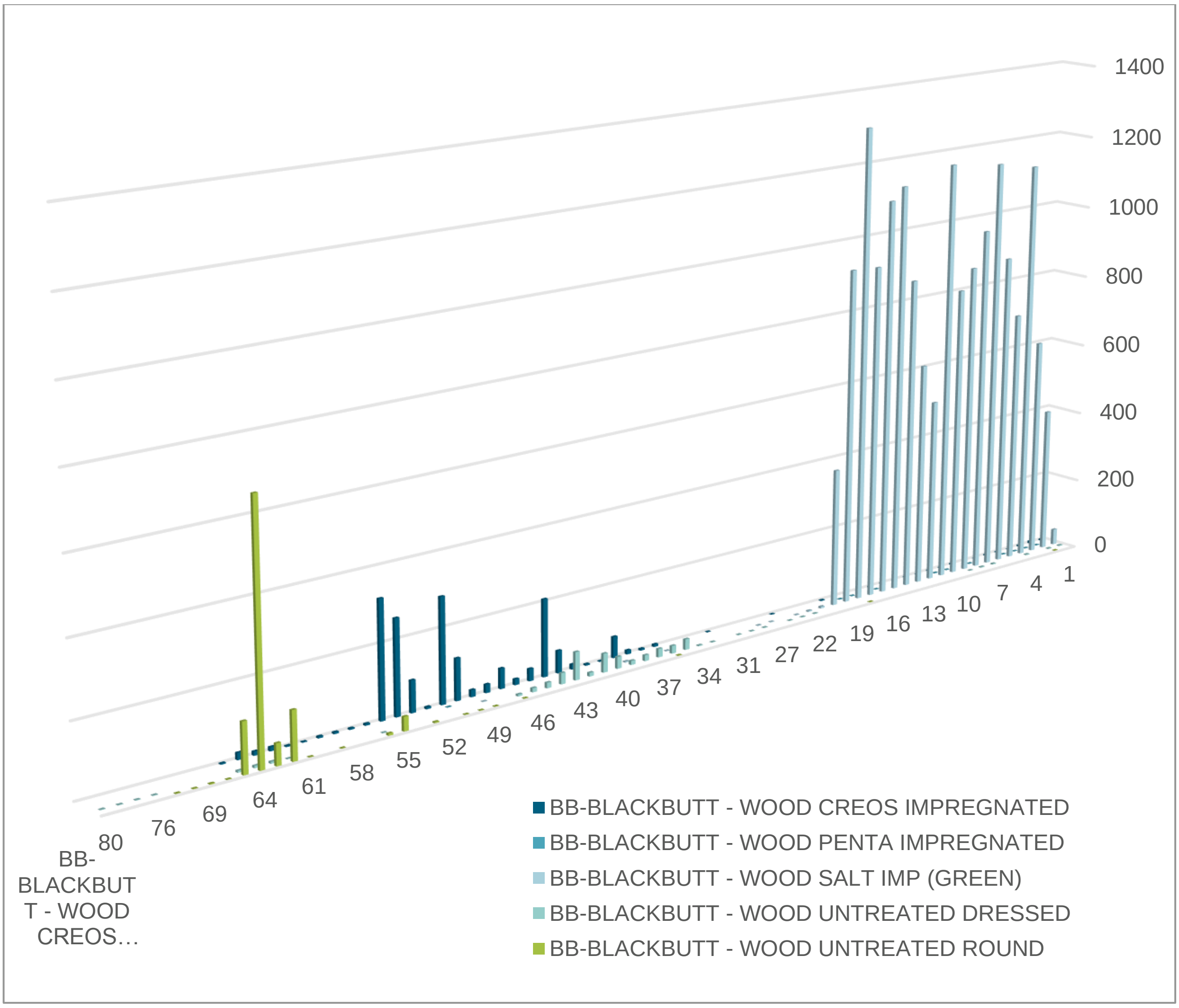

Figure 28 - Blackbutt Sub-Populations

BI – Broad Leaf Red Ironbark

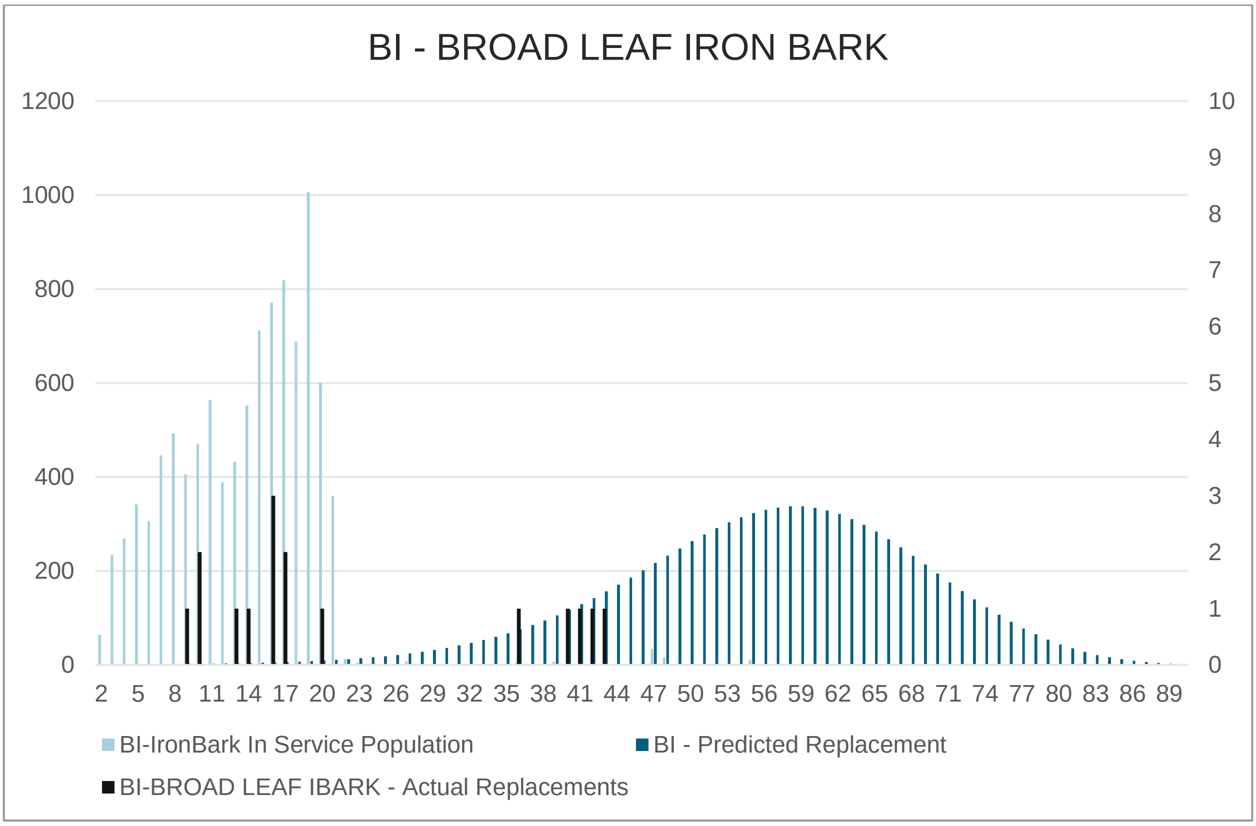

Figure 29 - BI- Broad Lead Red Ironbark Projection

The total number of Broad Leaf Ironbark poles in service is approximately 10047 poles with the majority being installed within the last 20 years.

The projection of replacements due to future functional failures per year is approximate due to low numbers of actual functional failures that have occurred over the last 10 years (only 16). Given the low confidence associated with parameters derived from only 16 data points the projection was made using a 2 parameter Weibull with a shape factor of 7.5 and a characteristic life of 51 years suggested by SME. These were not derived from a Maximum Likelihood estimate of the likely parameters. The 95% confidence limits calculated against the small number of functional failures do not support a position of confidence. Rather, SME suggested the projection be made on an engineering estimate of the plausible performance of a Durability Class 1, Strength Group 1, CCA treated pole.

The newer installed population is largely CCA treated and may exhibit soft rot functional failures before an in-service age of 15 years.[46]

[46] Analysis from CP/PAL data provided in file: Poles replacements_-_timber_(2009-2019)_final (002).xlsx

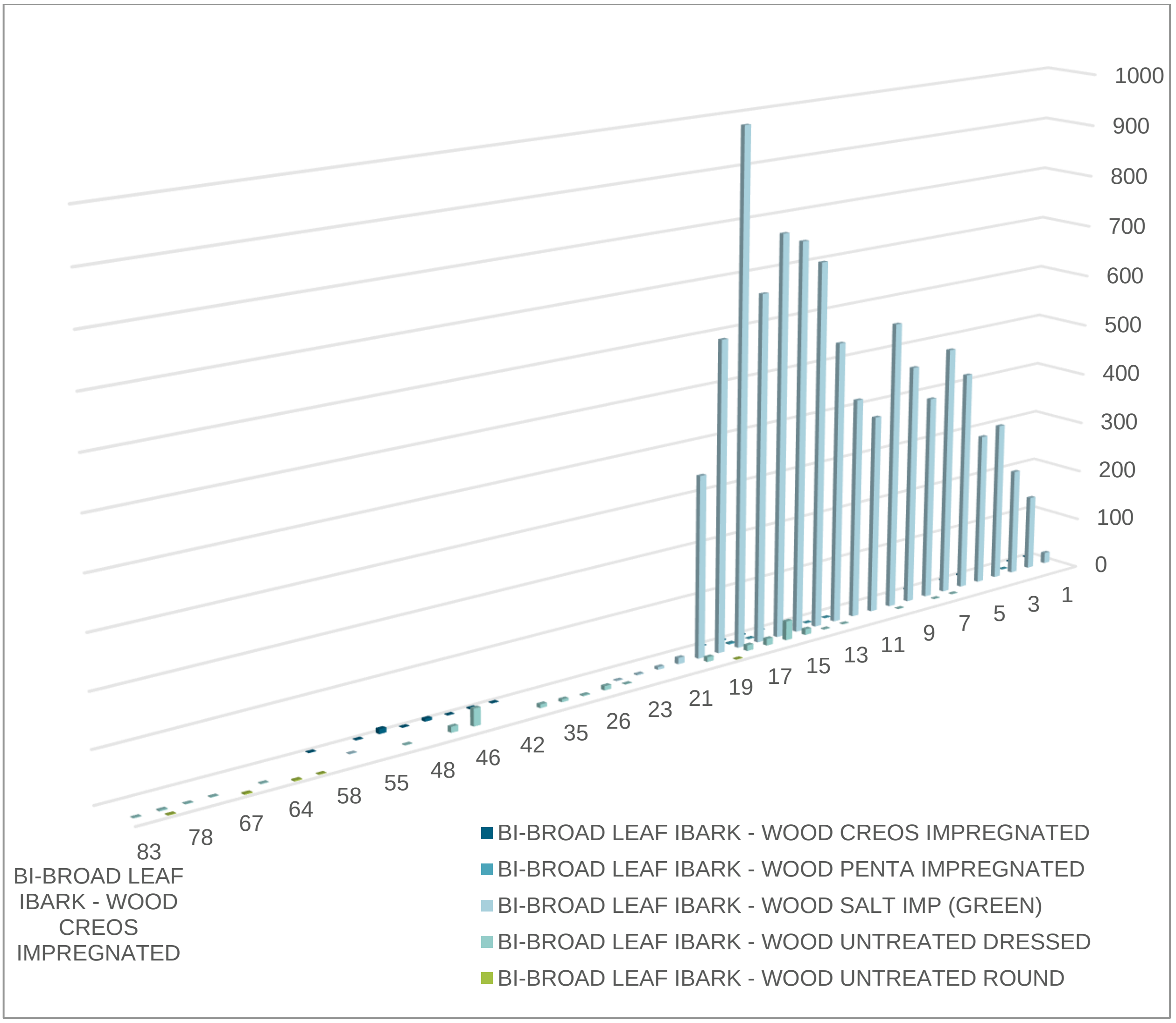

Figure 30 - BI Broad Leaf Iron Bark Population

The Broad Leaf Iron Bark in-service population is largely made of CCA treated timber installed over the last 20 years and is not expected to be a factor within the current 20-year projection window.

There are some very small quantities of other treatments which have been ignored because they are not of critical mass.

BS – Brown Stringy Bark

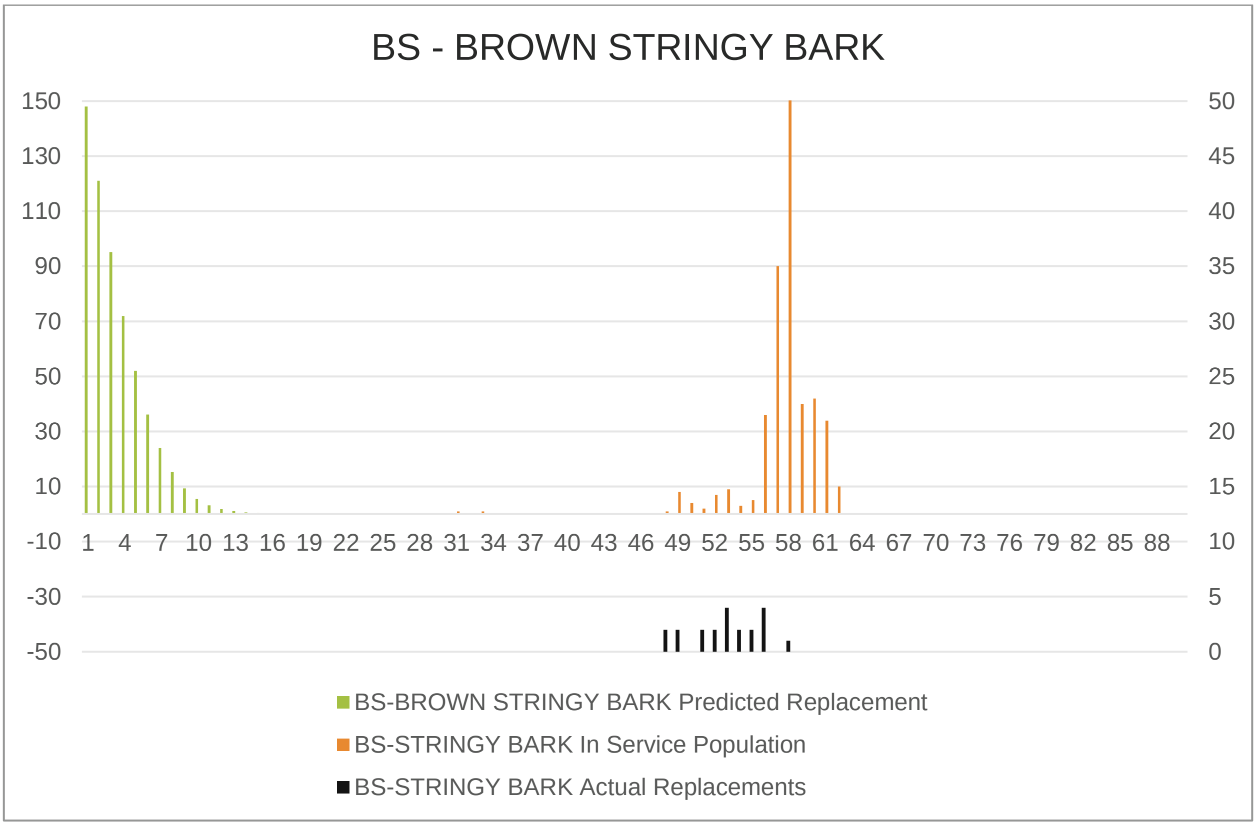

Figure 31 - BS- Brown Stringy Bark Projection

The total number of Brown Stringy Bark poles in service is approximately 511 poles with the majority being installed about 58 years ago. These are Creosote Impregnated Durability Class 3 poles nearing their end of useful service life.

The prediction of future functional failures per year is approximate due to low numbers of actual functional failures that have occurred over the last 10 years (only 16). The actual replacement poles ranged from 47 to 57 years of service and are also insertion censored.

Because the in-service population largely exceeds the life experience of the functionally failed units that were observed we cannot make a prediction based upon past functional failures. With a population at the end of its probable service life we can only project a possible retirement scenario for the 511 poles.

Therefore, prediction was made using a 2 parameter Weibull with shape factor of 8 and a characteristic life of 50 years to gracefully age out of service the BS poles. This prediction was not derived from a Maximum Likelihood estimate of the likely parameters regressed from functionally failed performance data.

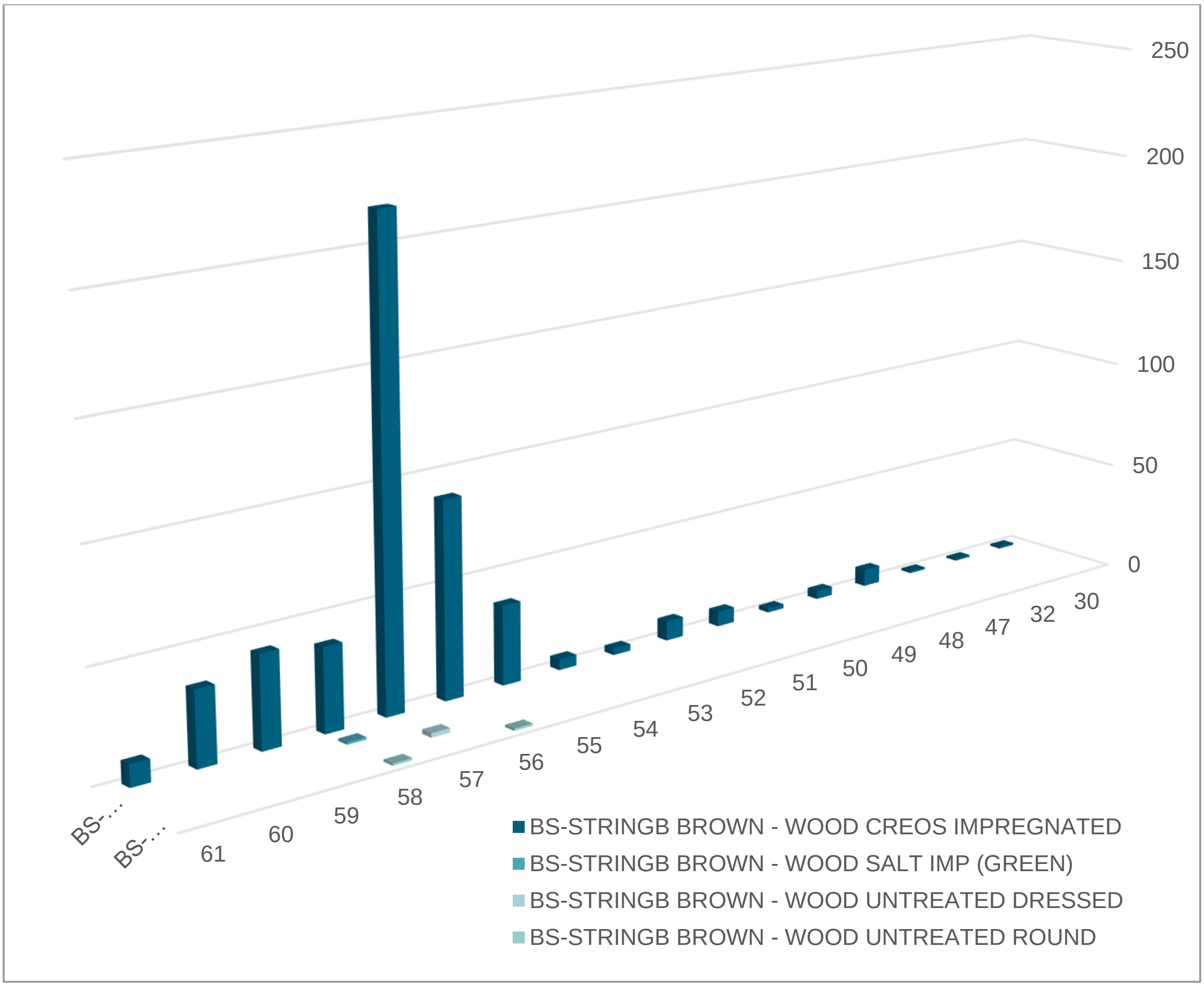

Figure 32 - BS - Brown Stringy Bark

The Brown Stringy Bark population sub-group is largely creosote impregnated. The small number of other treatments have been excluded due to low critical mass.

CB – Coastal Grey Box

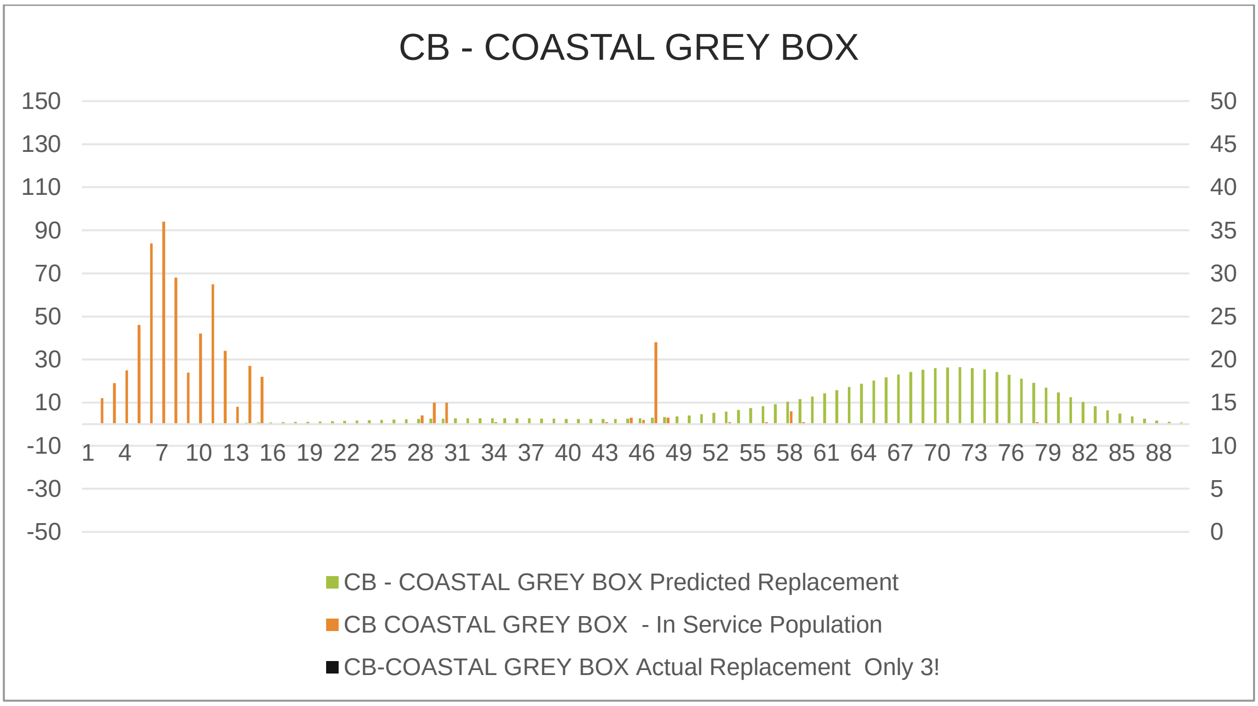

Figure 33 - CB - Coastal Grey Box Projection

There are 652 CB poles in service but in the 10-year window no functional failures available.

Without a past performance predictor a projection is made solely upon an engineering estimate using a 2 parameter Weibull with shape factor of 8 and characteristic life of 59 years. The small number of Creosote and CCA identified poles are accounted for in the forward projection.

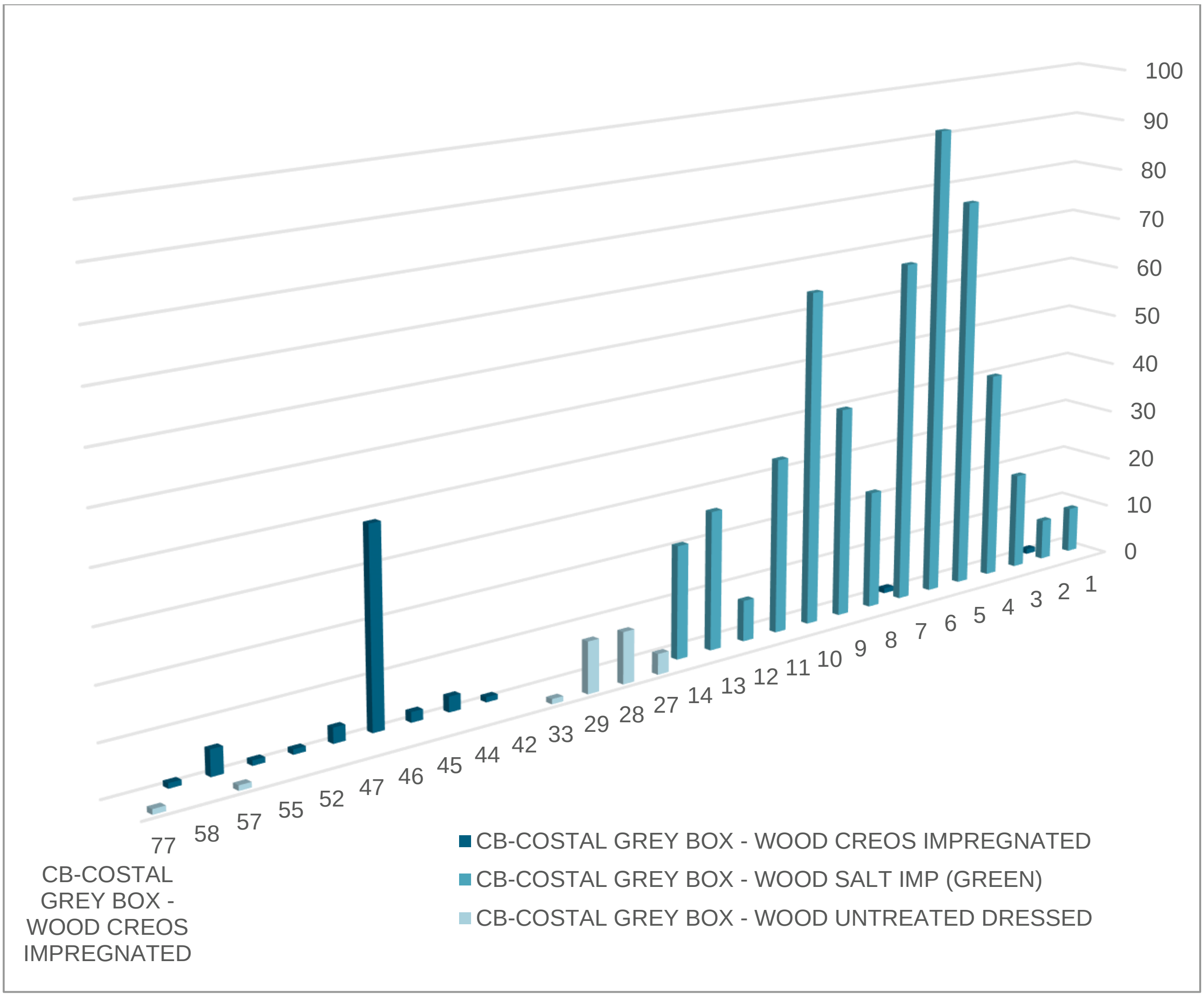

Figure 34 - CB - Coastal Grey Box -Sub-population profile

G1 – Grey Gum D1

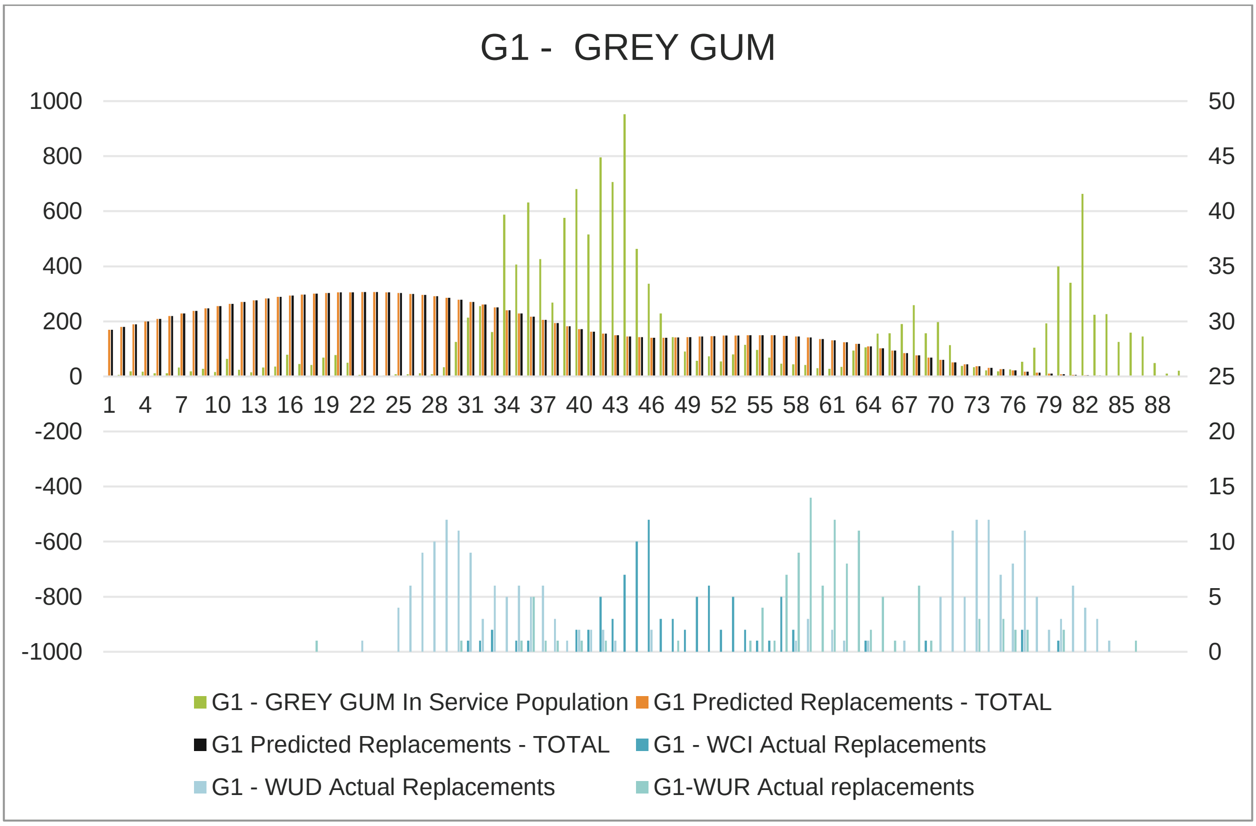

Figure 35 - G1 - Grey Gum Durability Class 1 G1 Grey Gum is a consolidated classification that was created to group durability class 1 grey gums into a common group and as such presents a complex composition of mixed sub-populations with in some cases in service poles that exceed functional failure distributions.

There are 14393 total poles in this group, and they have been installed in each of the last 100-year intervals. In recent times a small group of CCA poles have been installed over the last 20 years but none have functionally failed within the study window. The CCA poles are not a factor within the 20-year window of interest, as they have been projected using a 2 parameter Weibull with a shape of 8 and a characteristic life of 70 years because no poles have functionally failed from which a projection can be based.

Starting about 1956 a large group of Creosote impregnated poles were inserted into service. Of these, only 88 have functionally failed. These were projected using a 2 parameter Weibull with shape of 8 and characteristic life of 70 years.

Untreated wood that has not been de-sapped (Round) exceeds 80 years of service. The functional failures average 60 years. This sub-population was treated as a mixed sub population using a 2 parameter Weibull with shape of 8 and characteristic life of 85 years.

A 4th sub-population averaging 66 years which is untreated – de sapped dressed wood and replacement data shows bi-modal failure patterns with means at approximately 35 years and 77 years of service. This subpopulation was projected with a 2 parameter Weibull using a shape factor of 8 and a characteristic life of 85 years because the in-service poles could not be predicted with the functional failures.

The fifth sub-population is Penta impregnated wood but does not have critical mass to warrant prediction.

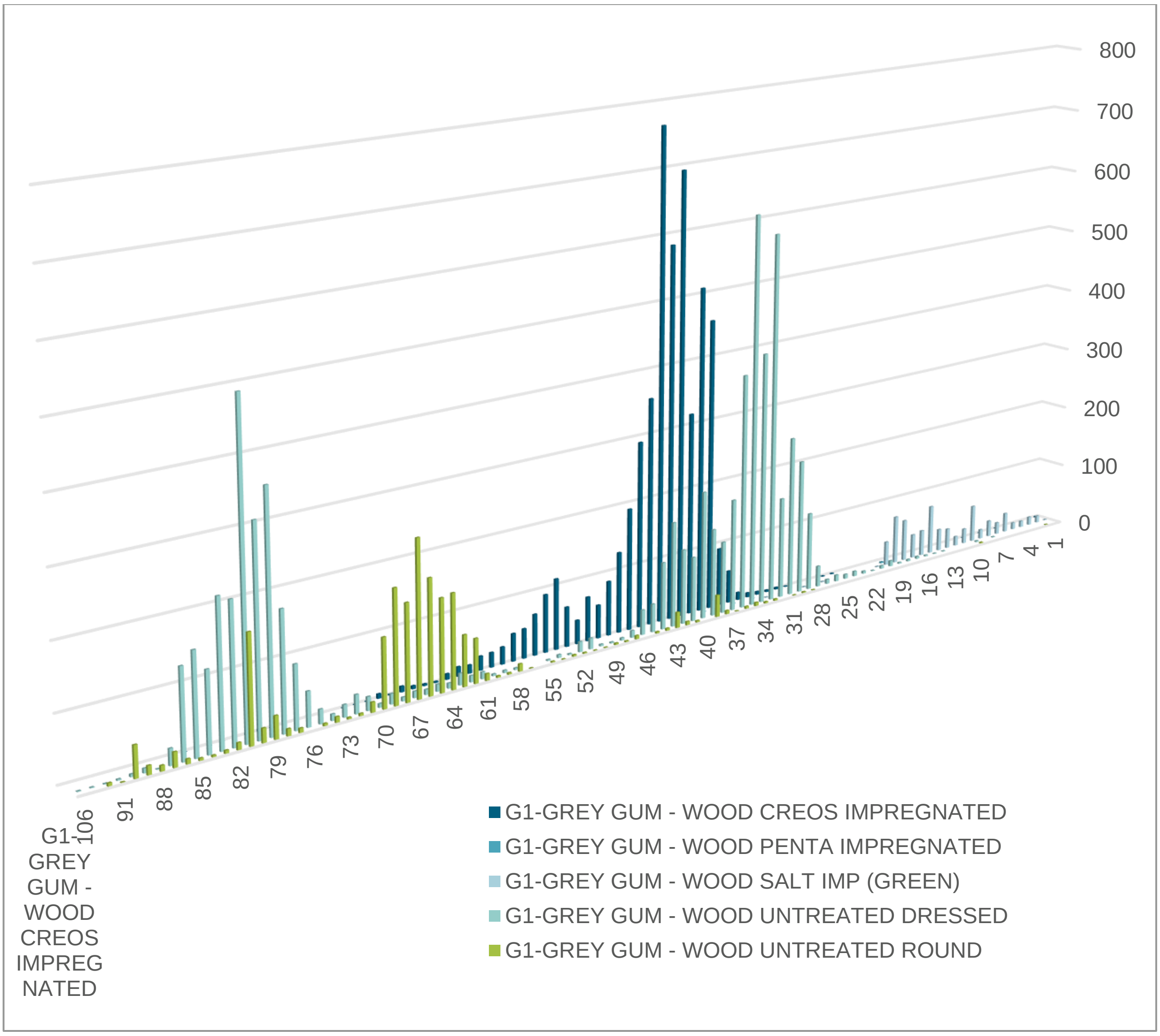

Figure 36 - G1 Grey Gum D 1 Consolidation

GB – Grey Box

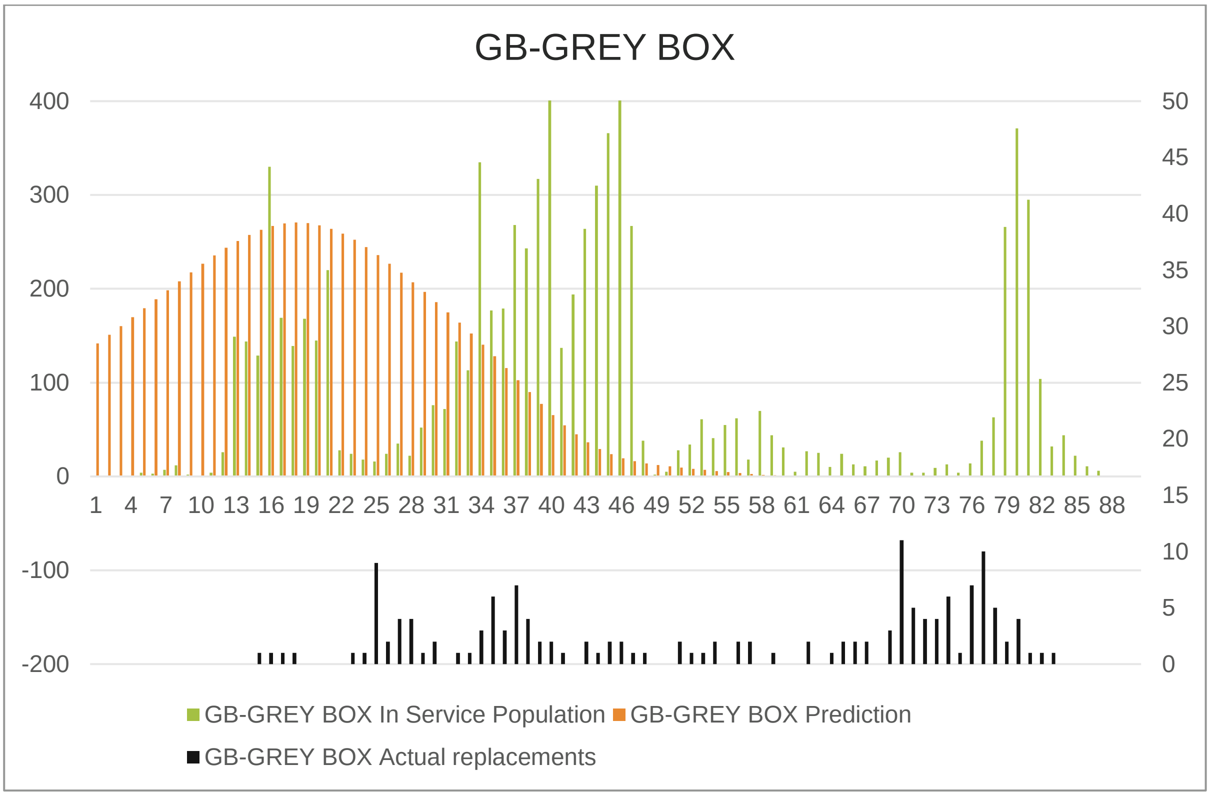

Figure 37- BS- Grey Box Projection

The total number of Grey Box poles in service is approximately 8173 poles. Grey Box poles have been installed in most of the last 89 years. The majority being installed in perhaps 4 different insertion time ranges. The most recent group of 1607 GB poles were installed from 11 to 21 years ago and pressure treated with CCA treatment.

Their forward performance is difficult to project from functional failure data because they have not yet failed in significant numbers from which a projection can be accurately based. A very small amount (3) of these poles registered as functionally failed but their data was confirmed suspect. The recorded failure location is above the 2-meter mark and the functional failure is caused by external or internal rot. Even with only 3 functional failures in approximately 1725 CCA GB poles that have been installed over the last 25 years, there is not enough performance information to justify a projection for this group. The expectation of performance estimate of a characteristic life of 49 years and a shape factor 8 was be used to produce a projection for this group but this projection is not expected to fall within the next 20 years for replacement.

Mr. Dennis Clancy informed that 1956 was the start of industry use of creosote pressure treatment which places a maximum ceiling on the in-service age of 63 years. Creosote is designated as WCI in data. This is the most populous group of 3047 poles in service is approximately 29 to 46 years old. Only small portions of the WCI treated poles have functionally failed between 33 and 47 years in service and because of insertion censoring, the future failure performance of WCI treated poles is not fully visible within the 2009 to 2019 data set. For this portion of the population, especially for those poles which have passed the last functional failure age, an estimate was used for the projection purpose.

A third but smaller population concentration centres on 56 years in service, and a 4th long life group has a mean at 80 years in-service life are premium timber which have stood the test of time recorded as untreated dressed timber or untreated round poles.

The functional failure performance is distinctly different between pressure treated and non-pressure treated poles. Ignoring the 3 CCA poles, prediction sub populations were calculated for each sub-population using estimated of the parameters (WCI characteristic life of 49 years – Shape factor =8, WUR characteristic life of 65 years – Shape factor =8, WUD characteristic life = 85 years, shape factor = 8)

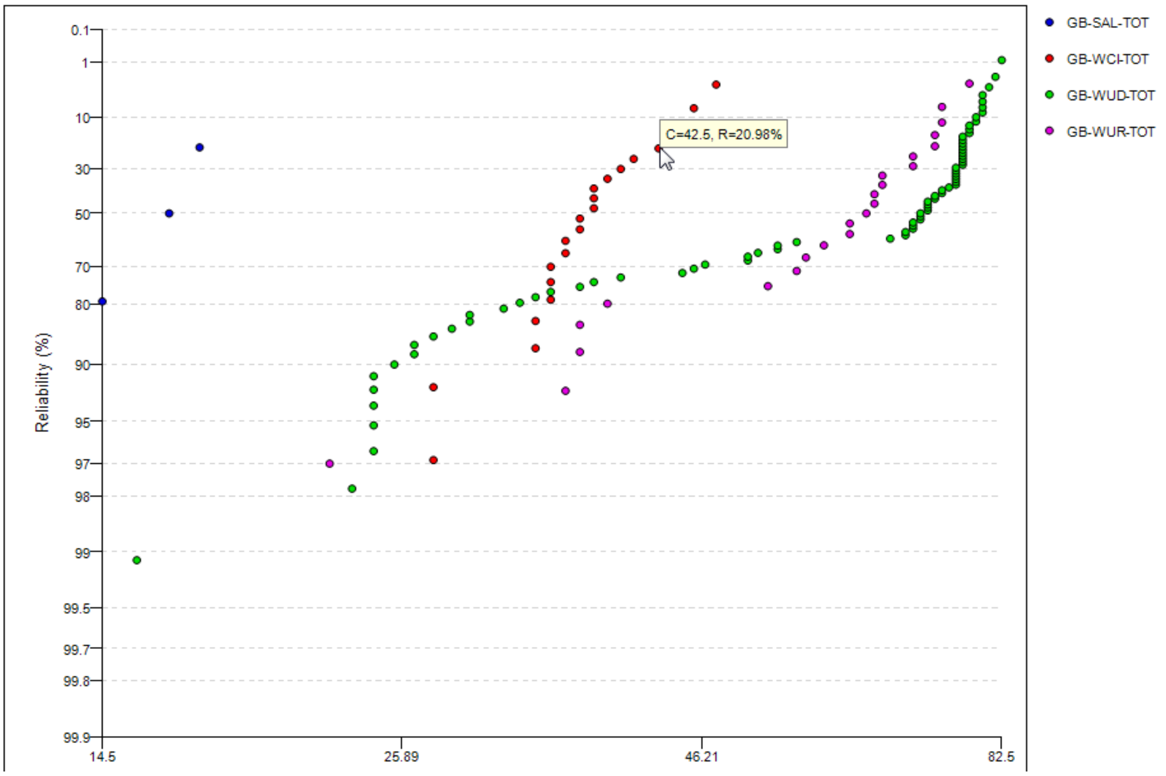

Figure 38 - Grey Box Performance by Treatment Type

In Figure 38 and 39 – the functional failure times are plotted using Isographs Availability Workbench to provide a comparative view. The horizontal axis is in service life (years).

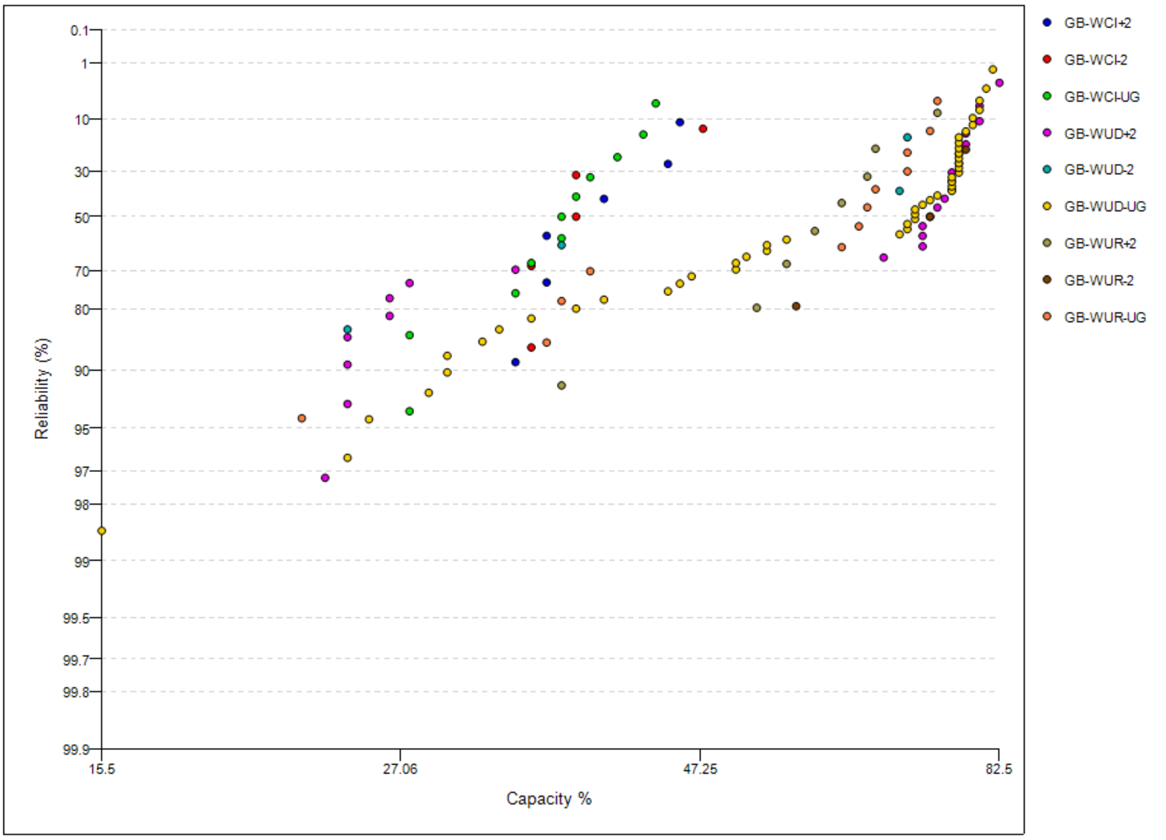

Figure 39 - Grey Box Failure Location Performance (Sparse amount of data)

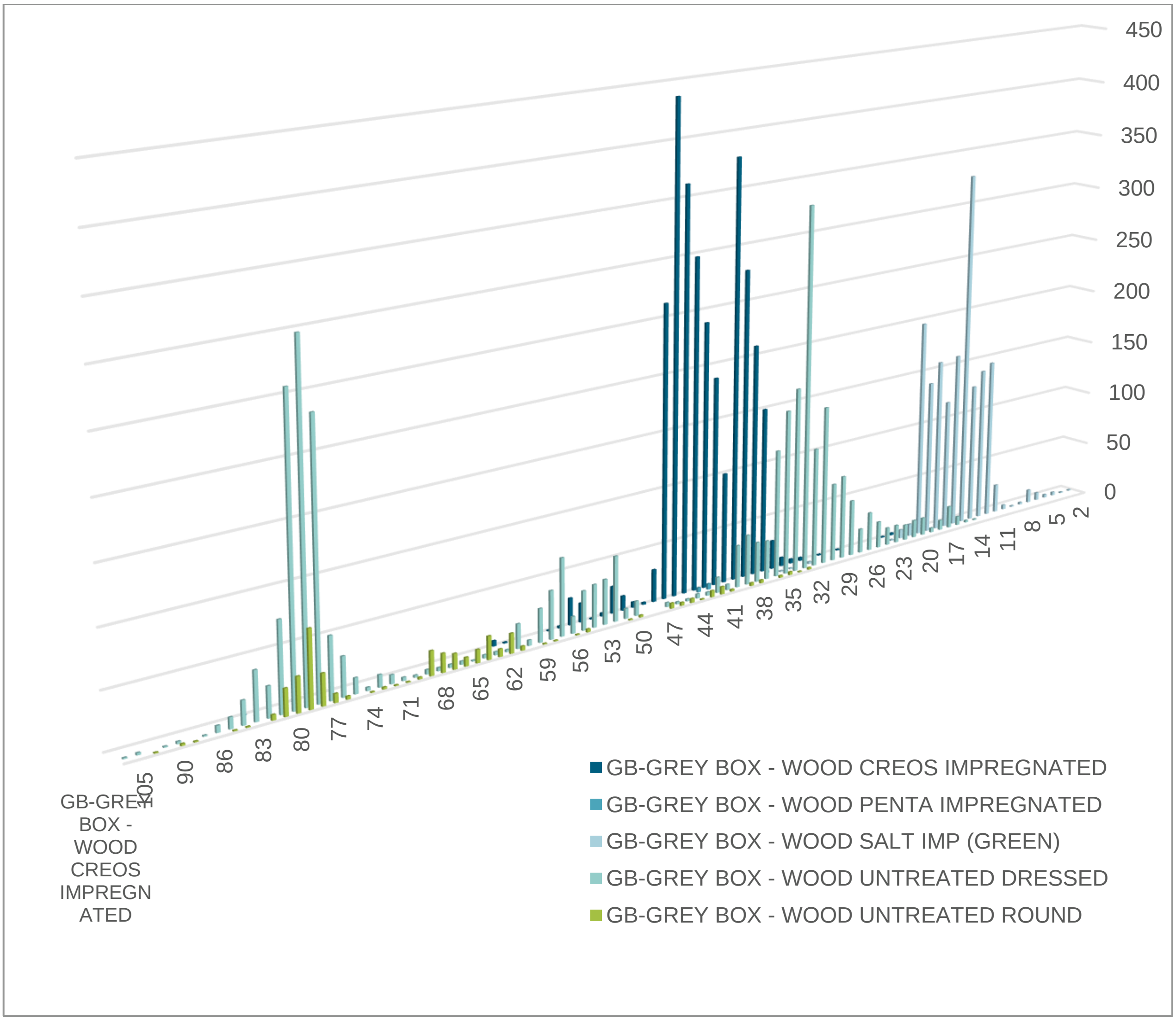

Figure 40 - GB - Grey Box Population Sub Groups

G3 – Mountain Grey Gum (Durability Class 3)

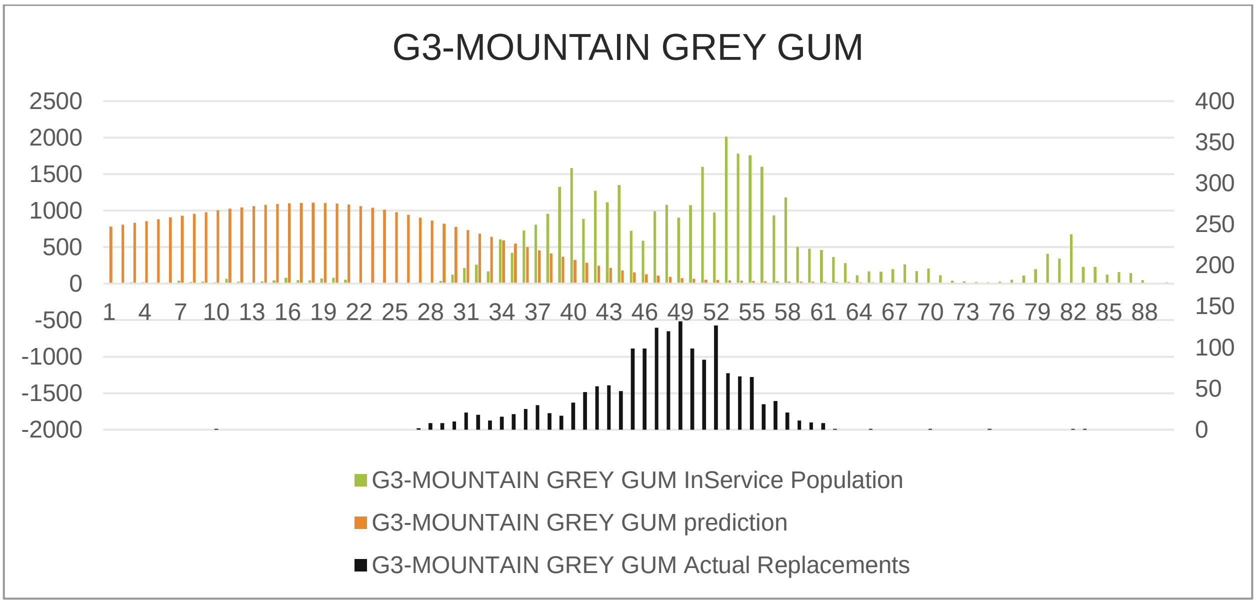

Figure 41 - G3 Mountain Grey Gum Durability Class 3 Prediction

G3 is a designation created for the RCM study that combined MT- Mountain Grey Gum and GG – Mountain Grey Gum which were durability classification 3 was attributed into a combined species classification. There are approximately 36300 G3 classified poles in service.

The treatment is predominately WCI with a small amount of older WUD poles whose mean is centred on 82 years in service. The prediction is made using a scale factor of 67 and shape factor of 8 and applied to 33901 WCI poles under the assumption that the functionally failed poles are “insertion censored” and have not reached their end of life at 56 years old. A second prediction for the older pole population was made for the 2399 older poles using an estimated scale factor of 83 years with a shape factor of 8. The combined prediction is shown above for the G3- species classification.

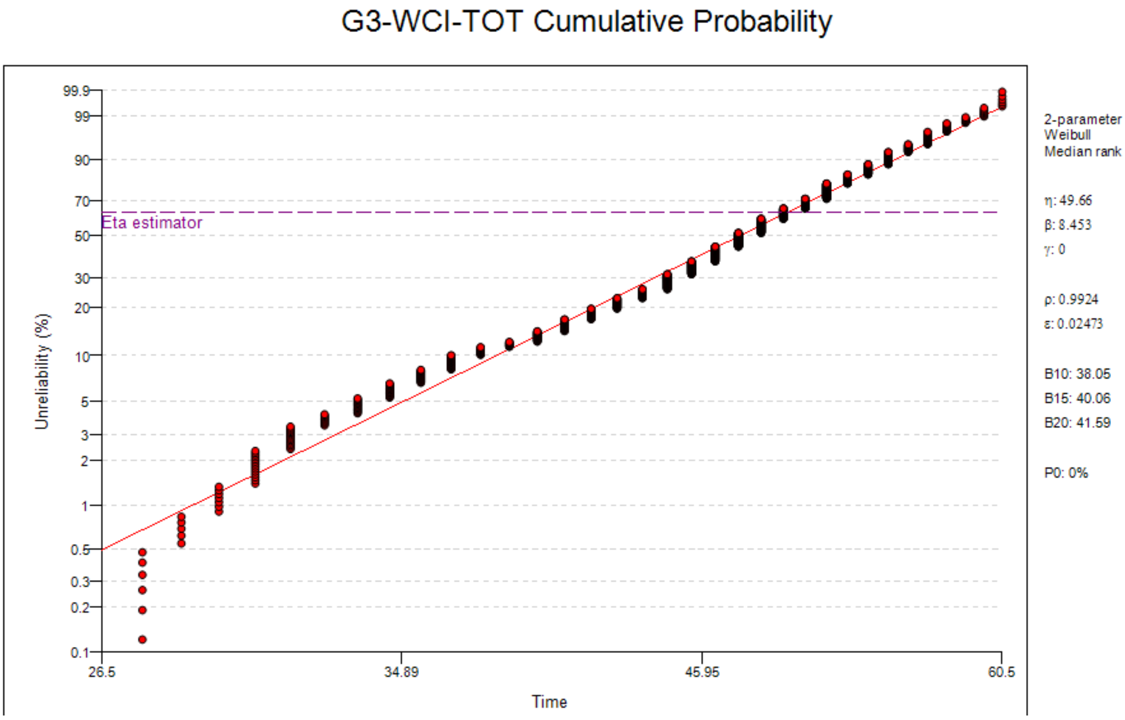

Figure 42 - G3 Mountain Grey Gum Failure Location Performance

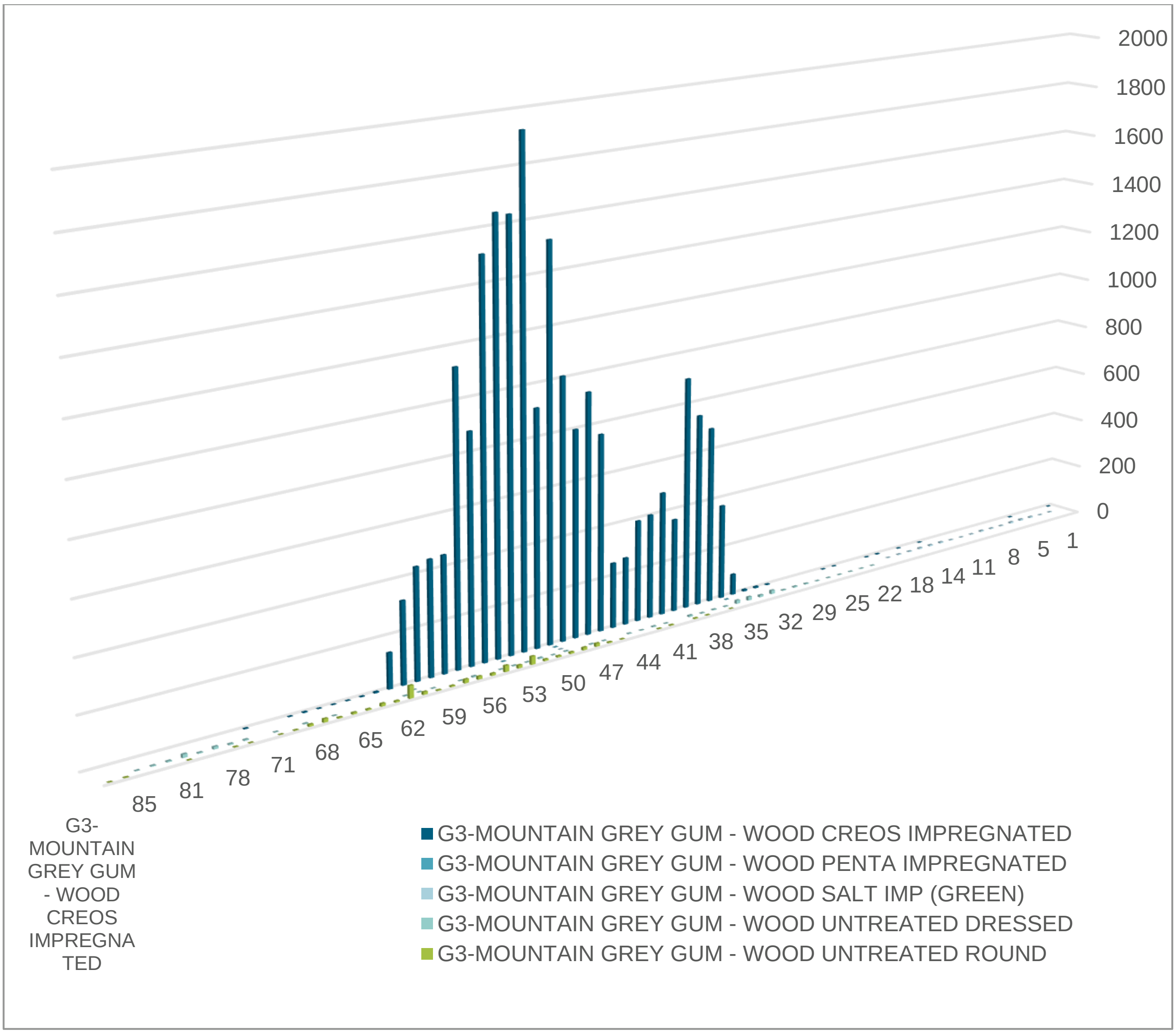

Figure 43 - G3 Mountain Grey Gum (Consolidated D3)

GI – Grey Iron Bark

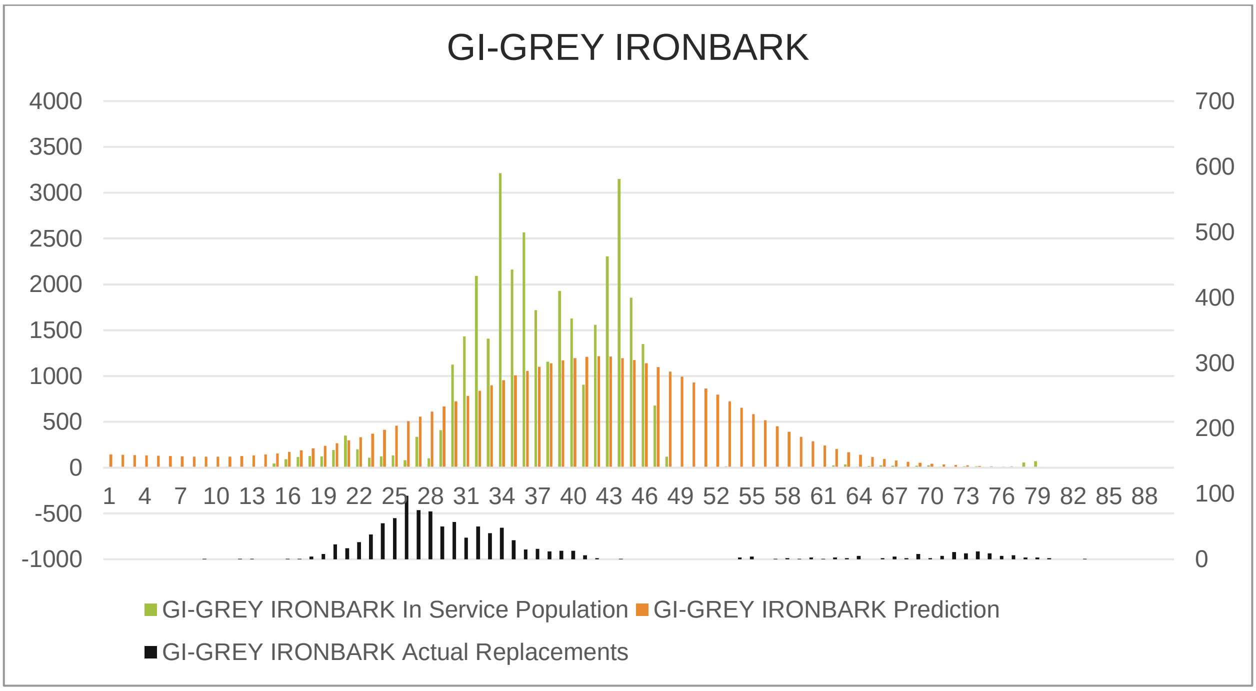

Figure 44 - GI- Grey Iron Bark Prediction

There are approximately 36295 Grey Iron Bark pole sin service. 13809 are recorded as WCI treated whose current mean life is approximately 49 years in service. 21165 poles are untreated dressed WUD poles which exhibit bi-modal life populations with means at approximately 39 years and 86 years in service.

978 pole replacements were made between 2009 and 2019 from a total in-service population of approximately 35440 poles with a mean of approximately 30 years rendering their use as an effective predictor not relevant especially where the in-service population age exceeds the replacement functional failure distribution limits of the functional failure distribution centred at 26 years.

Cognizant of the limited number of long life poles observed in the replacements made during the period of 2009 to 2019, the estimated prediction is made using a scale factor of 72 years with a failure free period of 8 years and a shape factor of 8 to produce a forward projection of an average service life of approximately 40 years more in service or an average age at retirement of approximately 80 years.

Within the next 20-year window of interest an estimated average of 146 GI poles per year will require replacement.

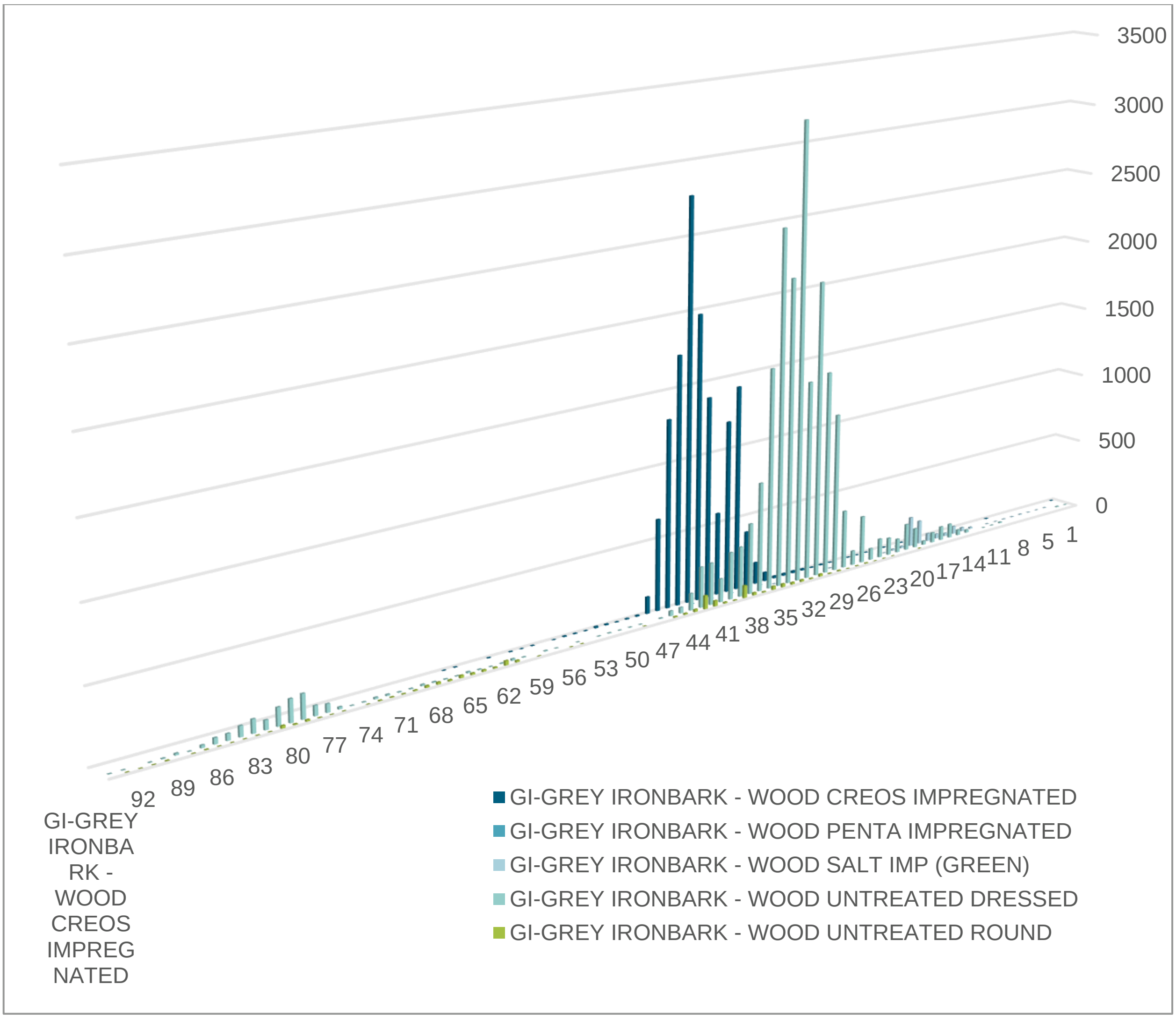

Figure 45 - GI Grey Iron Bark Sub Populations

IB – Iron Bark

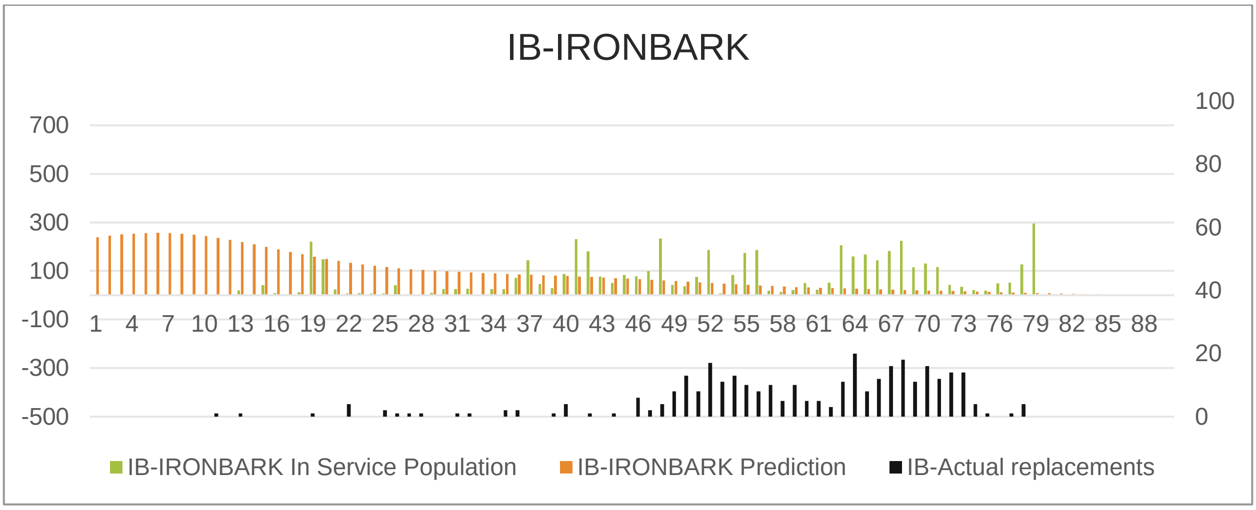

Figure 46 - IB - Iron Bark Prediction

There are approximately 7977 Iron bark poles in service with 4 different sub-populations separated by type of pressure treatment (SAL or WCI) or non-treatment (WUD or WUR). The youngest population is made up of 477 CCA treated and has an average life for the CCA poles of 29 years. The next sub-population is Creosote WCI polls makes up 988 poles and averages as a group 31 years in service. The untreated older timbers have population groups at 71 years an approximately 1974 poles are untreated Dressed premium timber. The final sub-population accounts for over 4400 poles with a significant in-service age peak at 88 years, and some poles recorded as over 100 years old.

Comparison of the functional failure recorded from 2009 to 2019 for the 4 sub-populations reveals that the recorded functional failures only support two (2) sub populations in any significant quantity and when the WCI and WUD functional failure profiles are examined, there is evidence of bi-modal performance within each sub-population suggesting there is a mixture of 6 sub-populations coupled with insertion censored data. Therefore, the next 20 years estimate is based upon age out of existing old in-service poles made by using a long characteristic life estimate of approximately 85 years with a shape factor of 8.

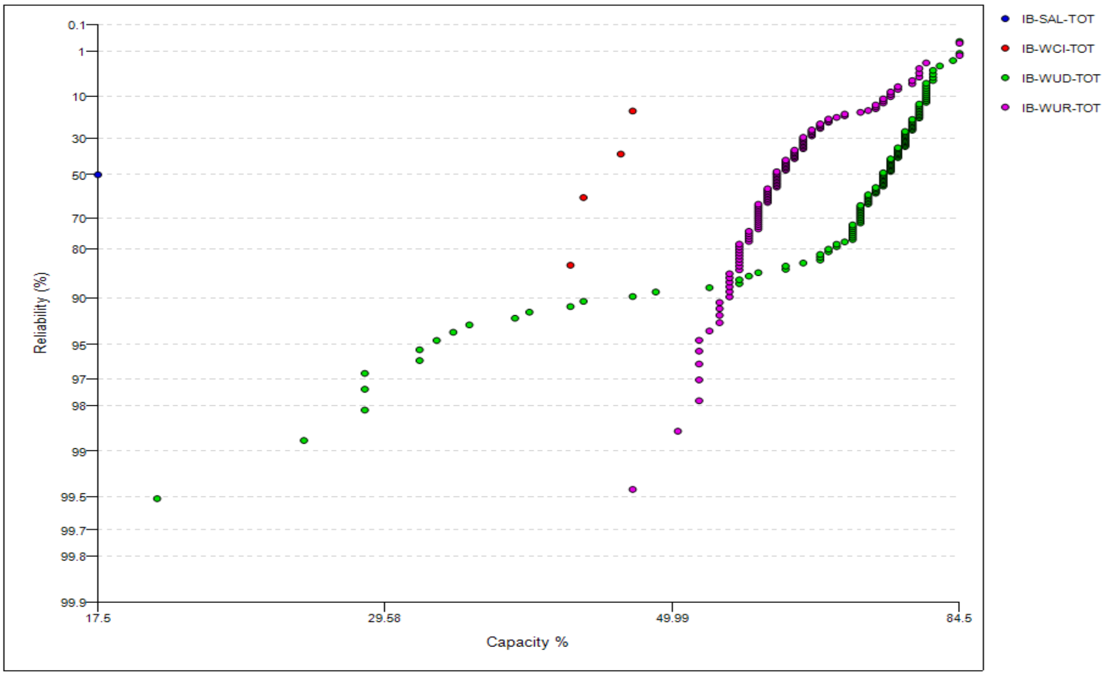

Figure 47 - IB - Iron Bark WCI and WUD functional failures

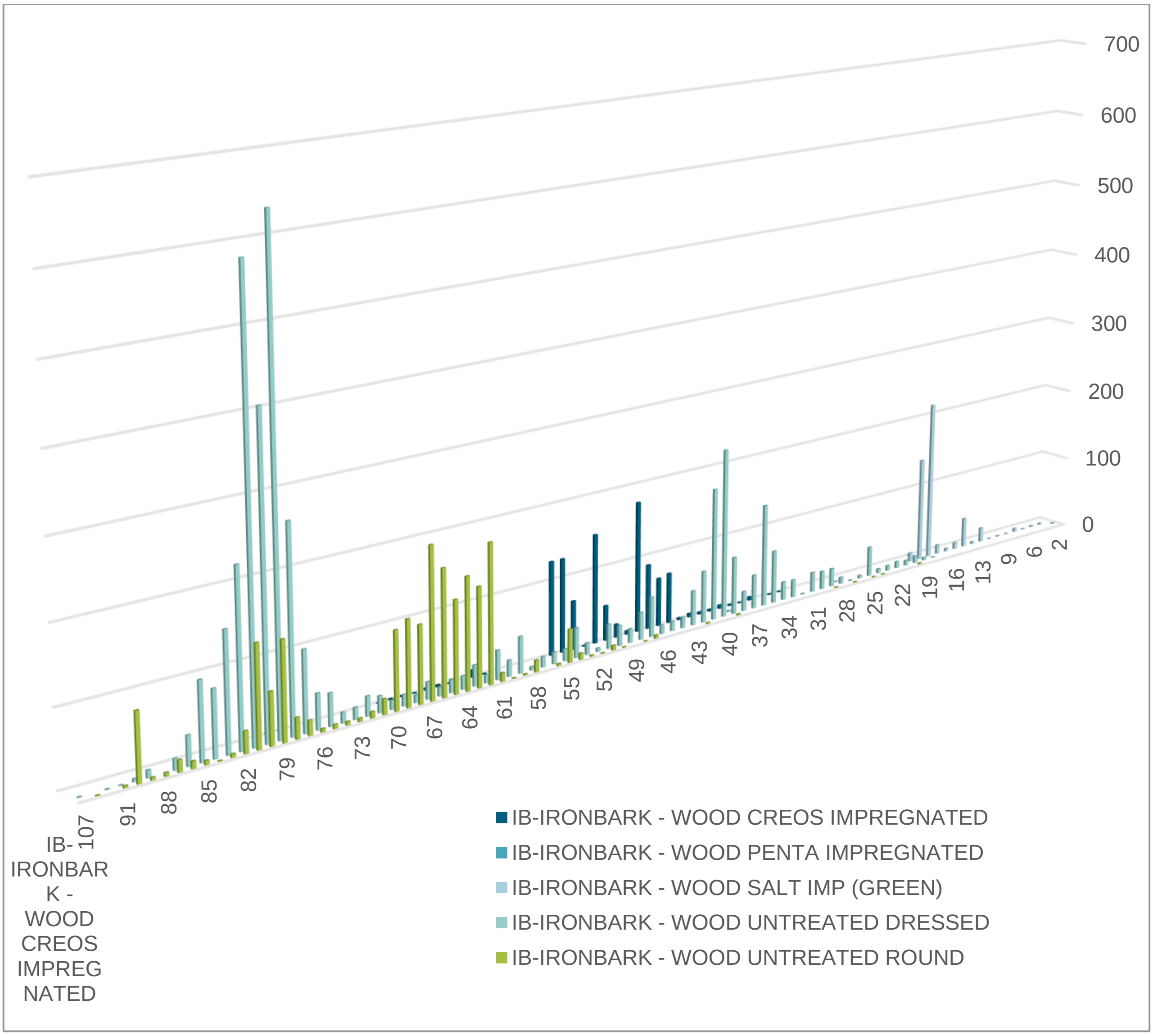

Figure 48 - IB - Population Sub Groups

MA – Mountain Ash

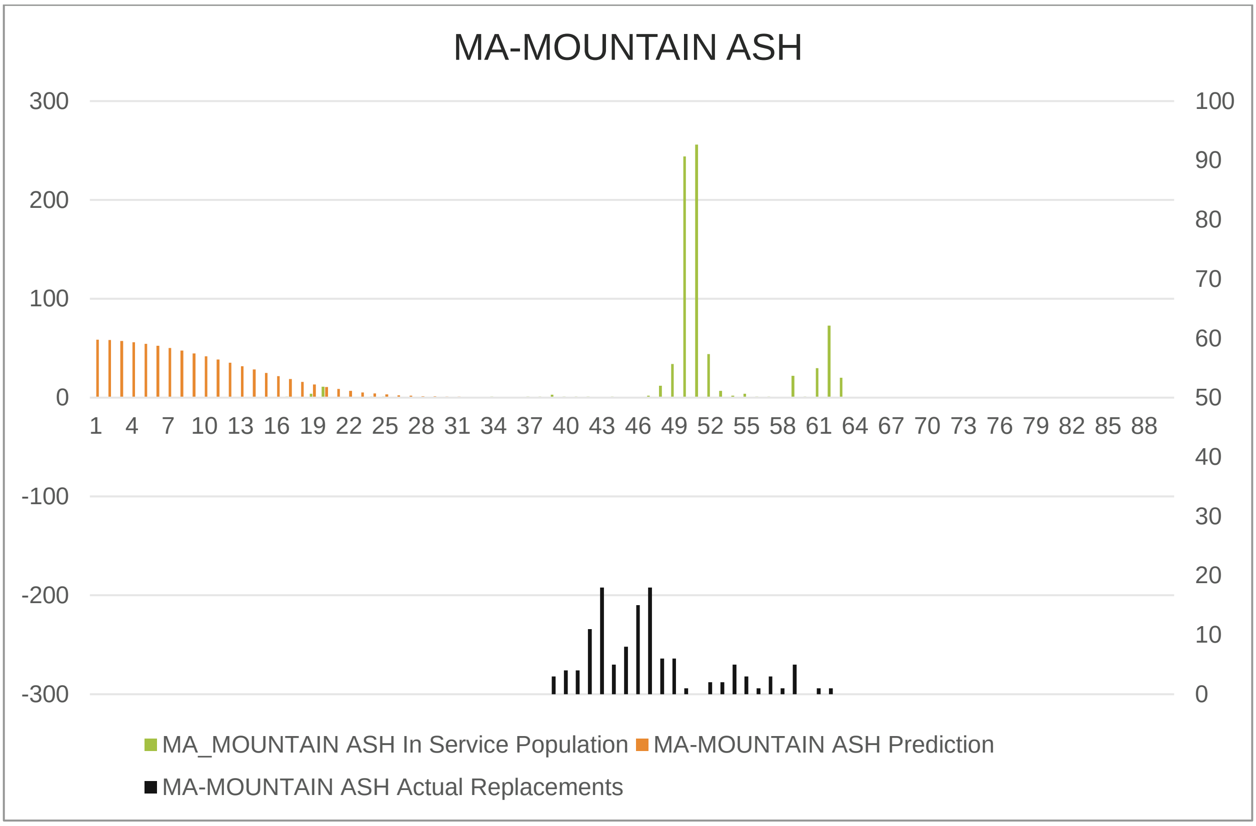

Figure 49 - MA - Mountain Ash Prediction

The Mountain Ash species is classified as a Durability Class 4 and Strength Group 4.

It is predominately pressure treated with creosote (WCI) with 762 of the 781 records indicating (WCI) pressure treatment.

The in-service population has two residual populations at 50 years and 60 years old.

The low amount of other treatments quantities does not warrant a projection.

The Mountain Ash species is not expected to be a significant factor over the next twenty years, and it is expected to age out shortly starting at a rate of approximately 60 poles per year.

The projection has been made using a scale factor of 57 and a shape factor of 6 applied against the residual population.

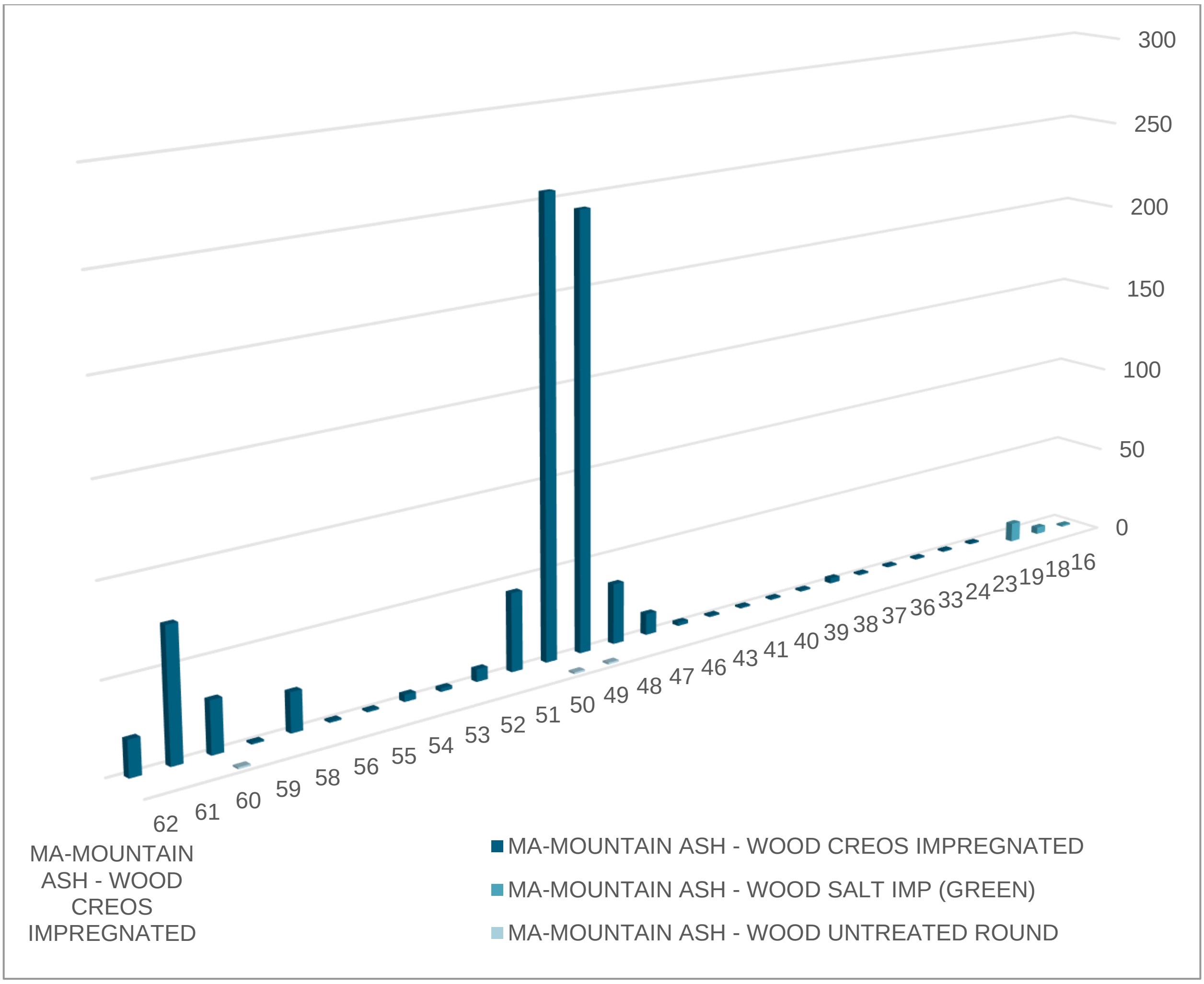

Figure 50 - MA Mountain Ash Population Sub groups

MM – Messmate

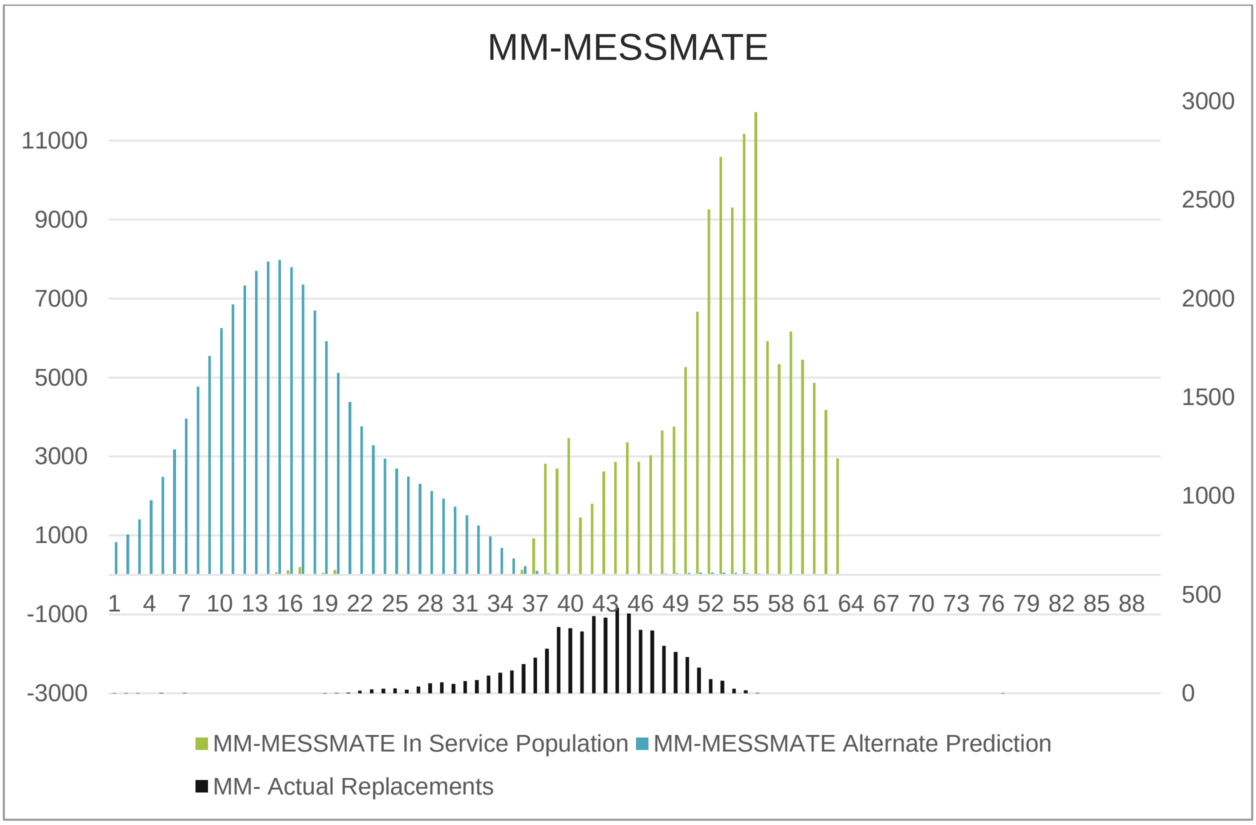

Figure 51 - MM-Messmate Prediction

The Messmate pole is durability classification 3.

It was introduced in large numbers starting 1956 and as a result the functional failures are insertion censored and so functional failures of age older than 63 years are not possible. There are currently 134012 creosote (WCI) poles of a total 135115 Messmate poles in service. There is a small amount of CCA poles whose mean is 20 years in service.

Messmate poles are recorded as the most likely pole to fail in service over the last 10 years and their in-service age ranges from 50 to 60 years as the most likely age to fail.

A projection of replacement is complicated by the relatively large number of poles installed from 1956 to 1964 that have not contributed to the functionally failed distribution and are now at an in-service age beyond the usefulness of a functional failure predictor.

While a small number of Messmates currently in service installed after 1964 might follow this predictor, the balance has been estimated to need replacement at an increasing rate over the next 16 years peaking at approximately 7500 poles per annum.

The forward projection in absence of a better predictor was made using a characteristic life of 50 years coupled with a failure free period of 18 years and a shape factor of 16.

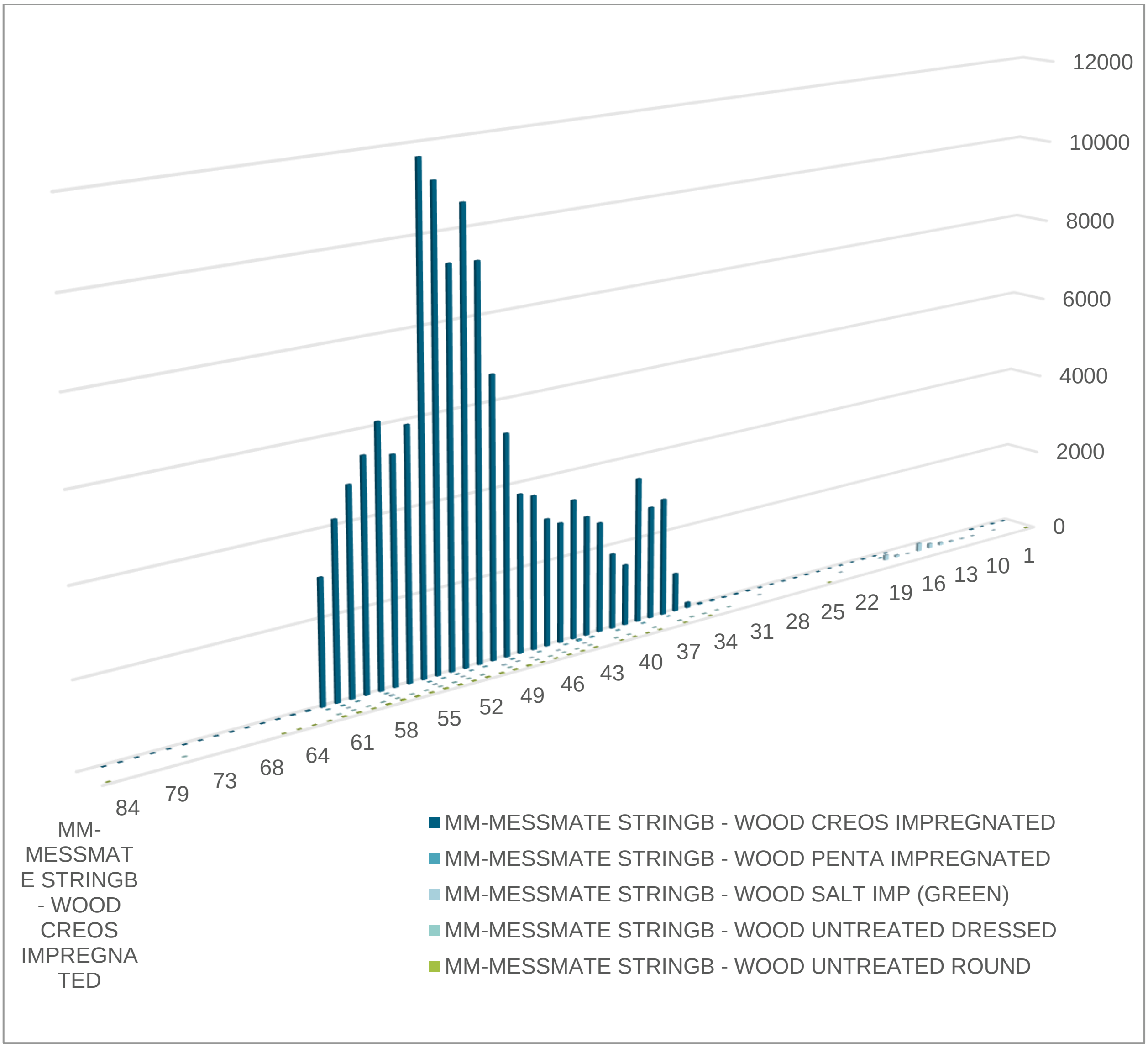

Figure 52 - MM - Messmate Population Sub Groups

P – Pinus Radiata

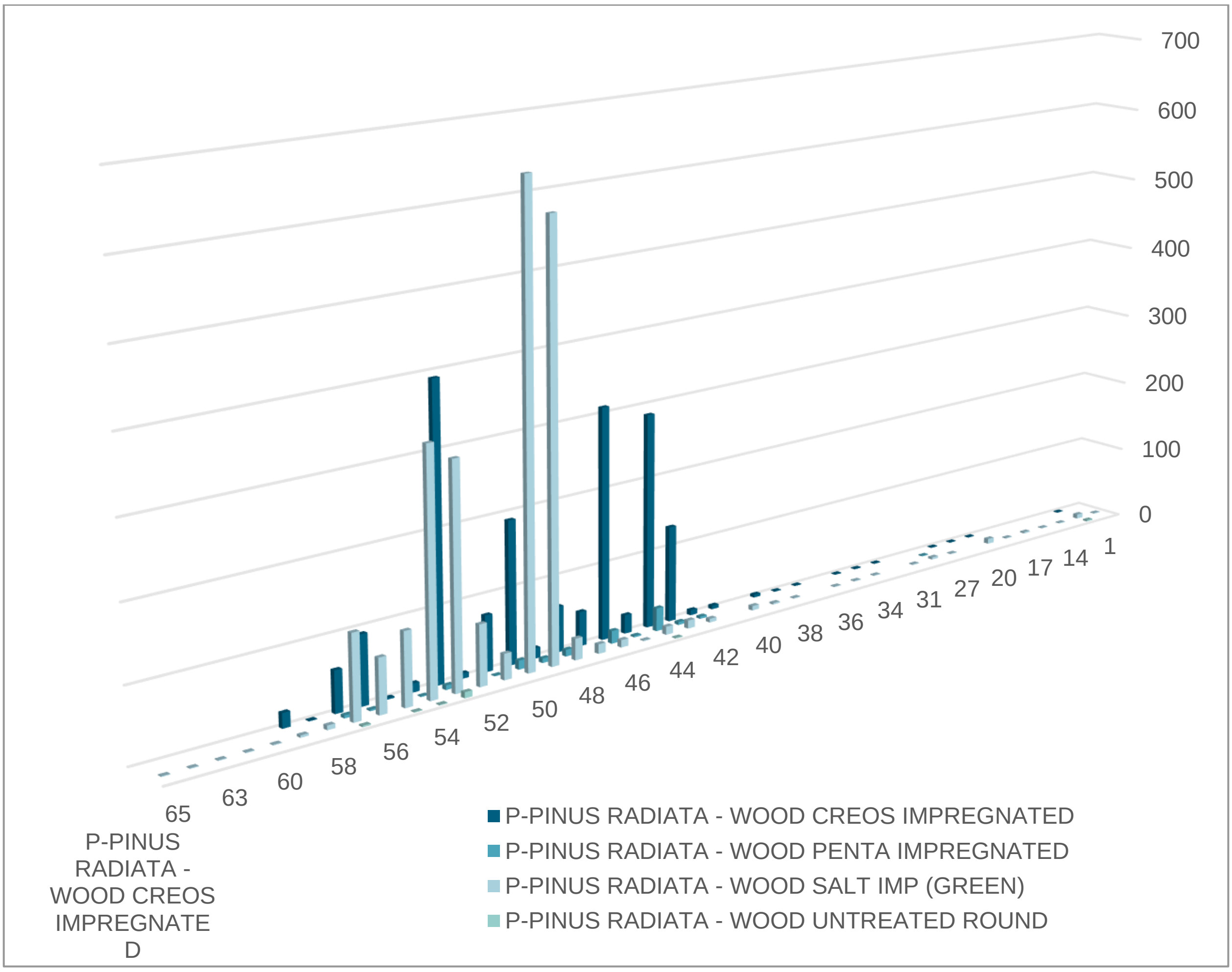

Figure 53 - P - Pinus Radiata Population Sub Groups

Due to low numbers a projection was not made.

RI – Red Iron Bark

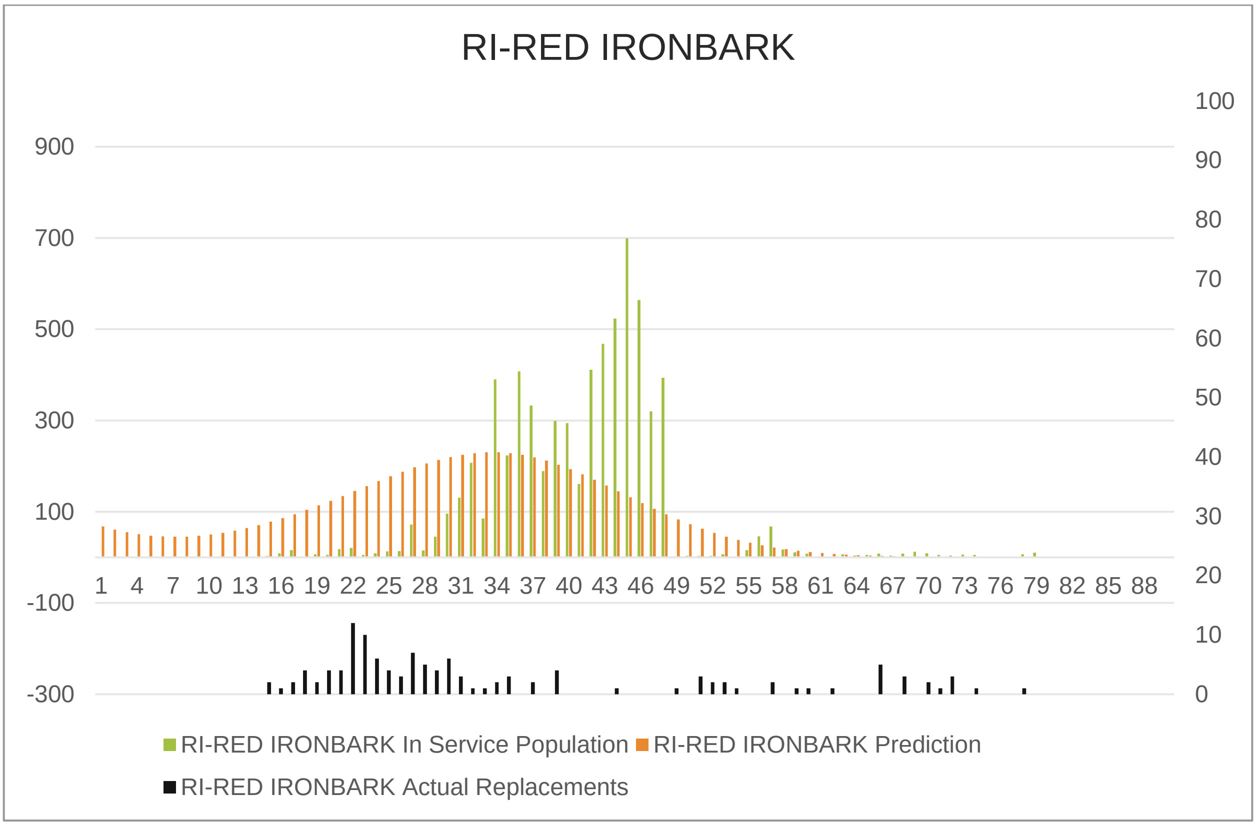

Figure 54 - RI - Red Iron Bark Prediction

There are approximately 6989 Red Iron Bark poles in service comprising 4 different sub-populations.

The most recent RI poles are CCA treated (SAL) and have an average in-service life of 20 years, with very few functional failures. The older pressure treated RI poles were treated with creosote (WCI) and average about 50 years in-service age. Older premium timber is untreated round (WUR) poles numbering 181 poles. 27029 untreated dressed poles (WUD) span a wide range of years and in some small numbers exceeding 100 years in service. The functional failures recorded from 2009 to 2019 are insertion censored data, with several age ranges not possible due to zero poles being installed during certain prior years.

Because of the relatively few functional failures recorded within the last 10 years a high-level estimate projection was made assuming the mean of the younger poles in service would reach 70 years of in-service age at about the year 2050.

Over the next twenty years of interest less than 100 RI poles per year are predicted to require replacement.

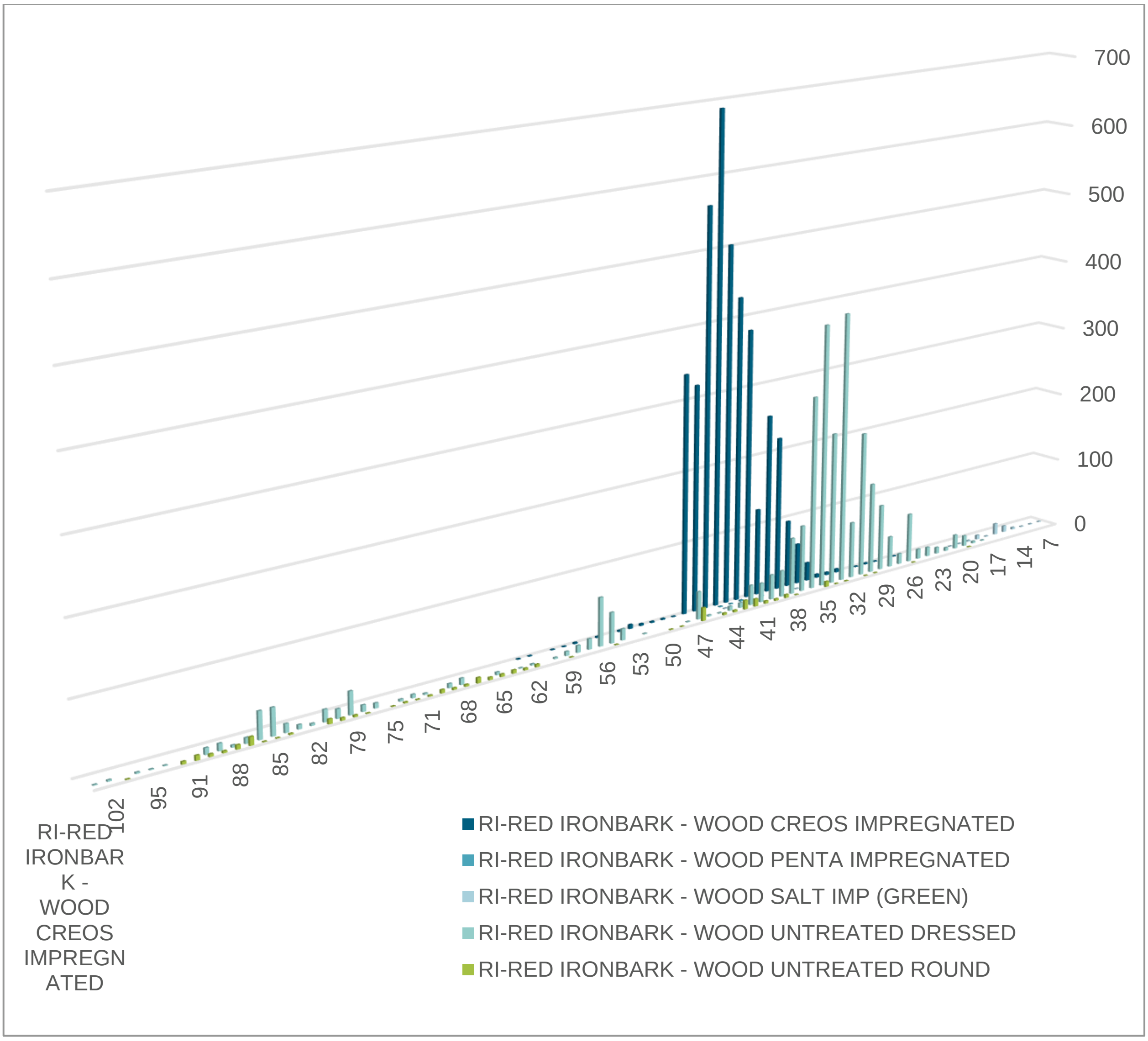

Figure 55 - RI - Red Iron Bark Population Sub Profile

RM – Red Mahogany

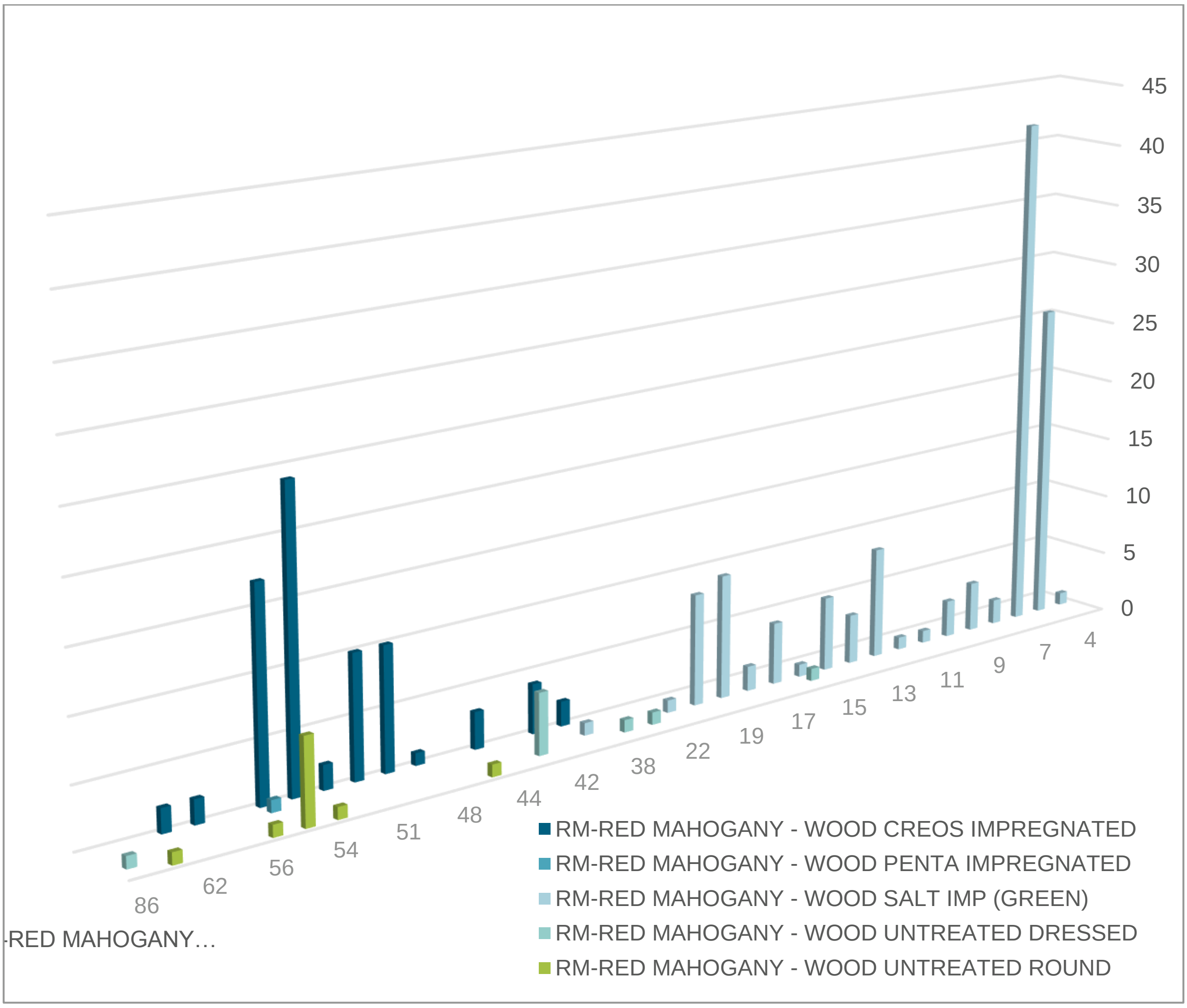

Figure 56 - RM - Red Mahogany Population Sub Profile

Due to relatively low numbers a projection was not made.

RW – Red Bloodwood

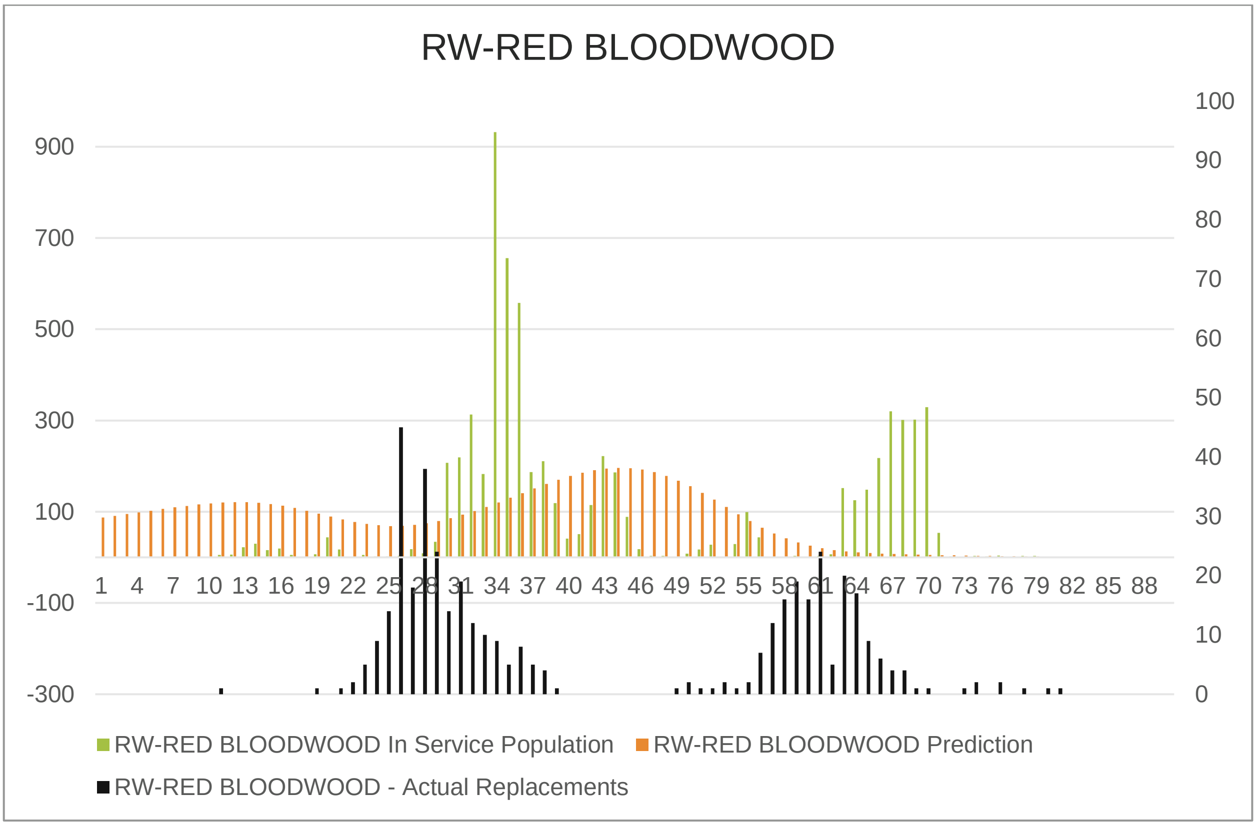

Figure 57 - RW- Red Bloodwood Prediction

There are approximately 6768 RW poles in service.

There are 4 distinct sub-populations. The CCA treated sub-population averages 20 years of in-service age. The WCI population averages 50 years in-service age. The untreated dressed (WUD) population averages 39 years of age and the untreated round population is averaging in excess of 70 in-service years.

Interesting to note is the in-service populations extend beyond the two relatively well-defined distributions of functional failures. Presenting a case where past failure performance is not a full predictor of future life.

Given all the variables, including a larger population of wood being listed as having a treatment of other, a projection was made using a 2 parameter Weibull with shape factor of 6 and characteristic life of 59 years. This is slightly inaccurate because the wood listed as other treated is older, and therefore predicted to require replacement over the next few years but given the smaller magnitude in total of RW poles, the error introduced over the next twenty years is minimal.

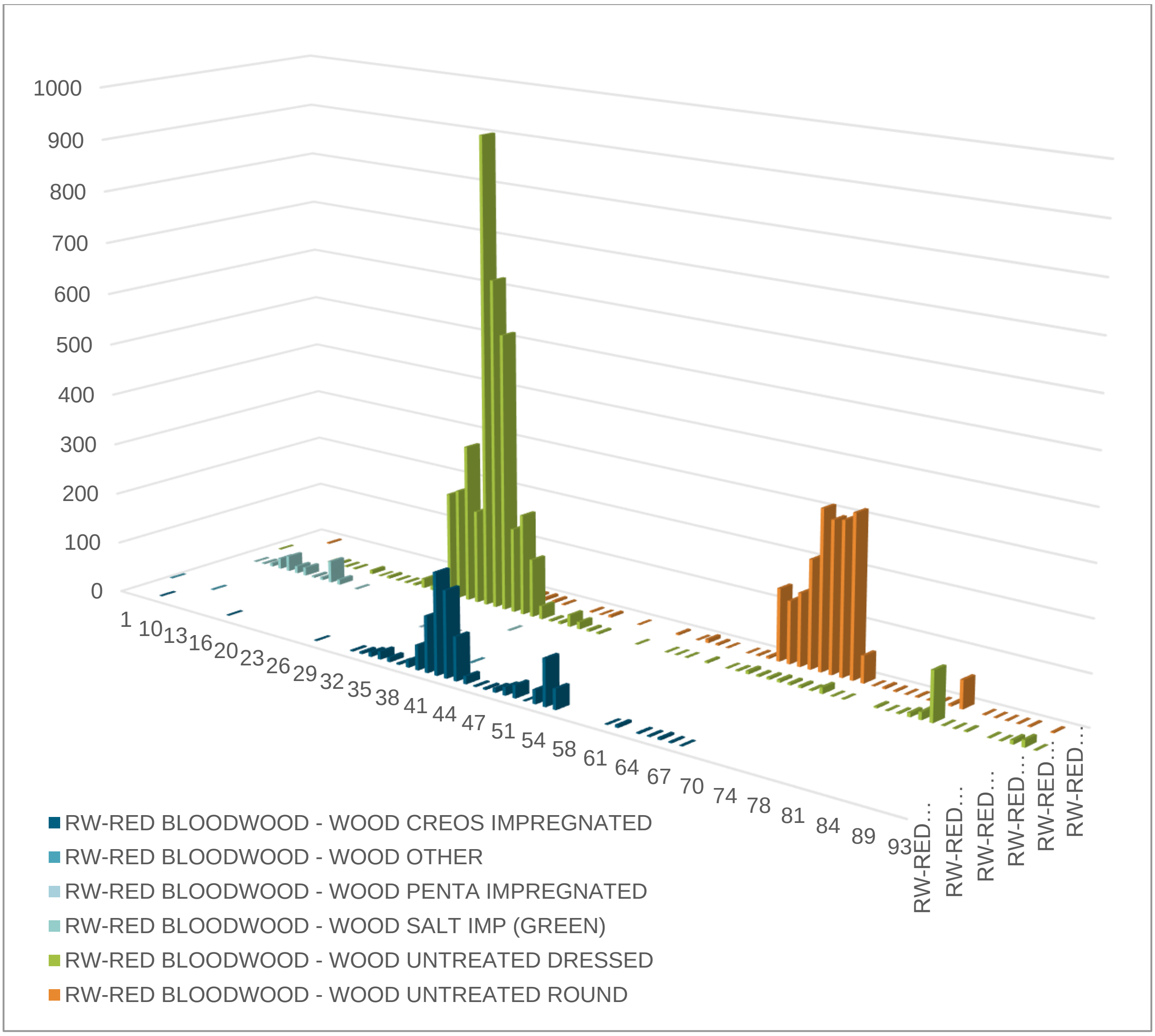

Figure 58 - RW Red Blood Wood Sub-populations

SG – Spotted Gum

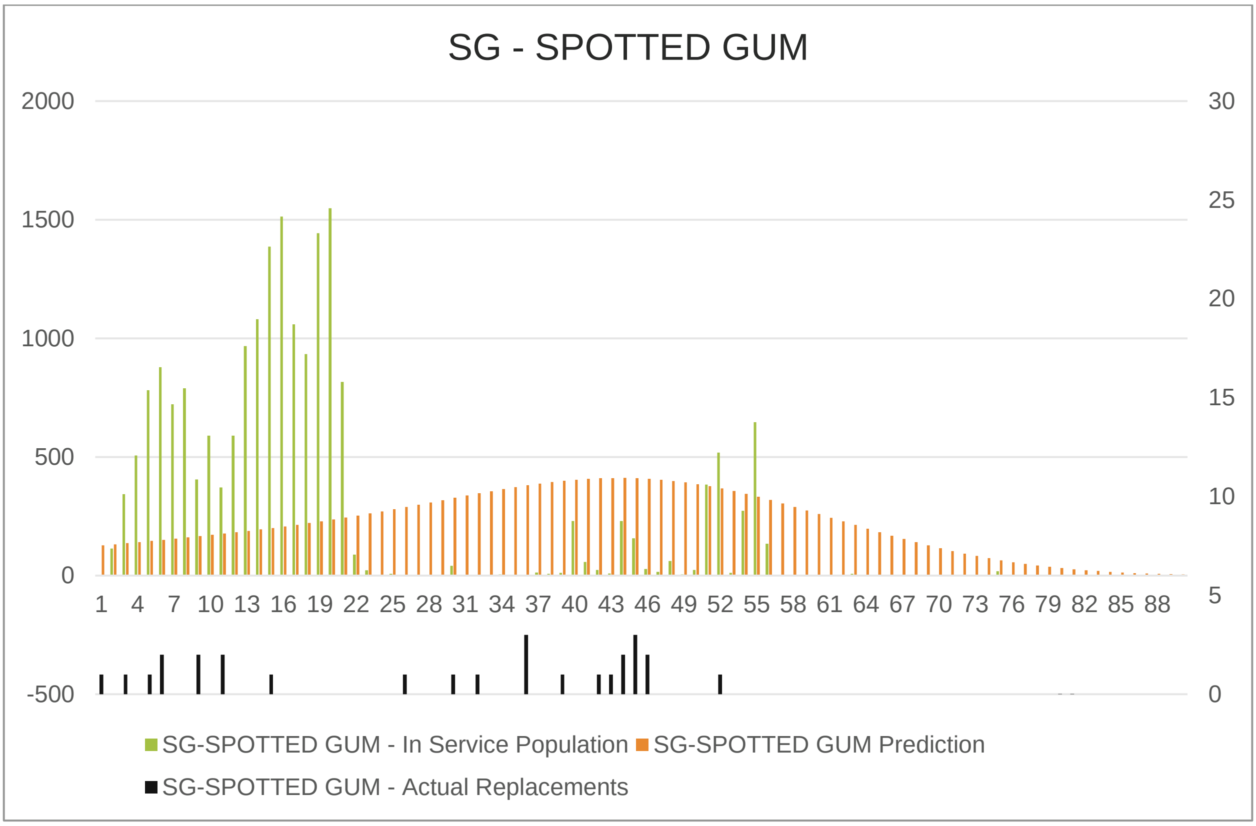

Figure 59 - Spotted Gum Projection

Spotted Gum has two sub-populations of record.

The largest is a CCA treated group that has been installed over the last 20 years (19000). This will not materially affect the next 20 years window of projection due to the relatively young age of the CCA poles.

There are a few hundred older Creosote impregnated poles whose average age is approaching 50 years.

Unfortunately, there are only 28 functional failures observed due to insertion censoring, so a prediction based on the past functional failures is not possible.

A high-level projection was made using a 2 parameter Weibull with a shape of 4 and a characteristic life of 60 years.

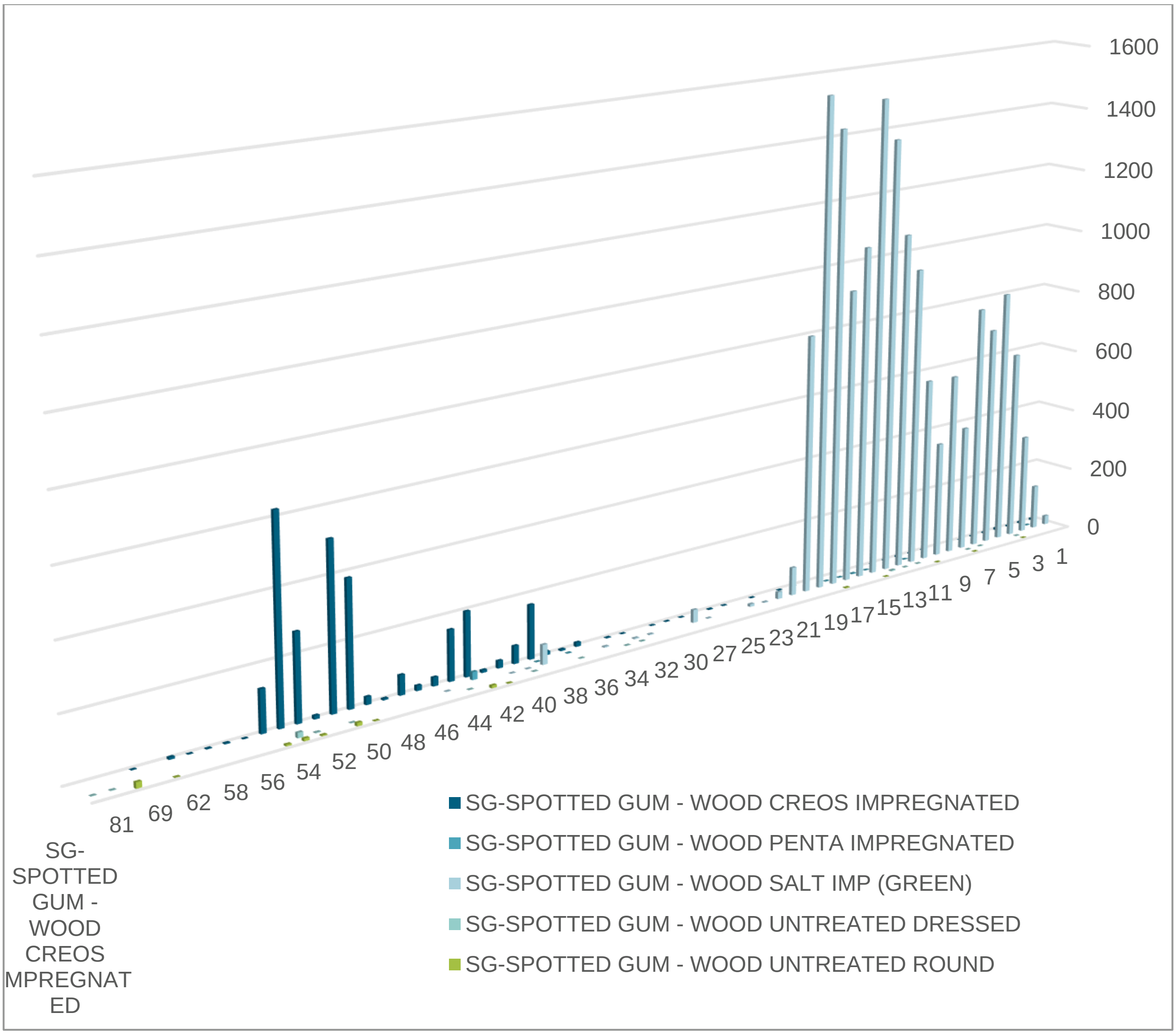

Figure 60 - SG - Spotted Gum Population Sub Profile

ST – Silver Topped Ash

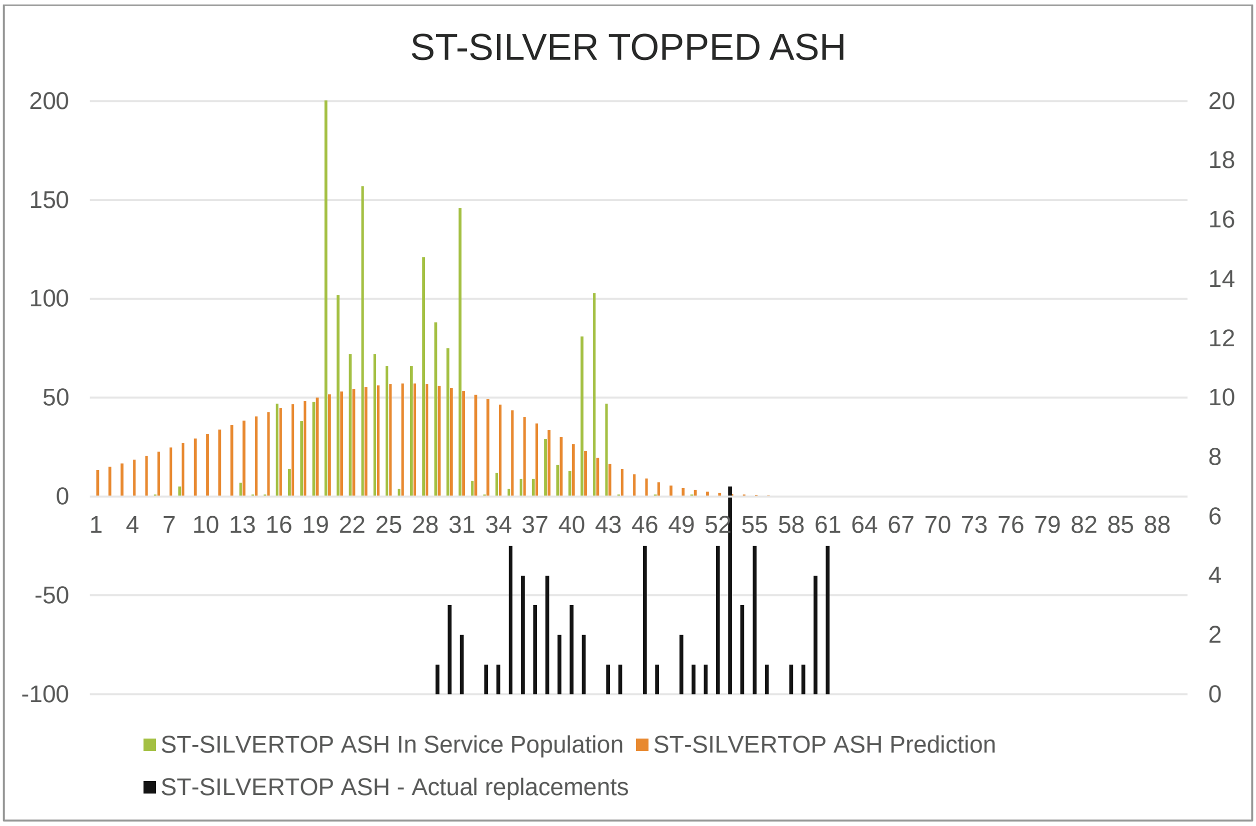

Figure 61 - ST - Silver Topped Ash Projection

The silver topped ash population in service is largely expected to functionally fail in a similar period of service years to those recorded within the 10-year window for replacement poles.

While relatively few poles failed (75 in total) of the 1739 in the population, a projection is made with some confidence using the functionally failed data to regress and fit the projection to a 2 parameter Weibull with shape of 6 and characteristic life of 52.34 years.

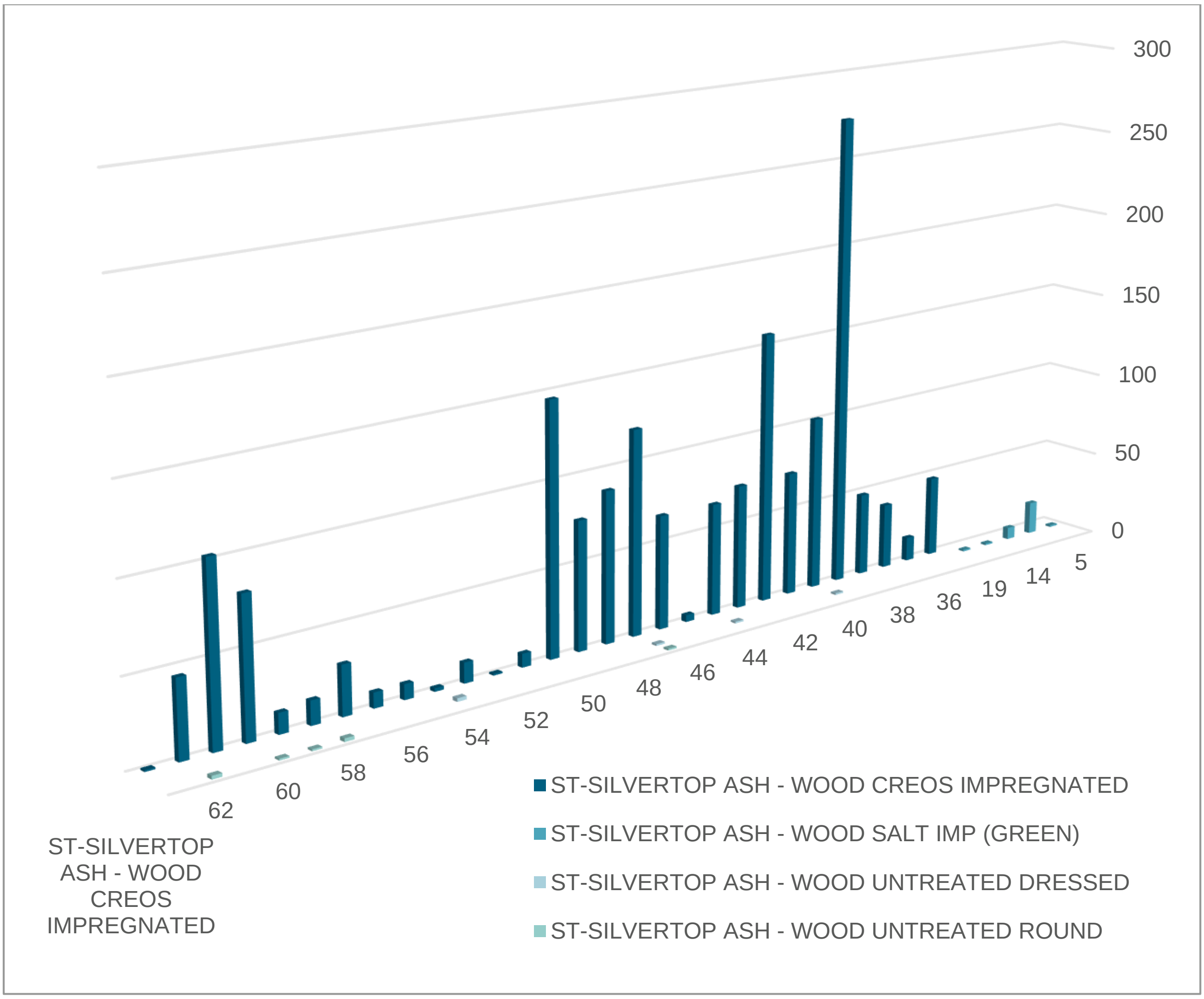

Figure 62 - ST - Silver Topped Ash Population Sub Profile

SY – Sydney Blue Gum

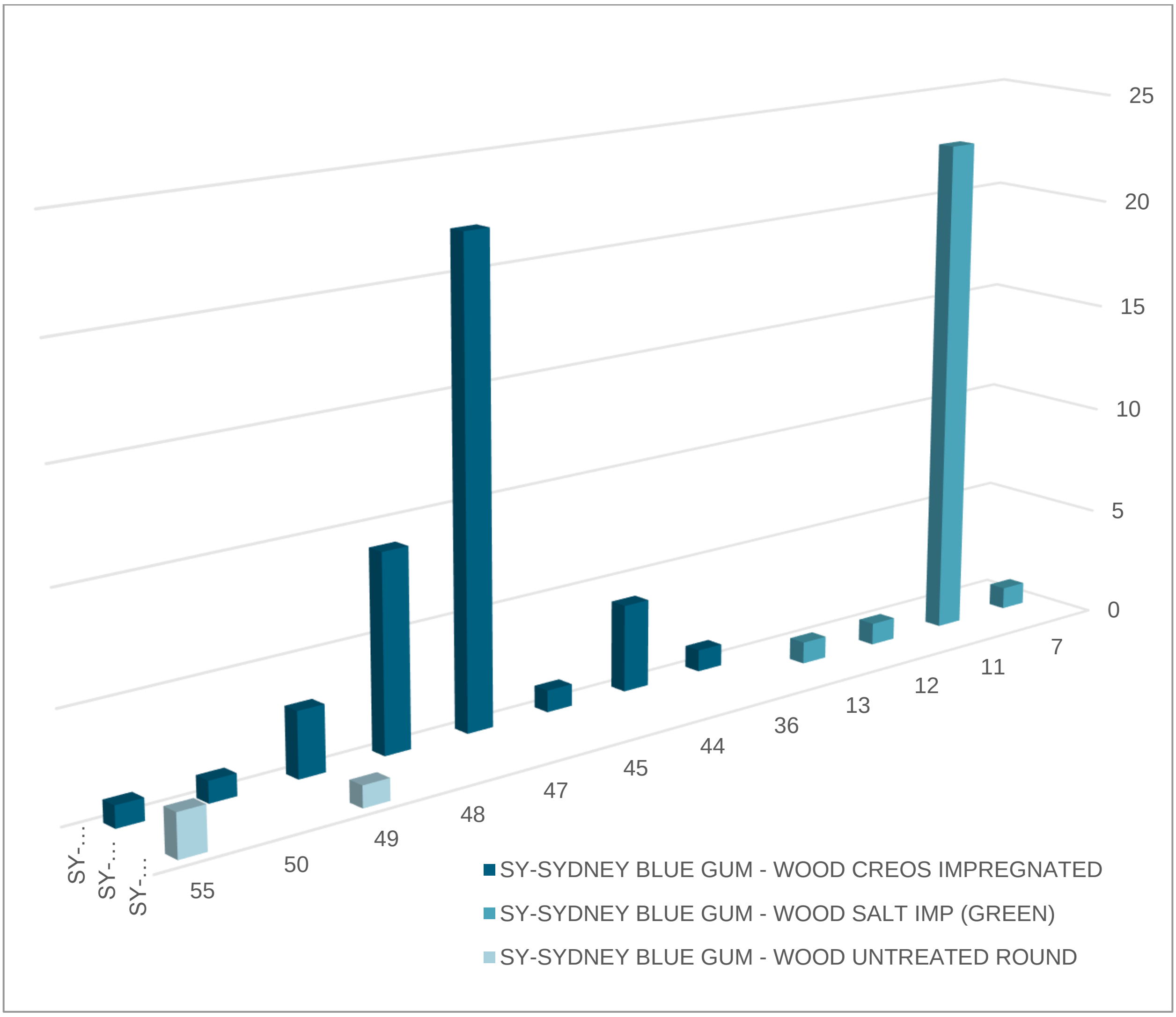

Figure 63 - SY – Sydney Blue Gum Population Sub Profile

Due to the small number of poles in this category a prediction was not considered.

TW – Tallowood

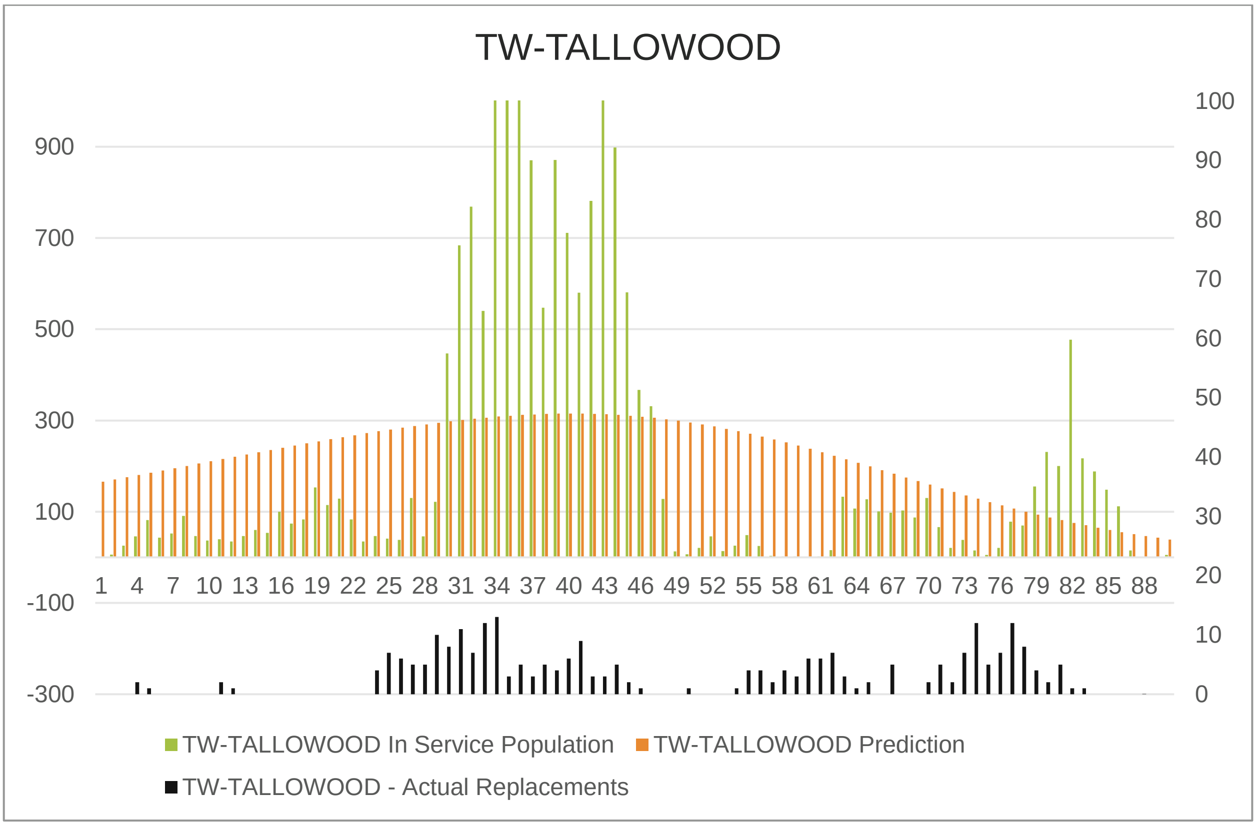

Figure 64 - TW - Tallowwood Projection

There are approximately 19915 Tallowwood poles in service with 4 different mixed sub-populations separated by type of pressure treatment (SAL or WCI) or non-pressure treatment (WUD or WUR).

The youngest population is made up of 1140 CCA treated and has an average life for the CCA poles of 15 years. The next sub-population is Creosote WCI polls makes up 5179 poles and averages as a group 31 years in service.

The untreated older timbers have population groups at 71 years approximately 12302 poles are untreated dressed premium timber. The final sub-population accounts for over 1285 poles with a significant in-service age peak at 88 years, and some poles recorded as over 100 years old.

Comparison of the functional failure recorded from 2009 to 2019 for the 4 sub-populations reveals that the recorded functional failures support only two (2) sub populations in any significant quantity and when the WCI and WUD functional failure profiles are examined, there is only 290 functional failures from a population of almost 20,000 poles.

Therefore, the next 20 years estimate is based upon age out of existing old in-service poles made by using a long characteristic life estimate of approximately 85 years with a shape factor of 8.

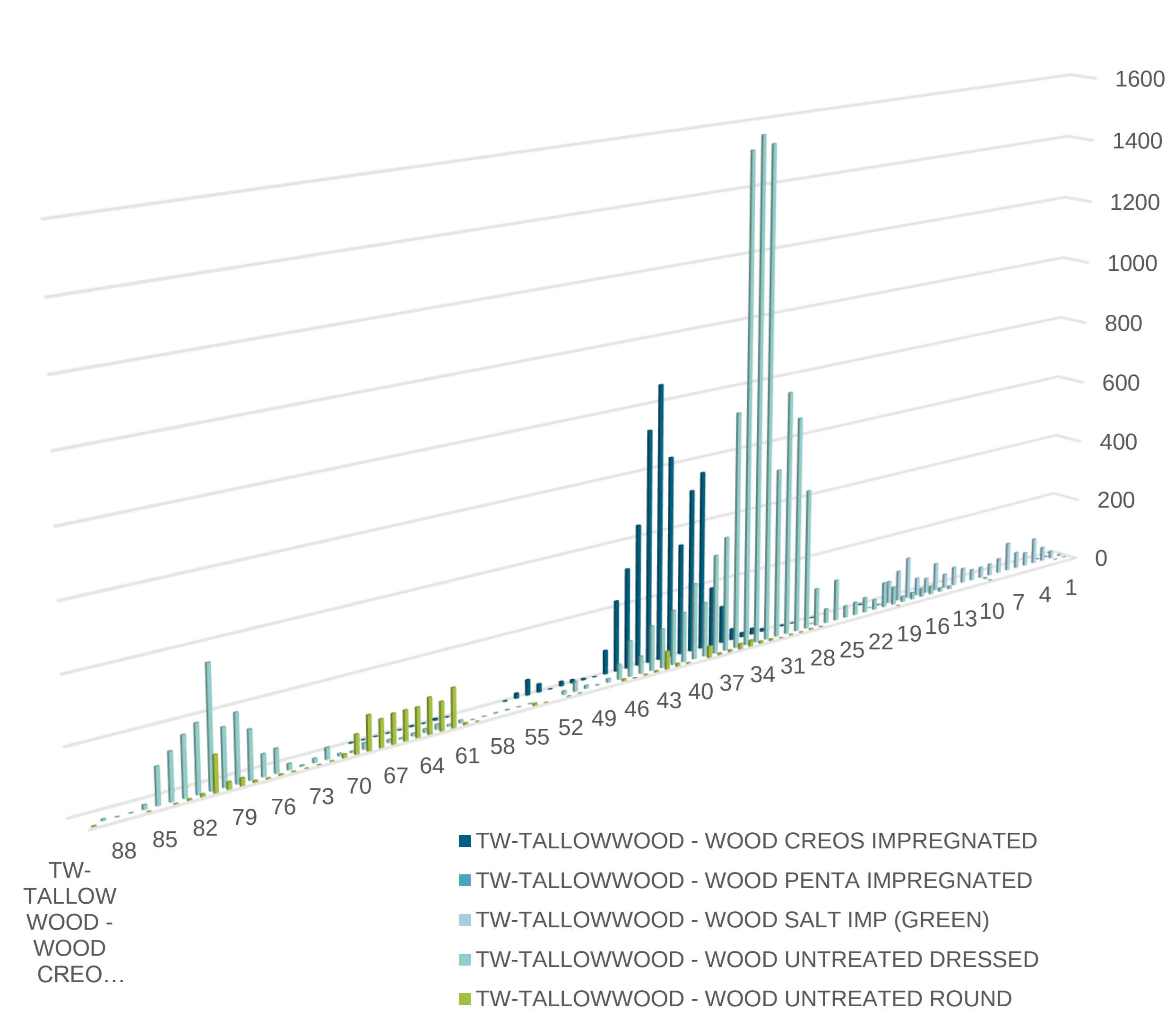

Figure 65 - TW - Tallowwood Population Sub Profile

WM – White Mahogany

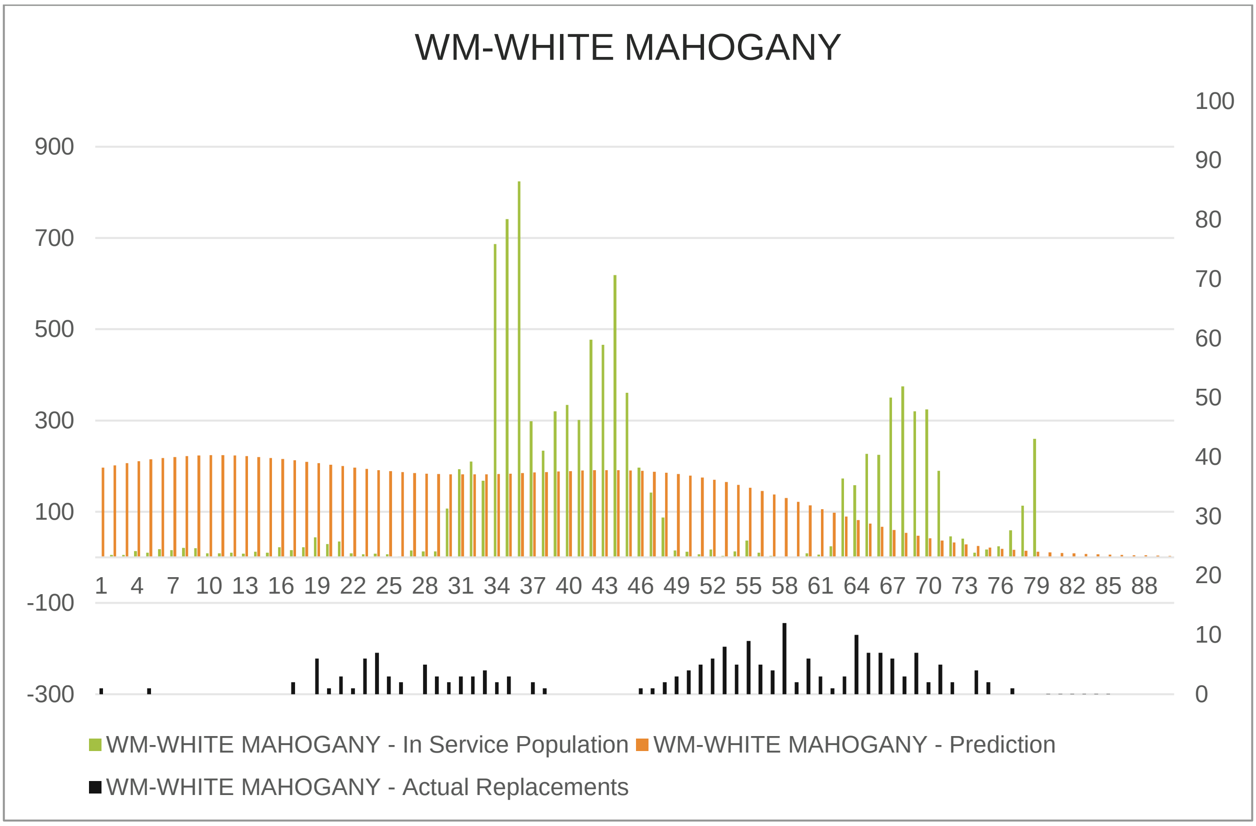

Figure 66 - WM - White Mahogany Projection

There are 10245 WM poles in 4 distinct sub-populations within the White Mahogany species.

The oldest wood is untreated dressed wood and averages about 80 years old with a second group about 30 years old.

The second sub-population is untreated round wood and averages about 65 years in service.

The third sub-population is creosote impregnated and averages about 40 years in service, and the 4th but smaller population of CCA treated poles have been installed over the last 20 years.

Within the 10-year window for replacements only 209 replacements have been made, making it difficult to use the past data as a predictor of future functional failures.

There has been almost no creosote of CCA failures observed. The mean of 91 undressed round wood is approximately 65 years and the balance of the functional failures on dressed untreated wood occur with a mean of approximately 75 years, but an in-service population exists with a mean of 83 years.

One could speculate further the apportionment of the mixed sub-populations and possibly refine the estimates for parameters but given the limitations of the observed functional failures a high-level estimate is made using a 2 parameter Weibull with shape of 6.2 and a characteristic life of 85 years.

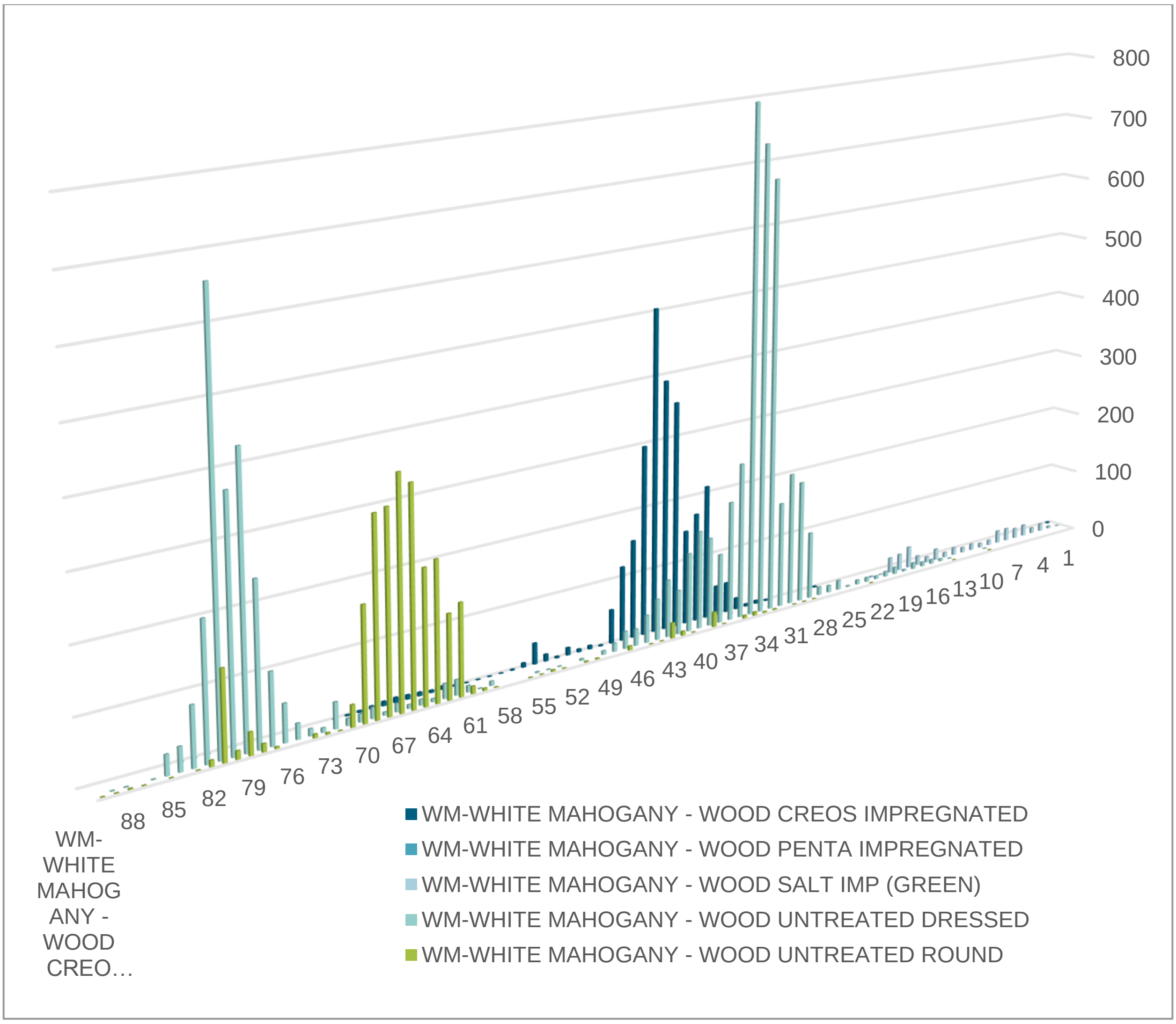

Figure 67 - WM - White Mahogany in Service sub-populations

WSB – White Stringy Bark

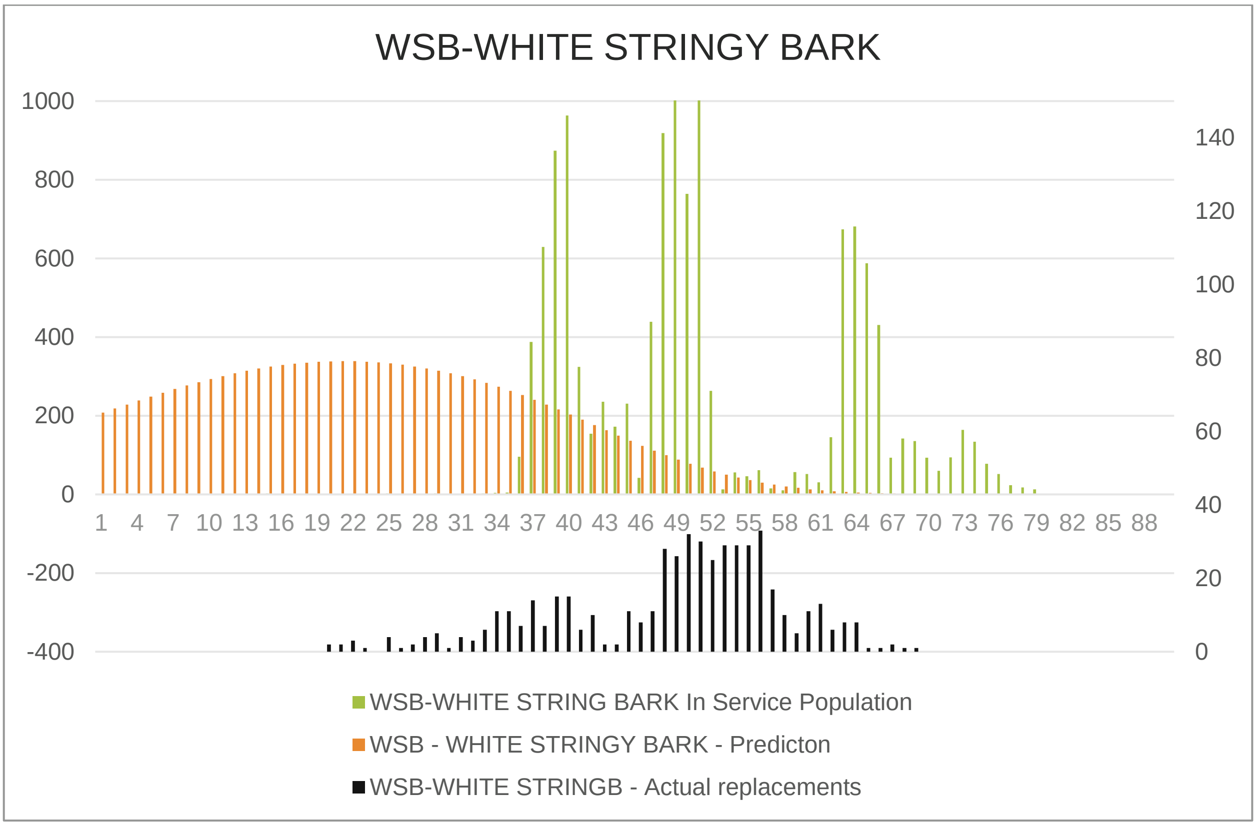

Figure 68 - WSB White Stringy Bark projection

There are 13205 white stringy bark poles in service made from two sub-populations that have critical mass to affect the 20-year prediction window. There is an older group about 63 years old (3803) which are untreated round wood. There is a younger and larger group (9818) which has been pressure treated with creosote that ranges in service age from 34 years to 54 years.

There are 514 poles that have functionally failed and been replaced during the 10-year window, but none are older than 74 years with the oldest appreciable quantity approximately 66 years old.

In this situation there is a large portion of the in-service population whose age exceeds the observed functional failure performance and thus one cannot utilize past performance as a future predictor for the untreated round wood poles. An estimate is made for the life expectancy of the 3803 older poles based upon the notion that these are premium timber and have a long-life expectancy and there are few observed functional failures over the last 10 years.

For the sub-population that has been pressure treated with creosote, uniquely, few have made it beyond 50 years in service and the characteristic life is 46.4 years and the shape factor is estimated to be 6.1, hence a projection that the existing population will follow this pattern and exit shortly.

The projection for the mixed sub-populations is made using a 2 parameter Weibull with a shape of 6 and a characteristic life of 75 years against the untreated round timber and a shape factor of 6.1 and characteristic life of 46 years for the creosote impregnated poles, which are nearing the end of their projected useful life.

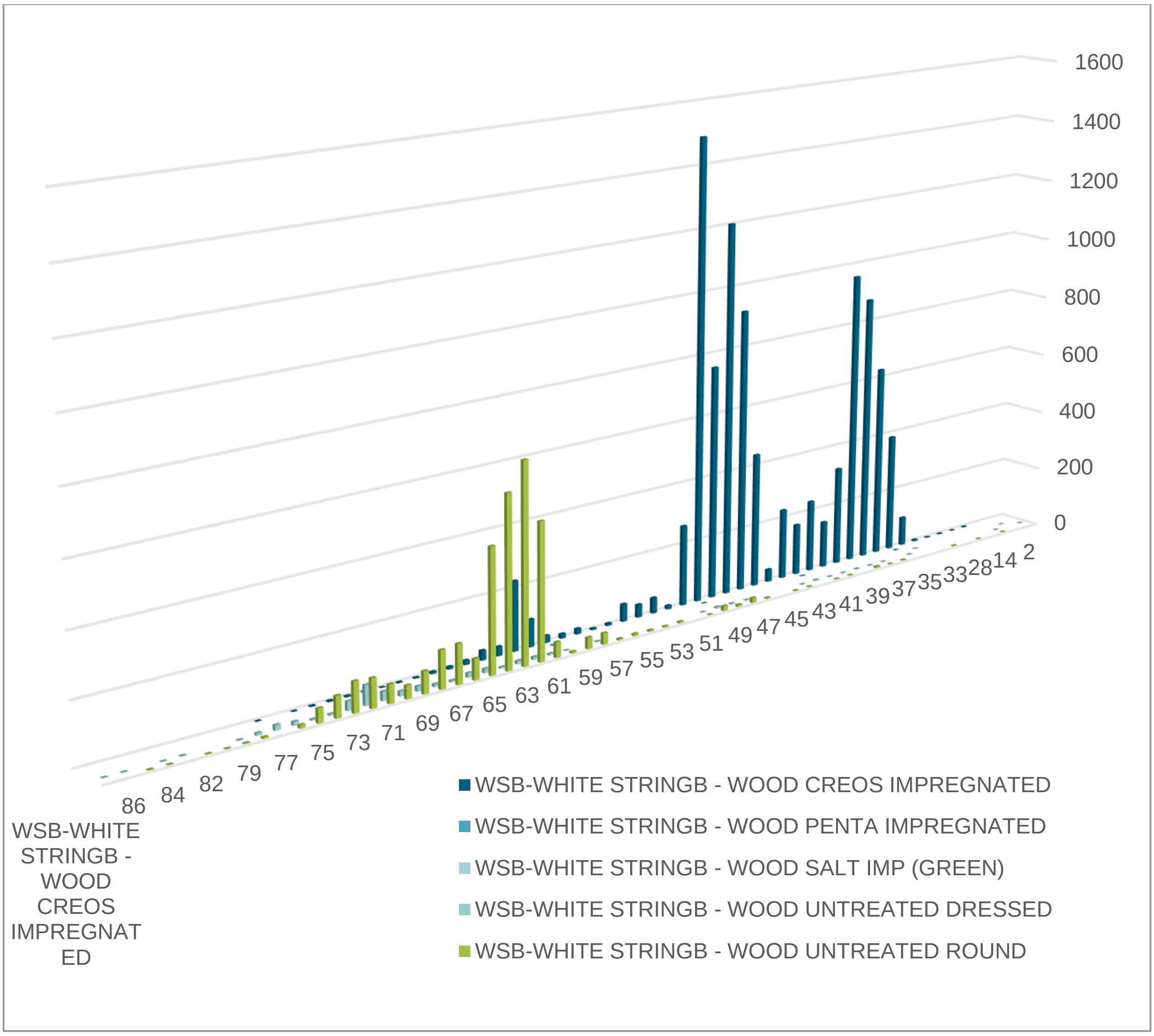

Figure 69 - White Stringy Bark Population Sub Profile

YSB – Yellow Stringy Bark

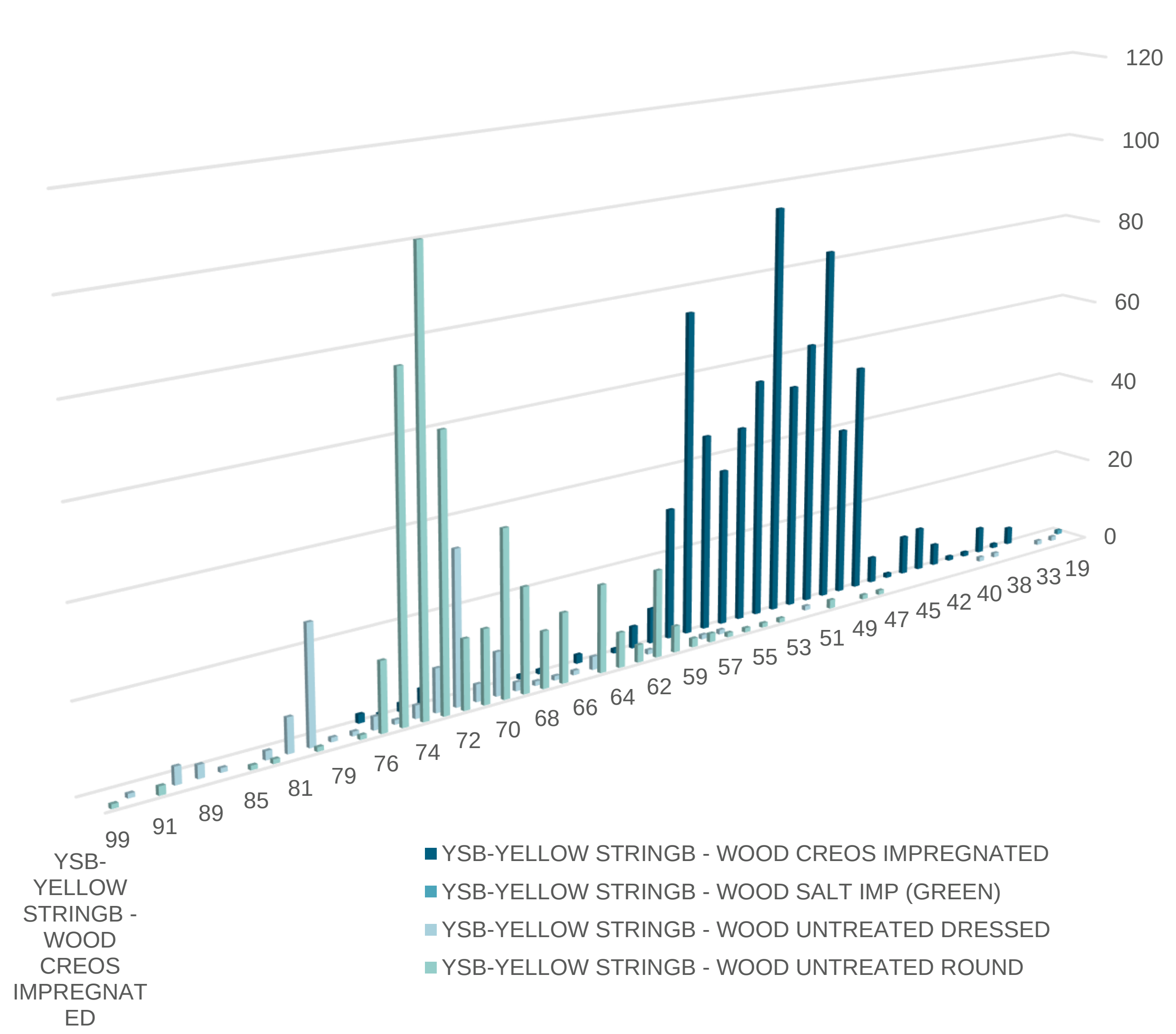

Figure 70 - Yellow String Bark Population Sub Profile

ZZ – Wood Unknown

There is a large population of poles for which currently there is no identification and they are listed as species ZZ – Wood Unknown. Because they have unknown characteristics, it is not possible to separate them into smaller groups for the basis of performing a prediction.

A small group is currently about 78 years old and is likely to functionally fail within the 20-year window requested for a forward projection.

Given unknown data, an attempt at projecting the unknown was not fielded.

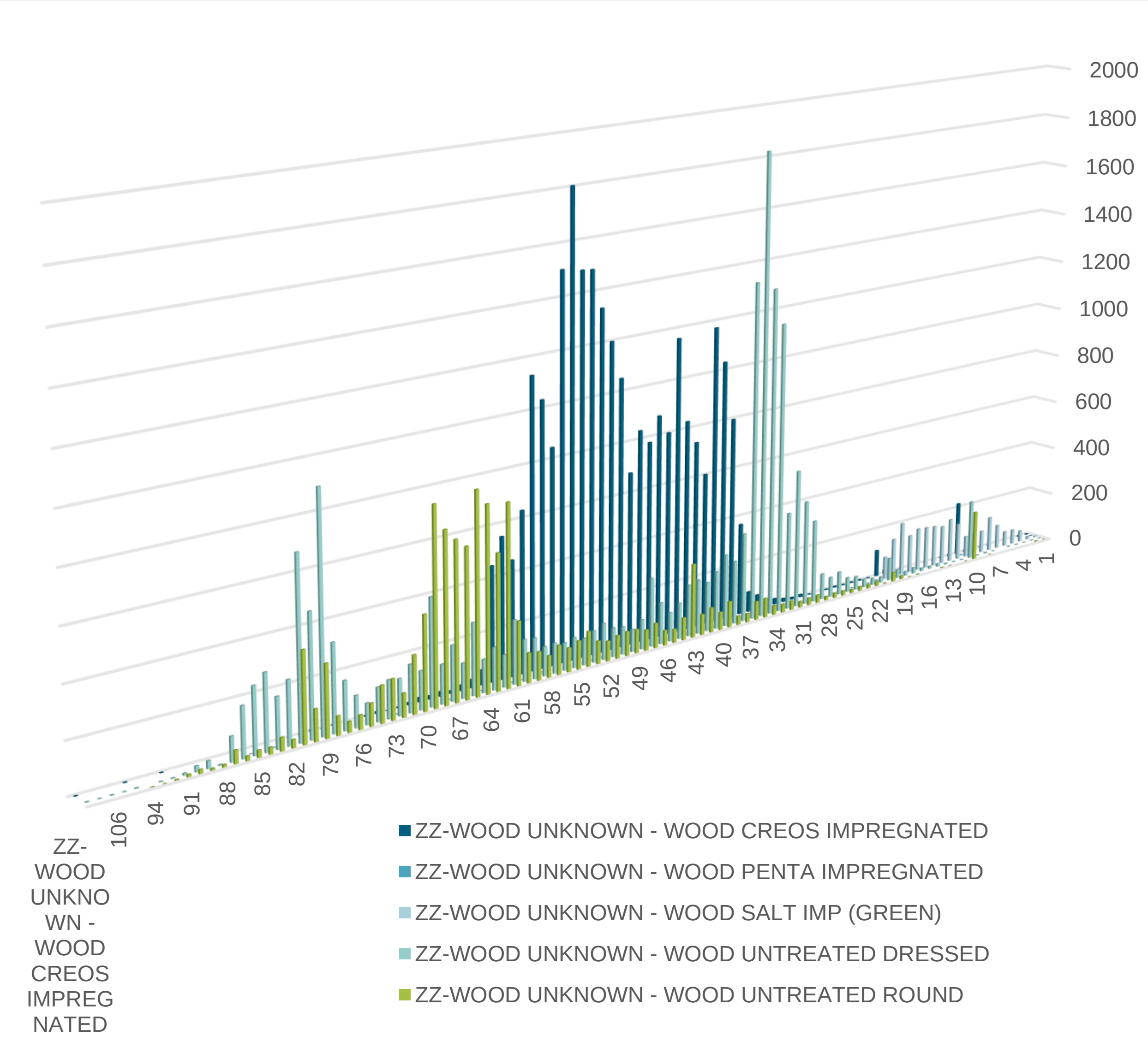

Figure 71 - Wood is Unknown

The "In Service Age" Calculation Method

Of the 404,554 wooden power pole records listed as in service there are 403,850 wooden power pole records that exist with a defined construction year. From this construction year datum, the age in service is calculated (in years) by subtracting the construction year from 2019.

From this large data set the average age of an in-service wooden pole is found to be 44.35 years.

Within the RCM study period beginning in 2009 and ending in 2019 a total of 14188 poles were recorded as replaced having met the retirement criteria for a functional failure (Unserviceable designation), This initially calculated for an average of 1418.8 per year (average over 10 years). The data was further reduced to eliminate remaining duplicates resulting in unique SAP equipment records producing about 10,000 pole replacements over the last 10 years.

The average age at replacement of the poles replaced between 2009 and 2019 was 48 years in-service.[47]

If replacements continued at the last 10-year average replacement rate of about 1000 poles per year it would take an estimated 400 years to replace or retire the current population (404544/1000 = 404 years). For this reason, one must conclude that the replacement rate will need to increase significantly soon as the current pole population ages out of service with the oldest poles possibly exceeding an unrealistic age over 300 years old.

The current in-service pole population is shown in Figure 72 This represents all species known and unknown as calculated from their construction year as extracted from SAP data. Each bar represents the count of poles currently at that age.

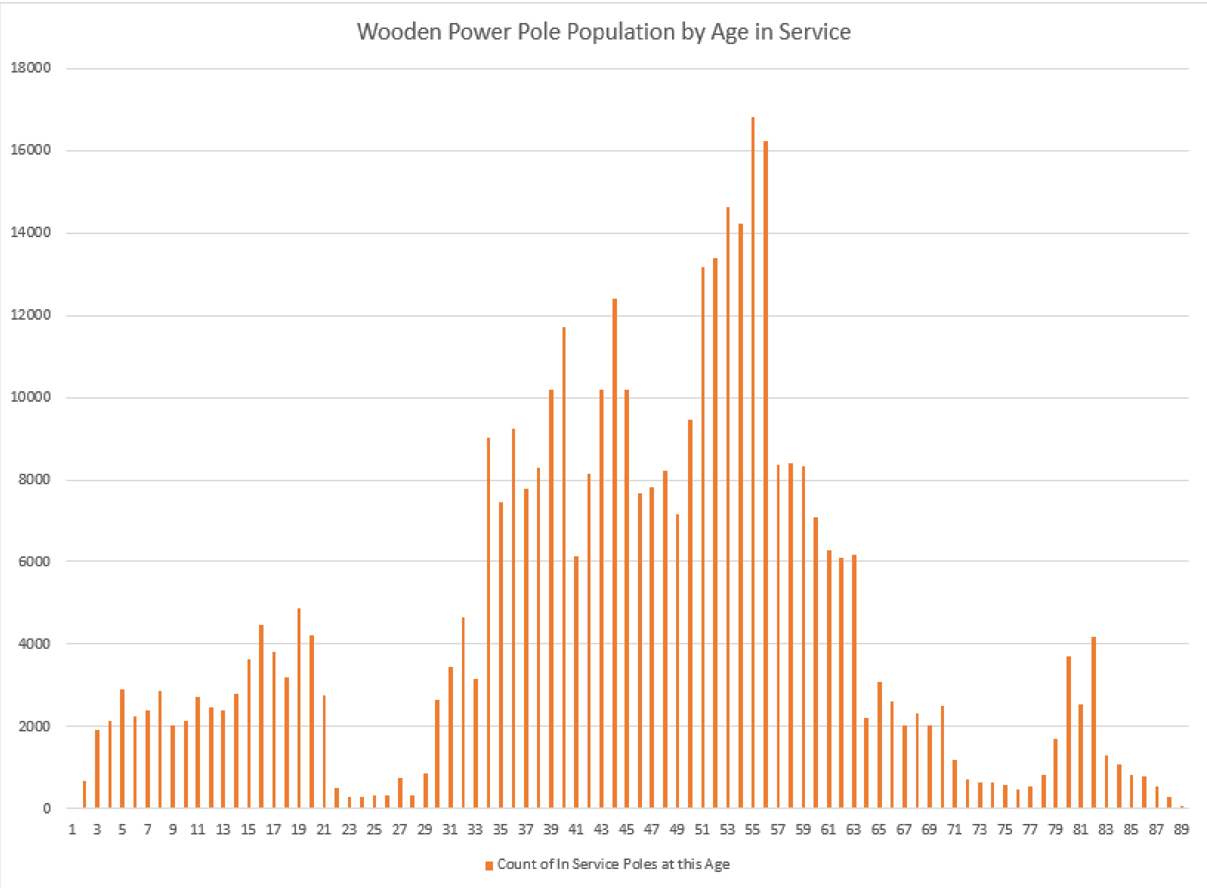

Figure 72 - Wooden Power Pole Population by Age in Service[48]

[47] Calculated from the average age at replacement listed in column J of file: Poles_replacements_-_timber_(2009-2019)_final (002).xlsx
[48] Age in Service calculated from SAP data provided in file Timber_pole_population_-_INST_INSV_4.csv

Renewal Cycle Sustainability

The low current replacement rate does not seem sustainable. Continuation would seem to require power poles whose average age would exceed a few hundred years.

Unfortunately,, the are no distribution businesses world-wide with 200-year-old power poles in service, so it is most likely CP/PAL will need to follow in the footsteps of other DB's and accelerate their population replacement rate to catch up. If the renewal rate is maintained at such a low rate, this would seem to lead towards a very reactive future state where an excessive number of poles will require replacement in a future year that given the current population average age could be realized within the next 15 years.

In order to increase the number of poles replaced each year and to reach a sustainable renewal cycle level, CP/PAL should consider adjusting its safety margins in preference to age replacement so that the number of poles scheduled for replacement increases until this replacement rate equals a 60-year replacement cycle. (This should be worked with a view to the KM hazard rate and survival analysis which shows the practical limit for most poles is about 70 years.)

The rational for doing this is simple.

If there must be some adjustment to increase the renewal rate. Why not favour safety?

The benefits are;

By increasing the safety margin, CP/PAL will further reduce pole failures if a portion of the pole failure rate is attributable to the result of variance in the business process or inspection task effectiveness.

By increasing the safety margin CP/PAL would achieve a much more sustainable renewal rate and avoid a tsunami of replacements that all things considered, seems to be likely, given the age of the current population in-service.

This subject should be worked closely with our population replacement projections and the critical path model to fully understand the rationale behind the recommendations.

If 80 years is assumed for the renewal cycle purpose of estimating a future pole replacement rate, 404.544 poles/ 80 years = 5056 poles per year must be replaced.

If 60 years is assumed for the renewal cycle purpose of estimating a future pole replacement rate, 404.544 poles/ 80 years = 6742 poles per year must be replaced.

For the last 20 years, CP/PAL records indicate they have installed on average 2700 poles per year[49] except during a period where concrete poles were favoured over wood.

For the last 10 years, CP/PAL records indicate they have replaced on average approximately 1000 poles per year.

The failure rate for staked poles is 50% higher than for the general population (0.45% replacement rate per year in our 10-year sample period (see Figure 73) compared to an average of 0.3% for the general population). While this is significantly higher, it is not as high as we thought that it may be.

[49] Average Number of Replacements for the last 20 years calculated from data provided in file Timber_pole_population_-_INST_INSV_5.csv

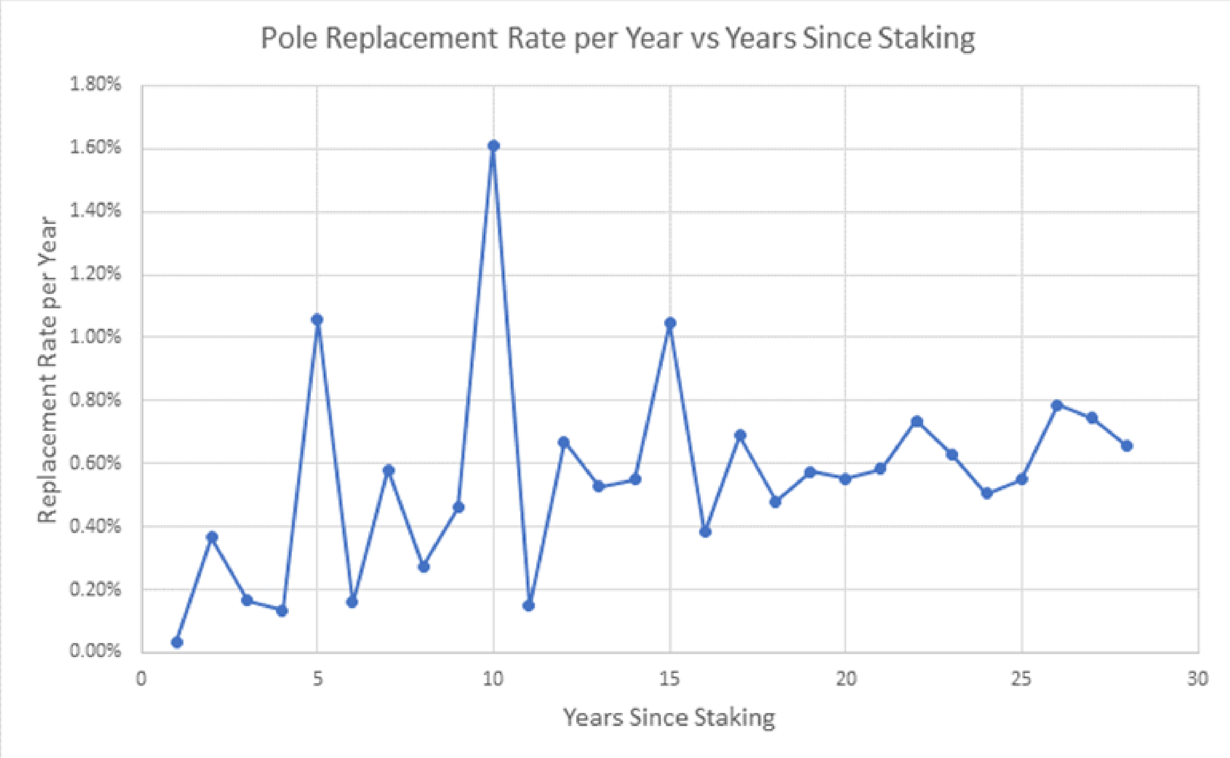

Figure 73 - Replacement Rate of Staked pole by Age since staking (Life extension)

You can see big spikes in the replacement rate in years 5, 10, 15, corresponding to the 5-year inspection frequency. Smaller peaks appear in between, in line with the 2.5-year frequency for the high-risk bushfire zone.

It is difficult extrapolating this chart too far into the future, as it would appear the current strategy is putting CP/PAL into maintenance debt. 28 years after staking the cumulative replacements for staked poles is only 15% - when are the other 85% of poles going to be replaced.

Splitting the data out into durability classes D1, D2 and D3 gives average replacement rates as follows:

Durability Class	D1	D2	D3
Average Replacement Rate	0.33%	0.47%	0.48%

Table 12 - Staked Average Replacement Rate

The failure rate chart for Class D1 is shown below in Figure 74. It follows the same trend as for the overall failure rate, but with a lower overall rate, and greater variability in later years as the sample set size is small[50].

[50] WOBKING, H. & HOTKLIJCNG, H. (1929). Applications of the theory of errors to the interpretation of trends. J. Am. Statist. Ass. 24, 73-85.

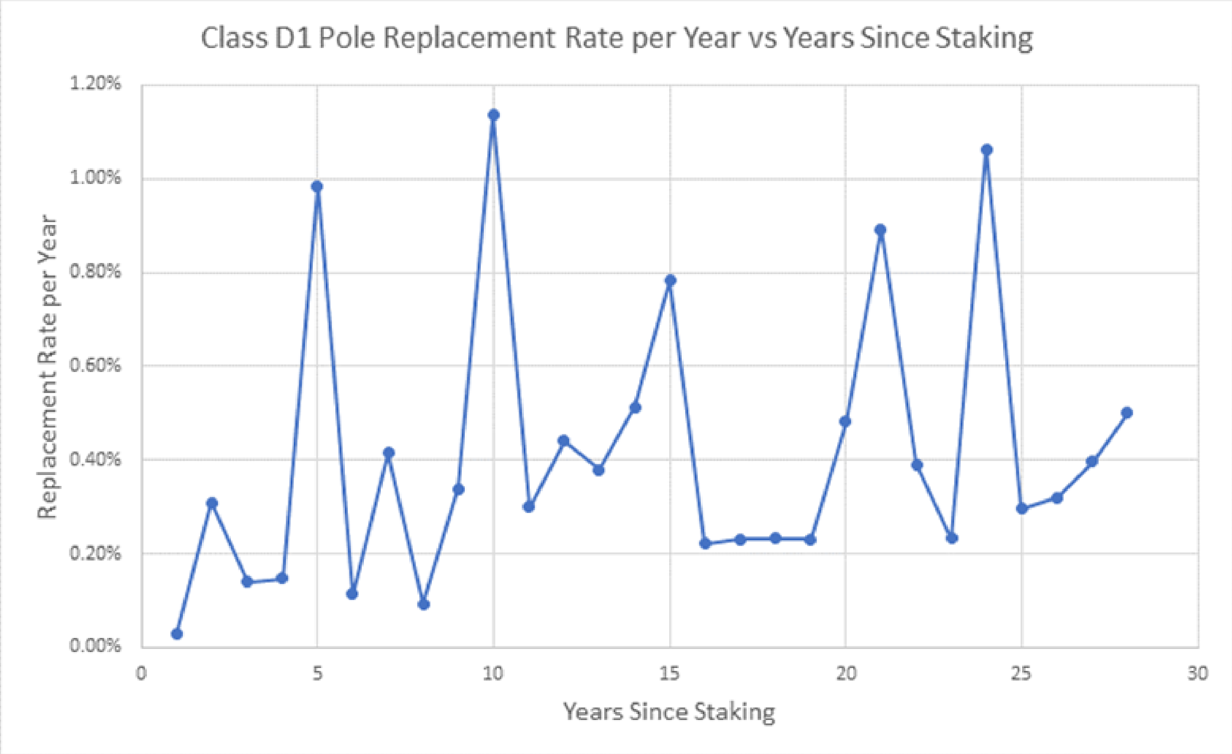

Figure 74 – Durability Class 1 Staked Pole replacement rate by Age since staked. (Life extension)

Class D2 has a smaller sample size again, so while a similar trend can be seen the white noise makes it less clear.

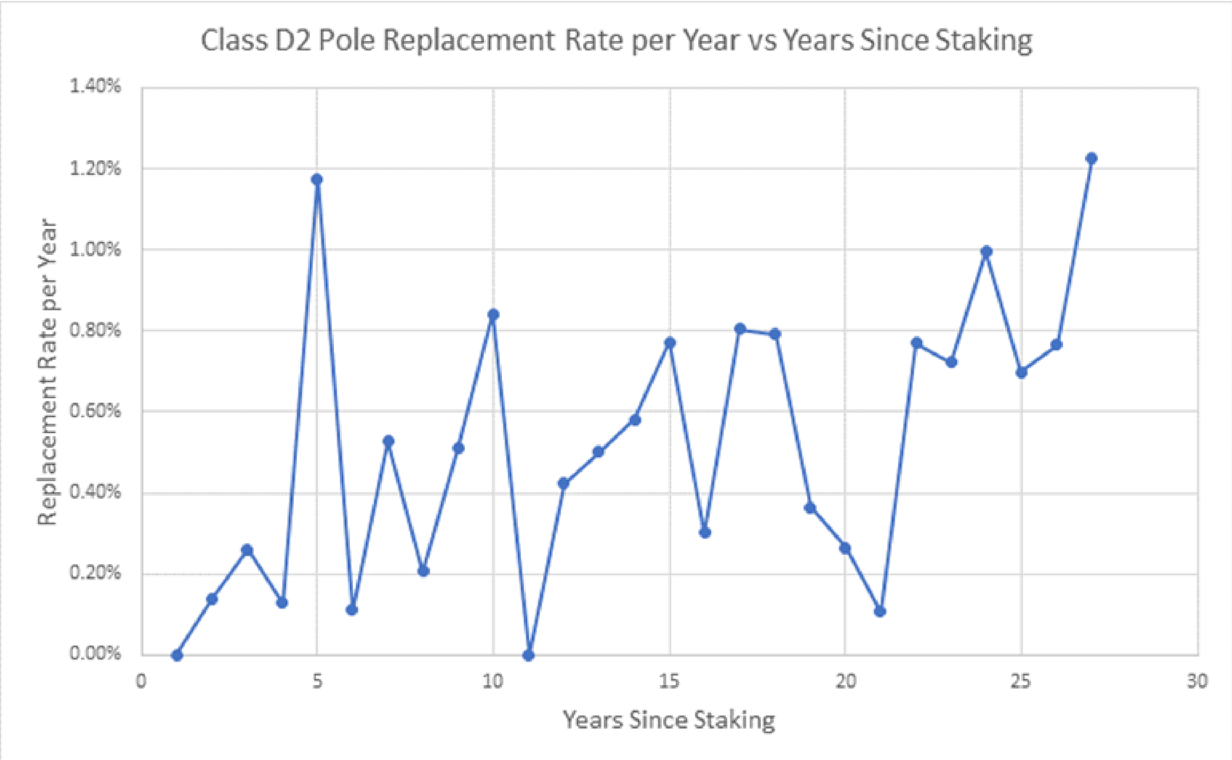

Figure 75 - Replacement rate for staked pole Durability Class 2

The Class D3 chart shown in Figure 76 again follows a similar trend, but with a higher average replacement rate and more stable results due to the higher sample size.

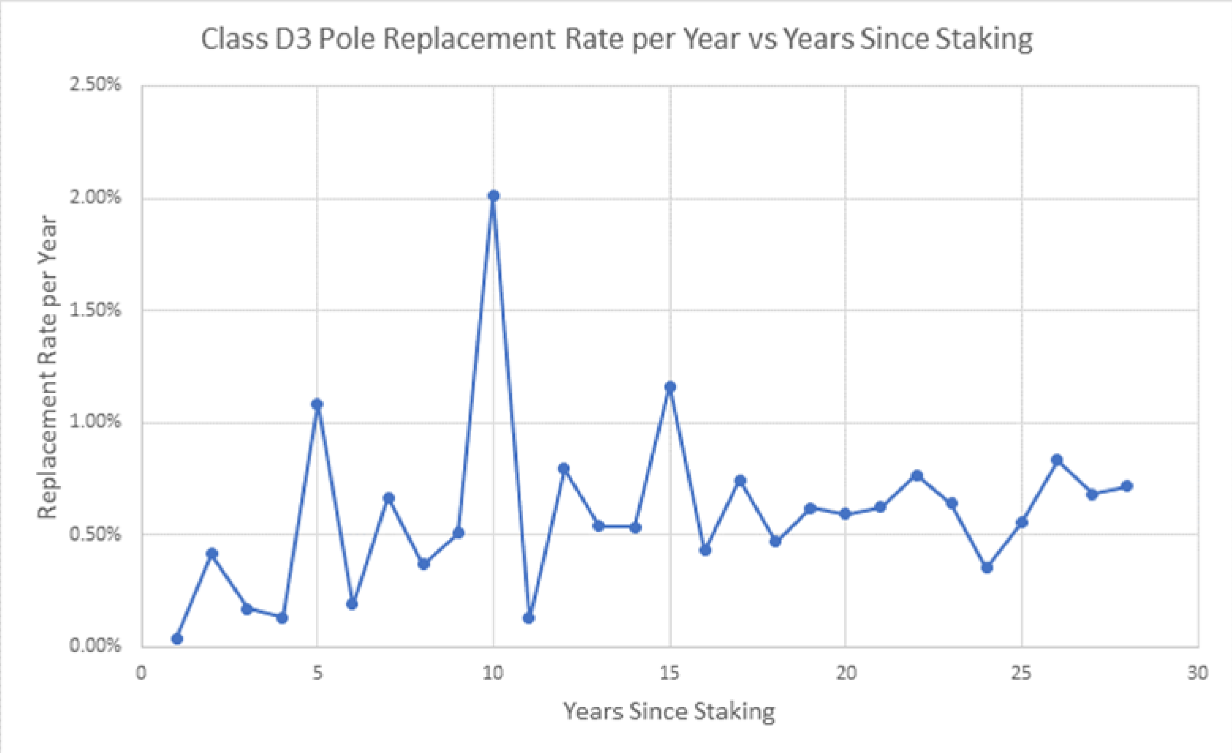

Figure 76 - Replacement Rate - Durability Class 3 pole by Age since staking

Powercor's Pole Inspection and Maintenance Process[51]

This section provides moderate details of the complicated inspection regiment used by CP/PAL to inspect and ultimately retire a wooden power pole from service. This section relates to understanding the current inspection regiment so that it is possible to consider more optimal inspection program frequencies.

The current Powercor practice at the time of the RCM study commencement can be summarized with comments made as to the programs key components as recently published in an ESV publication.

Wooden Power pole inspection and chemical treatment at time of inspection has been studied extensively in the southern hemisphere and the Powercor inspection process is like other distribution inspection processes. [52] [53]

ESV states[54] that Powercor's pole inspection practices require that all serviceable poles in HBRA shall each receive a full inspection every 30 months ± one month and a limited inspection every 30 months ± one month, which alternate on an overlapping cycle of 60 months as defined in the CP/PAL Inspection Policy.[55]

Scheduling of Planned Maintenance Packages			
PM Package	Schedule		Remarks
	Interval	Tolerance	
Class 1 – C1	30 months	1 month	Serviceable poles (HBRA only) – above ground Limited Life poles – above ground and below ground-line
Class 2 – C2	60 months	1 month	All poles - above ground and below ground-line

The fall of PM Packages over 2 cycles is shown in Figure 1.

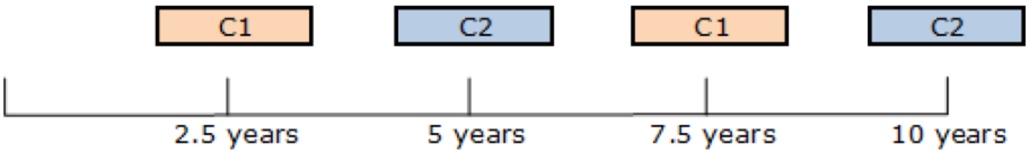

Figure 77 - Scheduling of Planned Inspection packages

The limited inspection (LI) (above ground inspection) includes:

- Visual inspection of the condition of the pole and pole-top assets.
- An assessment of the condition of the pole from ground level up to two meters, including a sound 'hammer' test to identify any pole cavities requiring further investigation known as "Thor's Hammer" testing.
- Identifying the presence of wood destroying insects (e.g. termites).

The full inspection (FI) (above ground and below ground inspection) includes:

- performing the limited inspection and;
- Excavation and assessment of a wood poles condition of the pole from ground line to a minimum of 300 millimetres below ground and to inspect for termite infestation.

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[51] ESV Technical Investigation Report – July 2019 - The Condition of Power Poles in South West Victoria
[52]] F. L. R. Vidor, "Inspection and Retreatment Procedures for in Service Wooden Poles Used in Electrical Networks," M.S. Thesis, Dept. Eng. Materials, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil, 2006.
[53] Inspection of Wooden Poles in Electrical Power
Distribution Networks in Southern Brazil, Flávio L. R. Vidor et all, IEEE Transactions on Power Delivery, February 2010 IEEE Xplore
[54] ESV Technical Investigation Report – July 2019 - The Condition of Power Poles in South West Victoria
[55] CP/PAL Network Asset Maintenance Policy for Inspection of Poles. Document No. 05-C001.D-390

- Drilling the pole with a 12-millimetre auger bit below ground, and / or use Woodscan above ground to ascertain the amount of sound timber remaining.
- Internally treating hardwood poles with preservative where drilled.

The same inspection processes outlined above will apply to all Additional Controls Serviceable (ACS), formally known as limited life poles. They will each receive a full inspection 12 months ± one month and a limited inspection every 12 months ± one month, which alternate on an overlapping cycle of 24 months.

The key commitments of Powercor's inspection and maintenance processes were included in its BMP (Business Management Plan) and submitted for ESV acceptance. Powercor's BMP includes references to policies, procedures and manuals that cover the inspection process in detail and are not replicated in this passage.

The results of pole inspection in HBRA are classified according to Powercor's system for maintenance action as either;

- S - Serviceable = fit for service, Reinspect in 30 months where:
  - A durability class 1 hardwood pole has an internal sound wood thickness measurement greater or equal to 40 mm OR;
  - A durability class 2 or 3 hardwood pole has an internal sound wood thickness measurement greater or equal to 50 mm.

- ACS = (Formerly known as Limited Life – LL which is a designation used in the RCM Study).

  In addition to preservative treatment of hardwood during inspection, other potential treatments include pole staking to return to serviceable condition to extend pole life, OR continue to monitor via 12 monthly inspections where:
  - A durability class 1 hardwood pole has an internal sound wood thickness measurement greater than or equal to 35 mm and below 40 mm
  - A durability class 2 or 3 hardwood pole has an internal sound wood thickness measurement greater than or equal to 35 mm and below 50 mm.

- Unserviceable P1 = requires pole to be replaced within 24 hours where:
  - A hardwood pole that has an internal measurement less than 16 mm.

- Unserviceable P1 = will otherwise be temporarily staked to reinforce the structure followed by a risk assessment with that added control in place, and then scheduled for a priority replacement. Replacement will not necessarily be within 24 hours for poles fitted with temporary added control that pass the risk assessment process.[56]

- Unserviceable P2 = requires pole to be replaced within 32 weeks where:
  - A hardwood pole has an internal measurement below 35 mm and greater than or equal to 16 mm, or has a defect caused by fire, vehicle impact, third party or lightning strike.
  - A defect has been identified below the excavation depth by the deep drill process.
  - A defect has been identified above two meters on the pole and is visually assessed from the ground.
  - Poles identified with wood destroying insects (e.g. termites).
  - Wood poles found with fungal fruiting bodies[57] above two meters.

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[56] CP/PAL response to ARMS question of SAP data for P1 resolution time - date Sept 4, 2019
[57] Type of fungi containing spores which rot poles as defined in the Australian Timber Resources for Energy Networks report by ENA and the Queensland Government. October 2006 Section on Timber Decay – Figure 34 (courtesy Professor Jeff Morell, Oregon State University) Page 92.

The RCM pole inspection involves three steps: visual assessment, hammer test and quantitative test of decay. Additional tests are subject to the condition of the pole and include the Wood Scan NDE technique.

The visual assessment of wood surface determines the extent of defects such as cracks, holes, burned or rotten points, presence of fungal fruiting bodies, etc.

The hammer sound test is used to detect a hollow core in the wooden pole caused by internal decay in the pole portion from the ground line up to 2 m. The clear sound and hammer rebound confirms that the internal condition of the wood is sound. As the assessment by visual inspection and hammer test is rather subjective, measurements of internal and external decay are also performed at the prescribed intervals.

The external pole inspection includes digging to assess the critical region below ground line (0.3 m). A complete excavation is made, the pole is brushed to be free of dirt and its surface is examined to evaluate whether it is rotten. The surface is scraped with a shovel or axe and all rotten wood is removed.

As external decay could eventually reduce the effective circumference of the pole this parameter is measured in two different pole regions at 0.10 m above and 0.10 m below ground line. The difference in the pole circumferences is used to estimate external decay. The internal pole decay is assessed by drilling a small hole (diameter of 12 mm) at ground line in an angle of 90 with wood.

To determine the thickness of solid wood (not necessarily sound), a probing rod adapted with a hook at the end is inserted into the hole. When the rod is pulled back the hook catches on the edge of the rot pocket and the marks on the sides of the rod indicate the shell thickness of the solid wood at drilling point. The measurement is used to estimate internal decay to 10 mm accuracy. All inspection drilling holes are treated with a Boron/Fluoride water-diffusible preservative (Pole Saver, Preschem Australia) and plugged with a PVC dowel to prevent decay.

The balance of the inspection process is detailed in the CP/PAL Network Asset Maintenance Policy for Inspection of Poles. As found in Document No. 05-C001.D-390.[58]

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[58] CP/PAL Network Asset Maintenance Policy for Inspection of Poles. Document No. 05-C001.D-390

Evaluation of NDE Methods

CP/PAL is currently utilizing the Wood scan technology as an evaluation of poles rendered to be unserviceable. Some poles are restored to serviceable, others to limited Life (LL) and the balance confirms the inspector’s decision or that of the pole calculator to retire a pole from service. The perplexing concern is the poles that are restored to serviceable by one inspection technique have been condemned by the current inspection method. While they may in fact still be serviceable, the difference suggests there is room for improvement in the older inspection processes using the learnings from the newer technology.

Woodscan provides a ground line assessment that determines the magnitude of deterioration and residual strength of the pole. The Woodscan plot provides rendering of the poles internal structure and maps the decay present.

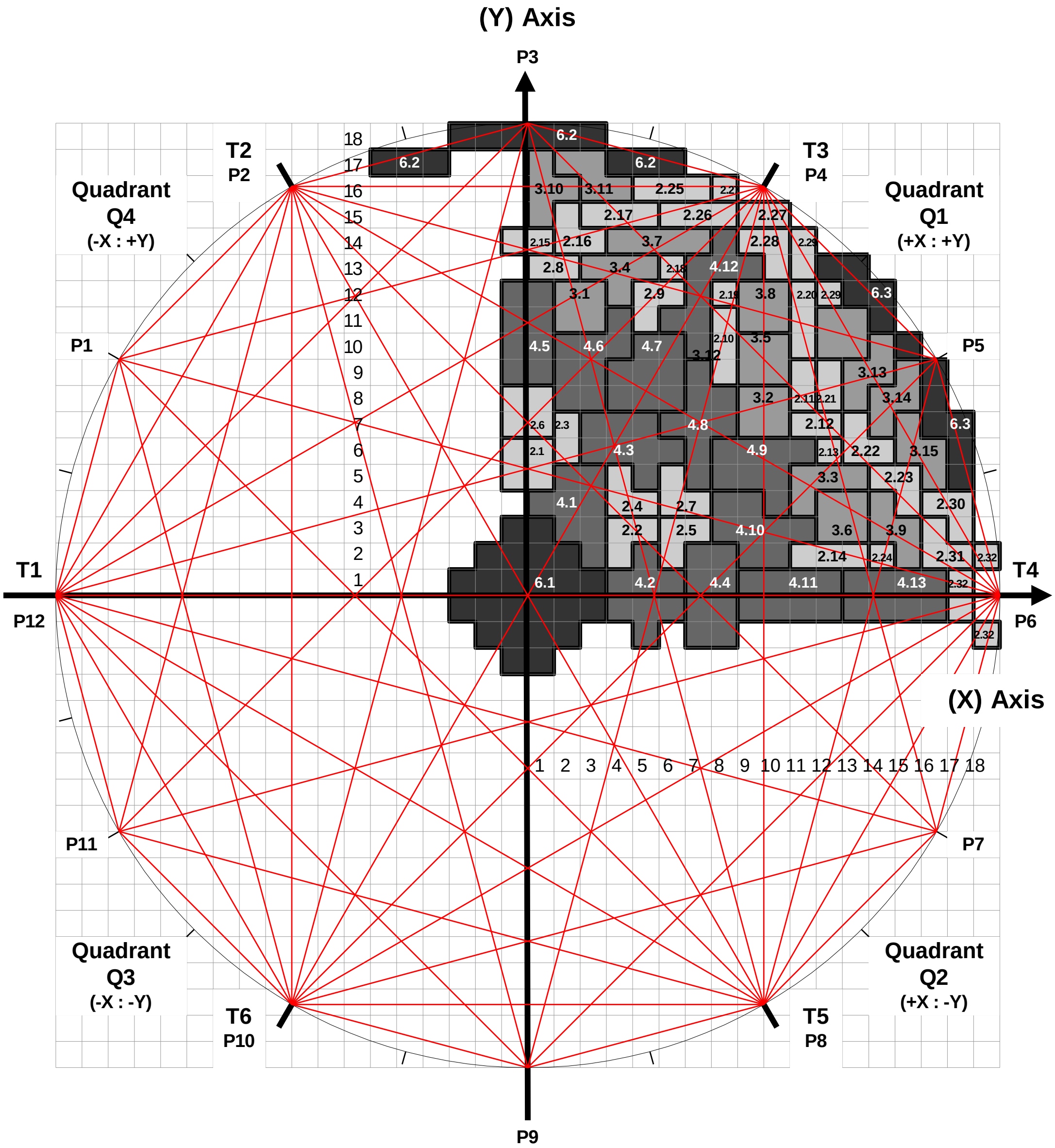

Figure 78 - Wood Scan reflection map overlaid on decay detected.

A report is prepared for each individual pole based on a series of readings taken from nails installed at or near the ground line. This method produces a 2-dimensional map of the difference as shown in Figure 78.

Business as Usual (BAU) Analysis

The desired business process was determined using Markov Analysis tools and validated during the RCM workshop to use the following state diagram process shown in Figure 79. It is overlaid upon the RCM PF curve for clarity when joining RCM concepts of a potential failure (P) and a functional failure (F) are included to the desired inspection process as shown. Added Serviceable Controls (ASC) is denoted by the older designation Limited Life (LL). Woodscan (WS) is a recent business process change introduced 18 months ago. This model helps focus intently on ways a pole failure occurs and areas for improvement of the condition-based maintenance policy.

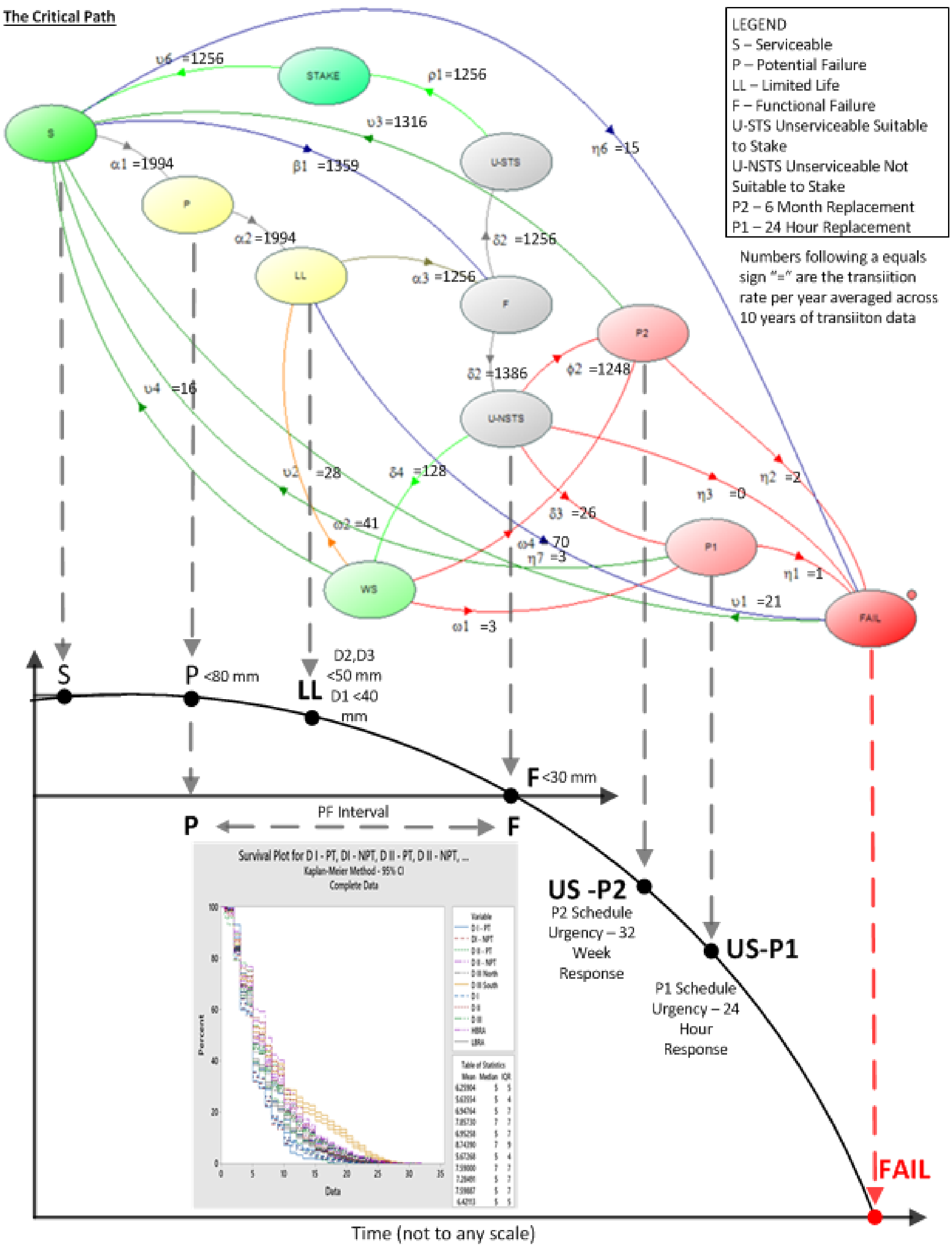

Figure 79 – The "Critical Path" RCM Pole Inspection - Business Process & PF curve

Transition Analysis

In order to evaluate the practicable ways a pole can fail the “critical path” model was populated with the 10-year average transition rate data prior to the RCM workshop. During the RCM workshop this was intently analysed to determine the specific paths a pole failure transitions to be able to target strategic counter measures aimed at reducing or eliminating pole transitions on any path leading to the FAIL state (pole failure). Additional analysis confirmed the rates after the RCM workshop.

The specific pathways a pole failure can occur need to be countered with practicable management strategies which should be derived from the RCM process.

The practicable paths of importance relevant to pole failure are;

ID	Transition Description		Quantity
η 6	S-Fail	Serviceable to Pole Failure	15
η 7	LL-Fail	Limited Life (ACS) to Pole Failure	3
η 2	P2-Fail	Un-Serviceable “P2 Priority Schedule to Pole Failure	2
η 1	P1-Fail	Un-Serviceable “P1” Schedule Priority to Pole Failure	0
TOTAL	10 Year Average of Pole Failures per year		20

Table 13 - Pole Failure Analysis

The recent changes to the condition base inspection process affect two of the 4 identified pole failure transition pathways. They are;

η 2 Transition Management:

- An increase of the safety factor for declaring a pole Un-Serviceable was made by increasing the strength minimum specification from a safety margin of from 1.25 to 1.40 for all poles on its network. The 25% safety factor assigned to prevent failure prior to replacement has now been increased to 40%. When a pole is identified for replacement, the 40% safety factor at that time ensures the pole is replaced well before it reaches a safety factor score of 1.00.

This largely affects the η 2 Transition as the time between the Un-Serviceable point declaration until P2 replacement is completed by the application of additional safety factor. The additional safety factor effects on average 2 pole failures per year.

This will positively influence a reduction in P1 declarations (near-miss) which total approximately 18 per year on average.

η 7 Transition Management:

- An increase in the frequency of inspection while in the Limited Life (ACS) state was made by decreasing the inspection and testing process from 30 months to 12 months for all limited life poles. This results in a more accurate and timely indication of pole condition minimizing the risk of unanticipated failure for poles in the LL state.
- This operates on the η 7 transition and should reduce the rate of failure from 3 failures average per year to less.

This will positively influence a reduction in P1 declarations (near-miss) which total approximately 18 per year on average.

The un-changed pathways for a pole failure are;

η 6 Transition Management:

- The transition from the Serviceable status to FAIL is particularly troubling. In doing so, the pole is transitioning from Serviceable by-passing limited life and Un-Serviceable states completely.

The management of this transition presents the single largest reduction opportunity for pole failures which currently average 15 pole failures per year.

η 1 Transition Management:

- The P1 to FAIL transition currently averages zero pole failures per year. This suggests that it is under control and no additional controls are needed for this transition.

Scenario	ID	Description
1	D1 Treated	Durability Class 1 – Pressure Treated with Creosote or CCA – Designated in data as (WCI) or (SAL) for salt
2	D1 Untreated	Durability Class 1 – Non-Pressure Treated Wood – either Untreated Dressed (WUD) or Untreated Round (WUR)
3	D2 Treated	Durability Class 1 – Pressure Treated with Creosote or CCA – Designated in data as (WCI) or (SAL) for salt
4	D2 Untreated	Durability Class 1 – Non-Pressure Treated Wood – either Untreated Dressed (WUD) or Untreated Round (WUR)
5	D3 North	Durability Class 3 Wood whose location is in the North region
6	D3 South	Durability Class 3 Wood whose location is in the South Region
7	Class 1	All Durability Class 1 Wood
8	Class 2	All Durability Class 2 Wood
9	Class 3	All Durability Class 3 Wood
10	HBRA	Any pole in a designated High-Risk Bush Fire Area
11	LBRA	Any pole in a designated Low Risk Bush Fire Area

Table 14 - Scenario Analysis Legend

		Scenario	1	2	3	4	5	6	7	8	9	10	11
ID	Transition	Total	D1 Treated	D1 Untreated	D2 Treated	D2 Untreated	D3 North	D3 South	Class 1	Class 2	Class 3	HBRA	LBRA
α 1 α 2	S-LL	1,707	63	356	47	40	567	274	419	87	1,194	684	1,023
α 3	LL-F	1,133	16	239	17	41	403	211	255	58	812	499	634
β 1	S-F	1,244	26	328	21	43	471	179	357	65	815	617	627
δ 1	F-US sts	1,192	15	351	16	46	293	200	367	62	757	397	794
δ 2	F-US nsts	1,224	29	225	23	41	596	197	254	64	896	739	485
δ 3	US nsts-P1	28	1	5	2	0.9	14	3	6	3	19	15	13
φ 2	US nsts-P2	1,116	25	213	20	39	540	175	239	60	808	677	439
δ 4	US nsts-WS	83	2	7	1	1	44	19	10	2	70	49	34
ν 4	WS-S	12	0.6	1	0.1	0.2	5	4	2	0.3	9.6	6	6
ω 2	WS-LL	35	0.6	4	0.7	0.4	19	8	4	1	30	22	13
ω 1	WS-P1	3	0.2	0.2	0	0	1	0.2	0.4	0	2	1	2
ω 4	WS-P2	34	0.7	2	0.4	0.5	20	8	3	0.9	29.5	20	14
η 6	S-Fail	15	1.5	2.4	1.3	2.2	3.3	1.7	4.1	3.8	5.4	0	0
η 7	LL-Fail	3	0.2	0.3	0.4	0.3	1	0.8	0.5	0.7	2	0	0
η 2	P2-Fail	2	0.6	0.1	0.1	0.1	0.7	0.4	0.7	0.2	1.2	0	0
η 1	P1-Fail	0	0	0	0	0	0	0	0	0	0	0	0
ν 2	P1-S	30	1	5	2	0.9	15	3	6	3	21	16	15
ν 3	P2-S	1,150	26	215	21	40	559	183	242	61	838	697	453
ν 1	Fail-S	20	2	3	2	3	5	3	5	5	9	0	0

Table 15 - Transition Analysis by Scenario- 10 year average 2009 to 2019

Additional transition analysis was performed to measure the variance in the PF interval, and to record its mean value. This knowledge proved very useful in calculating the number of inspections required to achieve a low threshold of pole failure risk.

PF Curve Variance

The estimate of the PF interval is used in the calculation of the risk of a pole failure and the estimate of the inspection frequency and as such, it is an important point for the RCM Study to consider.

The Potential Failure (P) to a functional Failure (F) has been calculated from SAP PM data. The key data is the transition of the pole condition status records yielding the time each pole was in that state. The transition data set considers 2009 to 2019 pole replacements but looks back in time from 2009 to capture the SAP state transition accurately, allowing for statistically complete data to be considered and avoiding left censoring.

After replacement or failure using SAP data, the individual pole's equipment record can be analysed uniquely to recover the equipment records status changes, and the date it changed status. From the status change data, we were able to reconstruct a state diagram configured with all of the reported state transitions from SAP PM data. From the status change dates we are also able to calculate the time (in years) a pole spent in any given state, and the combination of these two sources of information allows analysis of the BAU practice, and the variance observed in the PF interval.

In order to work with statistically complete data records, if a status began prior to the start of the data set interval in which began in 2008, that record was chased through the SAP data to recover its life spent in that SAP status, In this way the life within a status of S, LL or U was accurately reported using full status times. Various scenarios were considered as indicated by the second row of the table.

The PF interval between P and F is used to calculate the risk posed by missing a defect during an inspection, which could lead to a pole failure if unchecked by other action. The calculation of the probability of such a sequence of events is therefore of interest.

In order to determine the inspection frequency that will produce a theoretically low probability of pole failure, one must consider the estimate used for the PF interval itself, and then calculate with the missed inspection event as demonstrated in the next section. In this section we deal with the variance observed in the PF interval.

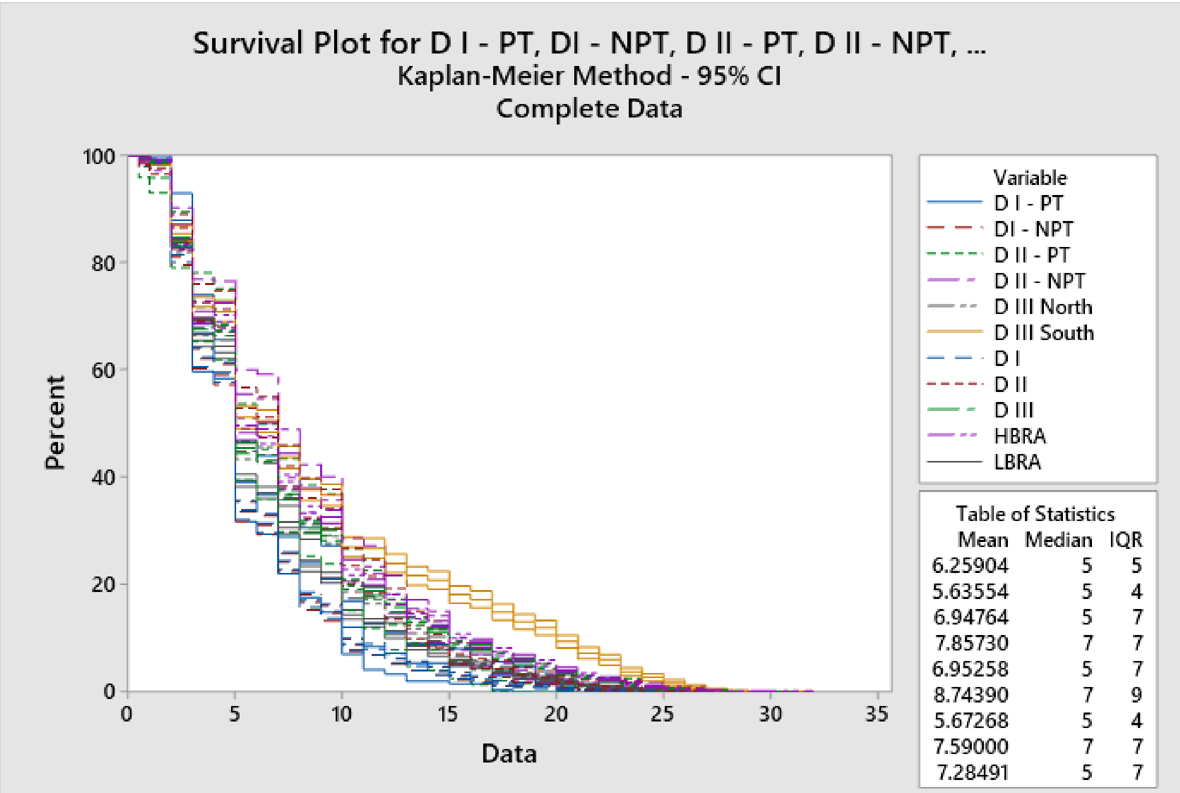

Figure 80 – PF Interval - Survival Plots by pole durability class and location.

In 2005 the PF interval was estimated to be either 10, 15 or 20 years. There was no attempt to utilize data to support a more refined PF interval, which is now possible in 2019. The PF interval has been estimated from the state transitions of the pole as it progresses from Serviceable – S to Unserviceable US.

The range of individual PF intervals was measured for approximately 10,000 poles in this study and processed using the Kaplan-Meier (KM) estimator to understand the sensitivities and worst-case scenarios. The PF interval data has been examined using histograms, and probability plots with fits attempted to both Weibull and Normal fits.

This analysis was performed with the help of the Minitab statistical software package for which a Table 16 is provided below. The column of survival probability, number failed, and number at risk can be used to evaluate the number of poles that will be likely managed by the inspection-based program and enter the LL state before entering the US state.

Kaplan-Meier Estimates

Time	Number at Risk	Number Failed	Survival Probability	Standard Error	95.0% Normal CI Lower	95.0% Normal CI Upper
0.5	36	2	0.944444	0.0381769	0.869619	1.00000
1.0	34	1	0.916667	0.0460642	0.826382	1.00000
2.0	33	5	0.777778	0.0692900	0.641972	0.91358
3.0	28	4	0.666667	0.0785674	0.512677	0.82066
4.0	24	3	0.583333	0.0821678	0.422287	0.74438
5.0	21	6	0.416667	0.0821678	0.255621	0.57771
7.0	15	3	0.333333	0.0785674	0.179344	0.48732
8.0	12	1	0.305556	0.0767737	0.155082	0.45603
9.0	11	1	0.277778	0.0746505	0.131465	0.42409
10.0	10	3	0.194444	0.0659621	0.065161	0.32373
11.0	7	2	0.138889	0.0576384	0.025920	0.25186
12.0	5	2	0.083333	0.0460642	0.000000	0.17362
13.0	3	1	0.055556	0.0381769	0.000000	0.13038
14.0	2	1	0.027778	0.0273893	0.000000	0.08146
15.0	1	1	0.000000	0.0000000	0.000000	0.00000

Table 16 - Kaplan Meier Estimates of Survival probability within PF interval – Blackbutt Species

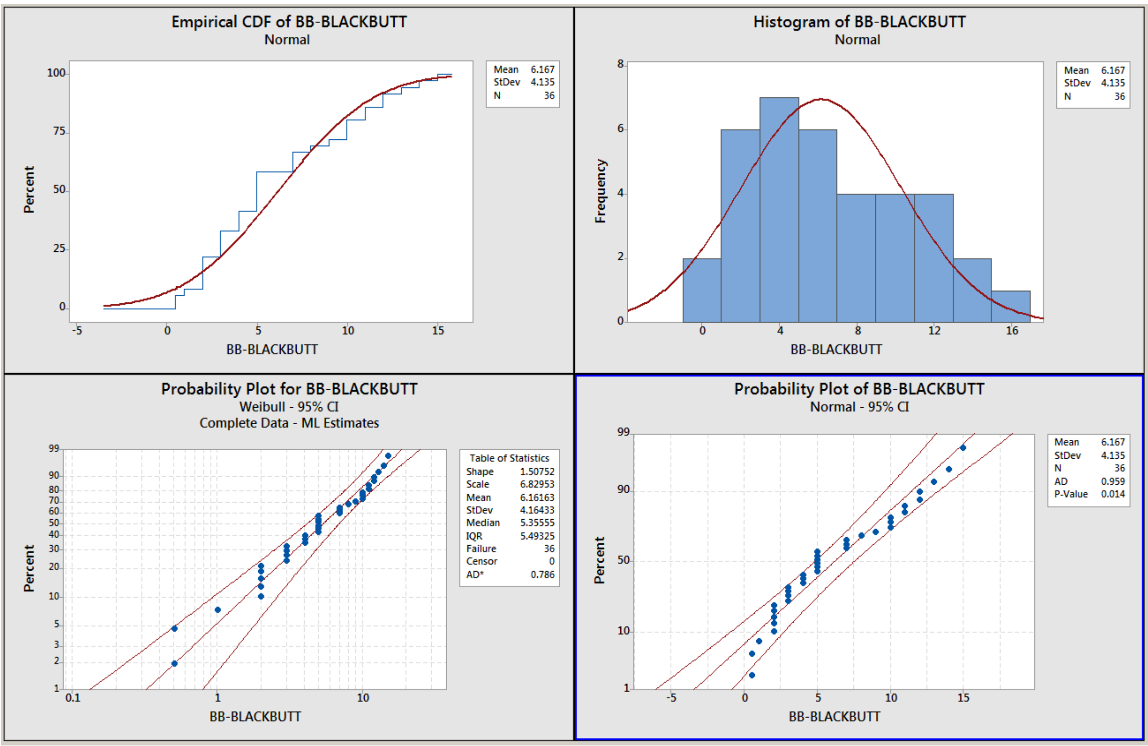

Figure 81 - PF Interval Analysis for the Blackbutt Species using 2009 to 2019 Transition data

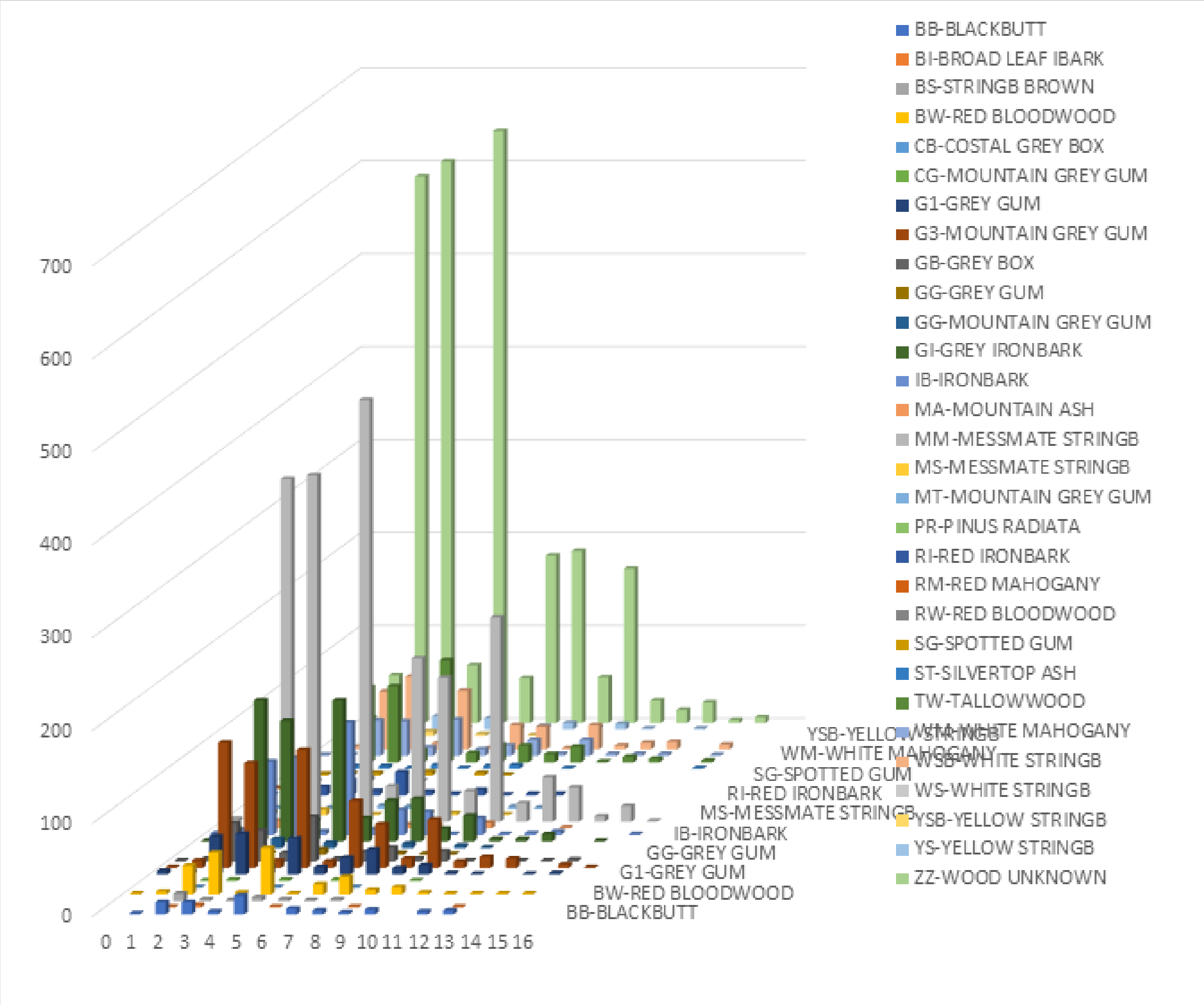

Figure 82 - PF Interval from measured data by species

The data shows that the PF interval variance is not a constant and does vary when measured across several species of wood (2009 to 2019 data).

Species	Min PF	Max PF	Ave PF	COUNT
BB-BLACKBUTT	0	15	6.5	34
BI-BROAD LEAF IBARK	0	10	4.7	14
BS-STRINGB BROWN	3	10	6.0	6
BW-RED BLOODWOOD	2	8	4.8	8
CB-COSTAL GREY BOX	3	3	3.0	1
CG-MOUNTAIN GREY GUM	2	12	6.4	70
G1-GREY GUM	5	15	11.7	3
G3-MOUNTAIN GREY GUM	0	15	8.3	74
GB-GREY BOX	2	11	6.2	28

GG-GREY GUM	1	12	5.5	50
GG-MOUNTAIN GREY GUM	0	15	5.9	411
GI-GREY IRONBARK	0	12	5.0	84
IB-IRONBARK	0	12	5.2	26
MA-MOUNTAIN ASH	2	12	6.2	52
MM-MESSMATE STRINGB	0	16	6.3	2019
MS-MESSMATE STRINGB	2	15	5.4	286
MT-MOUNTAIN GREY GUM	1	15	5.7	176
P-PINUS RADIATA	8	8	8.0	1
PR-PINUS RADIATA	2	7	3.5	4
QB-WHITE TOPPED BOX	None	None	None	None
RI-RED IRONBARK	2	12	6.4	10
RM-RED MAHOGANY	None	None	None	None
RS-RED STRINGB	2	2	2.0	1
RW-RED BLOODWOOD	3	3	3.0	1
SG-SPOTTED GUM	0	13	4.2	35
SS-SILVERTOP STRINGB	None	None	None	None
ST-SILVERTOP ASH	2	15	5.8	27
SY-SYDNEY BLUE GUM	None	None	None	None
TW-TALLOWWOOD	2	15	6.2	36
WM-WHITE MAHOGANY	2	15	4.5	19
WSB-WHITE STRINGB	0	16	6.3	152
WS-WHITE STRINGB	2	13	5.3	10
YSB-YELLOW STRINGB	3	12	6.4	16
YS-YELLOW STRINGB	0	15	10.2	13
ZZ-WOOD UNKNOWN	0	16	6.1	794

Table 17 - PF Interval Variance by Species from SAP data

As noted, the choice of a PF interval value must be tempered with an estimate to the KM estimate of the survival function and the risk of an inspection that misses a defect – called a missed inspection.

Strategically, it is the fast-moving poles that transition the PF interval in less than 3 years that challenge the safety margins of the condition-based inspection process.

PF Interval Scenario Analysis

The PF intervals were analysed using Kaplan Meier (KM) survival function and hazard function analysis.

The survivor function is most interesting because it directly yields the number of poles that would not likely be managed by the inspection process having achieved a status of LL (ACS) between the status of (S) Serviceable and (US) Unserviceable. This is particularly important when one considers those poles that are not being declared LL (Limited Life) and transition direct to unserviceable are candidates for a pole failure, if the pole degrades too quickly. This is important when one considers that 75% of pole failures came from a serviceable rating.

The KM survivor function is evaluated at year 2.5 by using linear interpolation between year 2 and 3. This is chosen to estimate the number of poles that would likely transition S to US because the degrading of the pole happens faster than the 2.5 yearly inspection cycle. In calculating this we have not considered the recent change to yearly inspections while a pole is in the LL state because the higher frequency inspection only applies while in the LL state and not in the S state. The scenarios were calculated various high-level ways to gain an understanding of the likelihood of a pole transitioning from S to US bypassing LL.

This data is taken from SAP and where needed the time spent in the state a pole was in has been taken back to its installation or the date it entered LL to remove the need to deal with left censored data as the start of the time in a given state is known. The analysis is made from complete data.

Kaplan-Meier Estimates

Time	Number at Risk	Number Failed	Cumulative Failure Probability	Standard Error	95.0% Normal CI Lower	95.0% Normal CI Upper
0.5	5305	30	0.00566	0.0010295	0.00364	0.00767
1.0	5275	18	0.00905	0.0013001	0.00650	0.01160
2.0	5257	826	0.16475	0.0050931	0.15477	0.17473
3.0	4431	726	0.30160	0.0063012	0.28925	0.31395
4.0	3705	40	0.30914	0.0063450	0.29671	0.32158
5.0	3665	1102	0.51687	0.0068609	0.50342	0.53032
6.0	2563	34	0.52328	0.0068573	0.50984	0.53672
7.0	2529	450	0.60811	0.0067024	0.59497	0.62124
8.0	2079	310	0.66654	0.0064728	0.65385	0.67923
9.0	1769	41	0.67427	0.0064343	0.66166	0.68688
10.0	1728	579	0.78341	0.0056555	0.77233	0.79450
11.0	1149	39	0.79076	0.0055847	0.77982	0.80171
12.0	1110	201	0.82865	0.0051735	0.81851	0.83879
13.0	909	141	0.85523	0.0048310	0.84576	0.86470
14.0	768	69	0.86824	0.0046438	0.85914	0.87734
15.0	699	174	0.90104	0.0040998	0.89300	0.90907
16.0	525	48	0.91008	0.0039275	0.90239	0.91778
17.0	477	87	0.92648	0.0035832	0.91946	0.93351
18.0	390	60	0.93779	0.0033161	0.93130	0.94429
19.0	330	52	0.94760	0.0030595	0.94160	0.95359
20.0	278	71	0.96098	0.0026586	0.95577	0.96619
21.0	207	50	0.97041	0.0023267	0.96585	0.97497
22.0	157	36	0.97719	0.0020497	0.97317	0.98121
23.0	121	50	0.98662	0.0015777	0.98352	0.98971
24.0	71	25	0.99133	0.0012729	0.98883	0.99382
25.0	46	16	0.99434	0.0010295	0.99233	0.99636
26.0	30	15	0.99717	0.0007290	0.99574	0.99860
27.0	15	7	0.99849	0.0005328	0.99745	0.99954
28.0	8	5	0.99943	0.0003264	0.99879	1.00000
29.0	3	2	0.99981	0.0001885	0.99944	1.00000
32.0	1	1	1.00000	0.0000000	1.00000	1.00000

Assuming a 2.5 year inspection interval as recommended by the 2005 RCM study, approximately 25% of poles in LBRA LL status would transition to US within the inspection interval.

This is interpolated from the 2 year and 3 year KM Cumulative Failure Probability as;
|0.16475 + 0.30160/2= 23.31%

An estimate of the number of poles that were declared LL and subsequently Transitioned beyond US into the Safety buffer is;

|30+18+826+726/2| = 1237 or on a per year basis
=1237/2.5 = 495 poles on transition B1

Table 18 – Kaplan-Meier estimates for high bushfire risk areas.

For LBRA

Kaplan-Meier Estimates

Time	Number at Risk	Number Failed	Cumulative Failure Probability	Standard Error	95.0% Normal CI Lower	95.0% Normal CI Upper
0.5	6758	28	0.00414	0.0007814	0.00261	0.00567
1.0	6730	66	0.01391	0.0014246	0.01112	0.01670
2.0	6664	1007	$\boxed{0.16292}$	0.0044922	0.15411	0.17172
3.0	5657	1229	$\boxed{0.34478}$	0.0057817	0.33344	0.35611
4.0	4428	150	0.36697	0.0058630	0.35548	0.37846
5.0	4278	1611	0.60536	0.0059456	0.59370	0.61701
6.0	2667	158	0.62874	0.0058771	0.61722	0.64026
7.0	2509	441	0.69399	0.0056058	0.68301	0.70498
8.0	2068	482	0.76532	0.0051553	0.75521	0.77542
9.0	1586	147	0.78707	0.0049799	0.77731	0.79683
10.0	1439	465	0.85587	0.0042723	0.84750	0.86425
11.0	974	102	0.87097	0.0040779	0.86298	0.87896
12.0	872	148	0.89287	0.0037622	0.88549	0.90024
13.0	724	147	0.91462	0.0033993	0.90796	0.92128
14.0	577	83	0.92690	0.0031664	0.92070	0.93311
15.0	494	124	0.94525	0.0027673	0.93983	0.95067
16.0	370	37	0.95073	0.0026329	0.94556	0.95589
17.0	333	76	0.96197	0.0023266	0.95741	0.96653
18.0	257	54	0.96996	0.0020764	0.96589	0.97403
19.0	203	32	0.97470	0.0019104	0.97095	0.97844
20.0	171	50	0.98210	0.0016131	0.97893	0.98526
21.0	121	32	0.98683	0.0013867	0.98411	0.98955
22.0	89	24	0.99038	0.0011872	0.98805	0.99271
23.0	65	23	0.99379	0.0009560	0.99191	0.99566
24.0	42	13	0.99571	0.0007951	0.99415	0.99727
25.0	29	13	0.99763	0.0005912	0.99647	0.99879
26.0	16	5	0.99837	0.0004904	0.99741	0.99933
27.0	11	8	0.99956	0.0002562	0.99905	1.00000
28.0	3	1	0.99970	0.0002092	0.99929	1.00000
29.0	2	1	0.99985	0.0001480	0.99956	1.00000
30.0	1	1	1.00000	0.0000000	1.00000	1.00000

Assuming a 2.5 year inspection interval as recommended by the 2005 RCM study, approximately 25% of poles in LBRA LL status would transition to US within the inspection interval.

This is interpolated from the 2 year and 3 year KM Cumulative Failure Probability as;
|0.16292 + 0.34478/2=25.35%

An estimate of the number of poles that were declared LL and subsequently Transitioned beyond US into the Safety buffer is;

|28+66+1007+1229/2| =1715 or on a per year basis
=1715/2.5 = 686 poles on transition β1

Table 19 – Kaplan-Meier estimates for low bushfire risk areas.

1181 poles on avearge per year will transition from Servicable to Un-servicable without entering the Limited Life state. This estimate should be worked with the β1 transition of the critical path.

Risk of Missed Inspection

The topic of a missed inspection is important because if the miss occurs while the pole is at risk of pole failure, a missed inspection event can result in a pole failure.

The risk evaluation methodology was guided by application of MIL-2173 (AS) and adjusted by an application of conditional probability[59] as required to work with the sub-population of poles that are actively within their PF interval that are at risk of becoming a pole failure if an inspection fails to detect a problem.

This section can also be viewed as an application of a conditional probability given the condition that the pole is at risk of failing if a series of "n" sequential inspections fails to detect the latent defect. The set of poles at risk of failing are the portion of those poles which are recognized to have a potential failure (P) and SAP Status of LL (Limited Life) that also have a short PF interval and includes all the poles that have been declared functionally failed (F) as indicated by their SAP status of US (Un-serviceable).

Note: Poles once declared unserviceable, can also be evaluated for their suitability to stake, and their replacement priority P2 (32 weeks) or P1 (24 hours).

The method is to calculate the level of risk of a pole failure when referenced to the total population count.

2005 Risk of Pole Failure Calculation

This section was included to create a logical tie to the prior 2005 RCM work. It is included in the consideration of the methodology utilized in the prior two RCM studies which were then used to inform the business about the number of inspections required within a PF interval. This calculation also assumes the case of a less than perfect inspection effectiveness or probability of detecting a potential failure.

This is related to the scope requirement concerning the optimization of inspection frequencies within the regulated hard time requirements.

The 2005 study followed the 1997 RCM study, and both utilized a probability of pole failure calculation denoted by "R" for the risk of a pole failure and made broad assumptions about the nature of the PF interval using a fixed value of 10, 15 or 20 years.

The acceptable level of risk of a pole failure was further quantified in the 2005 study was 20 pole failures per annum of a population (then) of 375,000 wooden power poles.

This acceptable level of risk equates to a pole failure rate of 0.000053 per year. When extrapolated to today's current population of 405,554 poles expands to 21.6 pole failures per annum.

In order to calculate the current risk of a pole failure attributable to an inspection miss, we must consider a plausible way in which a sequence of events could unfold that leads to a pole failure if an inspection series fails to detect a potential failure.

This sequence of events is as follows: If a pole has a latent defect that goes undetected, the defect eventually will cause the pole to fail. The pole must first have a condition of having a latent defect and then experience a lack of detection to proceed to a condition where the pole fails.

For a sequence of pole inspections to not detect the pole defect that will lead to a pole failure, the inspection probability of detection must be less than unity (less than 100%).

The probability of detection was estimated in 2005 and again confirmed during the RCM workshops to be 0.797 or 79.7%[60]. This is a high-level estimate that has not been examined in detail considering the varied types of inspections made at different frequencies, and is likely overly conservative, but it has been put forth in the RCM workshops without a better value proposed. The probability of detection is used in the calculation of the minimum number of inspections needed within a given PF interval needed in order to achieve a certain low level of a risk of a pole failure.

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[59] KOMOLGROV, FOUNDATIONS OF THE THEORY OF PROBABILITY, A.N. KOLMOGOROV Chelsea Publishing Company, New Yourk 1956
[60] EANSW NDE Project - Analysis of NDE systems - Prediction of Section Properties at GL, 2001

For a pole failure to occur, two things must be present:

1. The pole must have a latent defect. This is measured as the portion of poles which are in status LL (Limited Life) whose PF interval is short enough such that;
2. A series of inspections conducted within this PF interval misses detecting the latent defect.

The inspection process carries with it a probability of detecting either a potential failure (P), a functional failure (F). This probability of detection by inspection is a probability which is represented by the Greek letter theta Θ to be consistent with terminology used in the MIL-2173 standard.

In the 2005 RCM Review study the term “failure rate” was not defined so we will correct that issue herein and utilize the terminology of conditional probability to provide a better explanation of the definition of the poles at risk because if a pole is not at risk, the number of repetitive missed inspections does not result in a pole failure.

Failure rate as referenced in the scope section is typically defined as the frequency with which an engineered system or component fails, expressed in failures per unit of time. It is usually denoted by the Greek letter λ (lambda). This symbol is often used in reliability engineering to express the time invariant failure rate.

In practical applications the failure rate λ of a system can depend on time, and so a more correct representation is $\lambda(t)$ to represent a failure rate with the rate varying over the life cycle or time of the system. In simple reliability models, the mean time between failures (MTBF, which is $1/\lambda$) is often reported instead of the failure rate, but this is only valid for assets whose failure rate is constant with respect to time. This unique feature of a constant λ only occurs when the underlying failure distribution is exponential and only if the functionally failed poles are replaced with new poles immediately.

For most species and treatment types analysed, the wood does not exhibit exponential failure performance, and so this choice of a reliability model is not well suited to match the real-world performance of the wood over its lifetime.

In the case of wooden power poles there exists a different situation whereby the wooden pole ages to a certain point, after which a non-constant increasing failure rate is observed when measured over the population lifetime. This is to say, wooden power poles do not exhibit constant failure rate over their life, rather they age gracefully, and after a certain age they are more likely to functionally fail and require replacement.

In doing so, a probability estimate was created by taking the ratio of the number of pole failures in a given year and then divided by the total pole population in service for the given year. As an example, the 2005 RCM Review cited the acceptable risk (or probability) of pole failure as 20 pole failures from a population of 375,000 serviceable poles. As an estimate of the pole failure risk within any year of 20/375,000 this is a probability estimate and not a technically a “failure rate” as described in the scope requirement.

Calculation of the Number of Inspections Required

The calculation of the number of inspections required while a pole is within its PF interval is directly influenced by the actual PF interval assumed for the pole sub-population (data shows is extremely variable) and the probability of detecting a potential failure (P) with any single inspection.

The Mil-2173 RCM standard is the 1981 US Navy RCM standard for RCM processes, and it provides guidance on how to calculate the number of inspections that must occur within the PF interval in order to reduce the risk of a pole failure down to an acceptable limit, defined as PACC.

It is important because it clearly details a method for calculating the number of inspections required within a PF interval. The PF interval is based upon the concept of a prototypical PF curve and the probability of detecting a potential failure condition can only exist between P and F. (P) is called a potential failure, and it is the point where a physical change beyond an engineered allowance for decay is detected to exist in a wooden power pole. (F) is called a functional failure and is synonymous with (U) when a pole is declared to be unserviceable after a pole inspection.

The prototypical PF curve used in the critical path discussion and in this section were derived from Nowlan and Heap and was introduced in 1975.[61] It is a conceptual curve whereby a pole starts out life in a new condition with 100% resistance to the various forms of failure.

It is generalized at times for all forms of failure on a particular asset, but care should be taken, as the resistance to a specific failure mode is of interest. Over time the resistance to failure decreases until a physical change can be detected usually by some form of inspection or test. The amount of time delay between the installation time and the onset of a decrease in resistance is of importance, because during this interval when an observation of a physical change is impossible, inspection is essentially a wasted effort. It is only when the asset has begun its decent along the resistance to failure curve, which an inspection can detect the visible evidence of a potential or condition-based failure.

The terms PF interval, the CF interval used in the chart below is the same thing and the interchangeable use we trust causes no problems for the reader. Different publications use them interchangeably. Within the CF(PF) interval of length T, one must perform one or more inspections at a frequency of ΔT. The success of detecting the visible evidence of failure is tempered by the probability of detection (POD or Θ) of the single inspection.

If Θ is less than perfection, there exists the real possibility an inspection will occur while visible evidence of a potential failure exists, but it will not be observed and the pole will remain rated in good condition, when it in fact has visible evidence of a potential failure.

[61] Reliability Centered Maintenance – Nowlan and Heap – US Department of Defense 1975

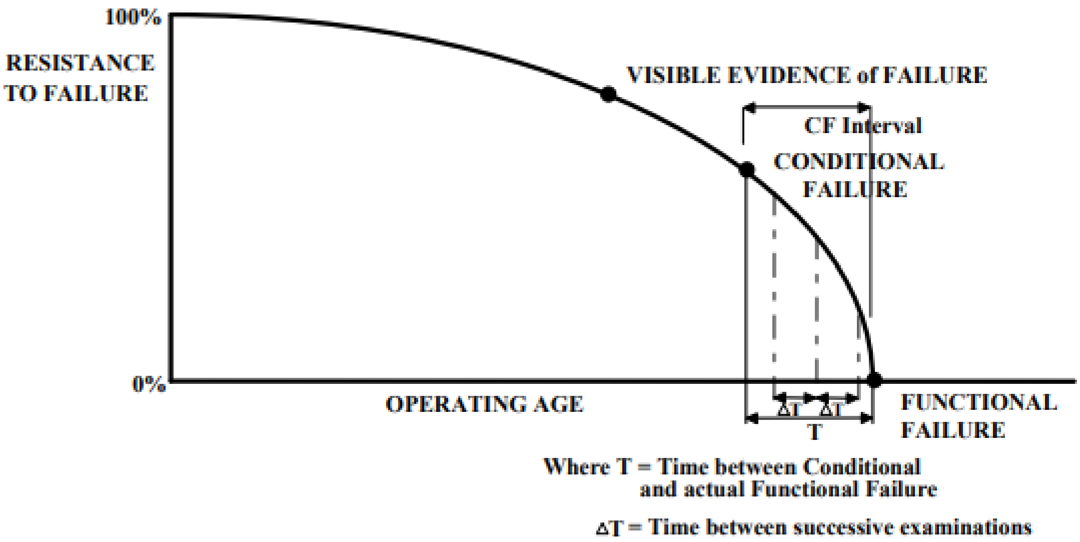


Figure 83 - PF Interval with multiple inspection points

Important to recognize is the case of a wood pole, when initially installed is well beyond its minimal capability, and the pole is meant to decay into a tubular shape, and so the centre wood is expendable over the usable life of the pole, and the key detection point for the PF interval is not to detect that rot has occurred in the centre of the pole, but rather the pole has passed a decayed state which most RCM studies would associate as a potential failure, and is proceeding towards a functional failure (minimal capability no longer exists).

For this reason, multiple inspections performed between (P) and (F) are often prescribed to further reduce the probability that a functional failure will remain undetected after having been subject to “n” repetitive inspections whose result did not detect the visible evidence of failure. The practicable challenge is associated with very short PF transitions which may be too fast for even 1 inspection to be accomplished.

As per Mil-2173 (AS) standard, the probability of inspection failure Pf can be calculated as;

$$Pf = (1 - \theta)^\wedge n$$

Where:

Pf is the resulting probability of not detecting visible evidence of failure, which is this case is the minimal residual capability as calculated by the pole calculator.

Θ is the probability of detecting a visible failure on a single inspection but would be different for each type of inspection in use. Θ of the pole calculator algorithm is a topic currently being developed by changes to the resulting thresholds for unserviceable.

n is the number of repetitive inspections performed during the PF interval which may be approximated by T, the time between repeated inspections.

1- Θ is the probability of inspection failure. It is reasonable to suggest that an inspection failure will lead to a miscoding of the SAP database and the assumption the pole is serviceable. In time this can lead to the occurrence of a functional failure of the pole (< 40 mm sound wood) and if not inspected further can also lead to the total failure of a pole or a pole fall.

Evidence of a failed inspection process can be deduced from the following sequences.

1. An actual pole failure or pole fall.
2. An inspection that results in an emergency condemnation and replacement of the pole within 24 hours. (P1)

Therefore, in some analysis P1 have been included as near miss events with actual pole failures. Care must be taken to consider that these numbers are influenced by the detection probability and the probability that the resistance to failure is visible. The probability that the resistance to failure is visible can be estimated by tabulating the number of visible and missed evidence of failure events and dividing by the number of times we looked each year.

The CP/PAL full inspection involves many measurements and the assessment of the condition of a wood pole is also on more detailed inspections undertaken using the pole calculator, making a high-level estimate of Θ difficult. The calculator was developed to overcome the issue of assessing the combination of external and internal degradation, particularly the inconsistencies in the criteria for handling degradation of full-length pressure treated poles. The pole calculator considers the outside diameter of remaining sound wood, the minimum thickness of wood remaining, pockets of rot found in the pole surface at or near the ground line, the locations of any test holes, the pole wood species, length, and rated strength.

The calculator has been developed to overcome the issue of assessing the combination of external and internal degradation, particularly the inconsistencies in the criteria for handling external degradation on full-length pressure treated poles. It has long been realized that the Victorian industry has, despite a very good record in reducing both condemning rates and pole failures, had no logical method to assist the inspector in this area.

The consideration of external decay has always been under emphasized and despite the existence of clear-cut limiting values published in the VESI manual VX9/7020/178, few poles have been condemned by the criteria unless they had cavities or penetrating pockets of rot.

The pole calculator is designed to give more logical classification of a pole's suitability for ongoing safe service. The calculator has been based on the calculated strength of each pole considering the following:

- The outside diameter of sound wood remaining: (commonly derived from a girth/diameter measurement). This is calculated by subtracting the depth of externally rotted wood from the measured diameter.
- The minimum thickness of sound wood remaining: From this, the calculator works out the diameter of hollow or degraded pipe in the centre. (Note that the average depth of sound wood is no longer used – all calculations are based on the most pessimistic figure).
- Any pockets of rot in the pole surface in the area where diameter or girth measurement was taken: The aggregated width of such pockets is subtracted by the calculator from the original girth measurement.
- The locations of any test holes in the pole are recorded and the calculator then subtracts the strength loss of each hole from its final strength prediction.
- The pole length, wood species and rated strength are entered the calculator.
- The calculator considers the amount of pole buried in the ground.
- The historical minimum values of sound wood entered the calculator are compared with the historical minimum figures from VESI Manual VX9/7020/177 and if the pole would have been downgraded by those figures, it will still be downgraded to the same classification.

The calculator then considers the inherent strength of the wood species as well as the dimensions of remaining sound wood to work out the remaining strength, which it compares with the rated strength and prints out a decision:

- Serviceable, Limited Life (labelled on the pole as Added Controls - Serviceable),
- Unserviceable (P2) or Urgent (P1).

The classifications are based on the same safety factors used in the old chart of minimum pole girths in VESI manual VX9/7020/178.

The pole calculator then renders a decision and from these decisions we can merge the RCM and PF curve concepts of a potential failure (P or C), a functional failure (F), and end in a total failure (RTF).

The pole calculator decisions are:

- Serviceable: Potential Failure has not occurred, resistance to failure is acceptable
- Limited Life: A potential failure has occurred, and visible evidence of a future failure has been detected. (ACS)

- Unserviceable (P2) priority: A potential failure has progressed towards a functional failure and replacement is required.
- Unserviceable (P1) priority: A functional failure has already occurred, and the pole requires URGENT replacement.

The failure of a pole is thence a pole that progressed from a functional failure, through a functional failure undetected by the inspection process, and completed a total failure event.

Therefore, the following observations can be drawn:

- Poles that are rated as Serviceable have not entered the PF interval.
- Poles that are rated as Limited Life have entered the PF Interval and are beyond P.
- Poles that are rated as P2 are also in the PF interval beyond P and closer to F
- Poles that are rated as P1 are beyond the PF interval past F.
- Poles that fall or fail are beyond the PF interval and well past F.

From these observations and relationships, the probability of being within the PF interval can be estimated by use of basic probability methods.

$$INPF = \frac{LL}{S+LL+Fail} = 0.04735$$

At any instant of time the estimate of poles within the PF interval is 4.7% of the pole population.

The probability of a pole not yet having a visible failure as rendered by the pole calculator is;

$$B4PF = \frac{S}{S+LL+Fail} = 0.94977$$

At any instant of time the estimate of poles that are in the serviceable state is 95% of the pole population.

The probability of experiencing a total pole failure given a 2019 population of 404553 poles is;

$$PFail = \frac{Fail}{S+LL+Fail} = 0.00009145 =\sim 0.0001$$

The conditional probability of failure given the condition that the pole is within the PF interval can be calculated from observed data assuming a failed pole can only occur if it has passed through the PF interval.

The conditional failure calculation is;

> $P(Fail|PF) = (PFail$ and INPF)/P(Fail) = 0.0019 or .19% of the poles in the PF interval progress to pole failure or approximately 36 poles fail per year on average. The 10-year sample is 378 pole failures in 10 years = 37.8 pole failures per year (average).

From the conditional failure probability one can calculate the limits of inspection effectiveness on the probability of detection from the equation found in MIL-2173 (AS);

$$\theta = 1 - \sqrt[n]{PFail|PF}$$

From the observed snap shot of data, we can then establish the limits on the probability of detection of the inspection process operated under BAU.

> For n=2 inspections the probability of detection is at most 0.96
>
> For n=3 inspections the probability of detection is at most 0.86
>
> For n=4 inspections the probability of detection is at most 0.79 which is approximately equal to the 2005 RCM study assumed value for the inspection task effectiveness of 0.795.

Given the current probability of failure the number of inspections required to reach a desired probability of failure is then;

$$n = Log(PFail|PF)/(\text{Log}(1-\theta))$$

In developing the probability of failure of a pole due to repeat missed inspection we must consider a basic probability consideration whereby repeated sequential tasks all fail to detect a problem in a wooden pole, resulting in that pole failing unexpectedly. This is the case for 75% of the actual pole failures (on average) each year. (Reference the η6 transition in the critical path discussion).

When the probability of detection of a problem in a pole is less than perfection, there exists a probability that during any single inspection, the inspection will be actioned, and while the pole is indeed deficient, the problem will go undetected. If the pole is subject to a series of inspections, just like the flip of a coin, there is a possibility on each inspection, the defect will go undetected.

If the pole is subject to multiple inspections, the probability of a defect remaining undetected is low, but not zero, and most importantly, it is calculable.

In this case we are calculating the probability that "n" inspections will miss a defect, given a known probability of the inspection's capability to detect the flaw.

We also need to reconsider what is a Probability of an acceptable level of risk, (Pacc). This notion is not aligned to the notion of practicable.

If Θ can be estimated at a high level, the number of inspections required to meet a n arbitrary level of risk can be calculated, but needs to be tempered with the KM analysis for fast moving PF intervals, which work to eliminate multiple inspections as a practicable way to manage.

From the 2005 RCM Review - Equation for Number of Inspections Required:

$$n = log(R\ x\ MTBF)/(\log(1-\theta))$$

$$n = log(R\ x\ 1/\lambda)/(\log(1-\theta))$$

The rational for an adjustment in the equation is supported when one considers the conditional probability of a pole failure. If one assumes that for a pole to fail, it first must be in the set of unserviceable or Limited Life, and then the inspection must miss detecting a potential or functional failure.

MIL 2173 (AS):

$$n = Log(Pacc)/(\log(1-\theta))$$

Where:

Pacc = Acceptable Failure Probability or the Acceptable Pole Failure Rate Risk

R = Risk as defined in the 2005 RCM study is the acceptable risk to the business or acceptable probability of a pole failure and is equivalent to Pacc as used in the MIL 2173 (AS) standard.

λ = Constant Failure Rate of an Exponential Distribution = 1/MTBF but includes LL poles that have not functionally failed.

MTBFF = the Mean Time Between Functional Failure

MTBF was defined in the 2005 document as the ratio of cumulative time (p.a.) to the total number of US & LS poles (p.a.) noting the cumulative time for the 2005 study was 7 years. This calculation can be traced within 2005 study excel documents. This is found to be the failure rate λ = 1/MTBF, which in 2005 was assumed to be time invariant and constant.

As used in 2005 – MTBF = 7 Years * 84390 Poles in population = 590730 Years – Poles in Population/ 1407 Functional Failures (count of LL and U) = 419.85 (Years – Poles in Population)/ (Pole Retirements for LL or U)[62]

In this calculation for the MTBF, the 2005 study is including the running time on all functionally failed poles (U) and including the statistically censored poles in service that have not failed that are still (LL) running. This accumulated time is divided by the total number of failures (Count of U within study period) and is effectively a maximum likelihood estimate of the MTBFF.

[62] 2005 RCM Audit Poles Worksheet for Decisions – PCA Wood CL 1 Untreated Count of poles = 84390

$$MTBFF = (\sum_{i=1}^{n} TTFi)/r$$

Where

r = Count of (U) Functionally Failed Poles that have been replaced during the study period.

TTFFi = The time in service until a functional failure from (LL) to (U).

MTBFF = Mean Time Between Functional Failure

This estimator of the MTBF does has theoretical backing if the distribution is exponential.[63]

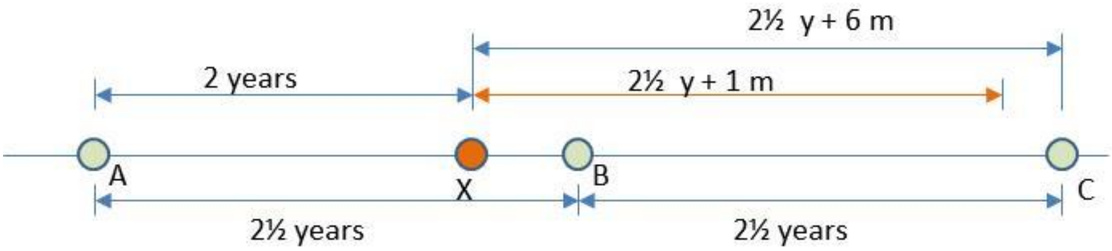
Unfortunately, there are two issues with the MTBF calculation as utilized on 2005.

The first issue is when a pole transitions into unserviceable state (U), it is replaced by a new pole whose state is Serviceable (S). The serviceable state (S) is not considered to be in the population of poles in the states of either (LL) or (U), and so when a pole is replaced, the remaining time the pole accumulates within the study period in state (S) should not be included in the summated time used to calculate the MTBFF. The net effect of this small error is the MTBF used in 2005 was over estimated.

The second issue is more likely problematic in that wooden power poles do not generally follow an exponential distribution for functional failures. As a result, modelling life or deriving calculations for the MTBF of an exponential distribution is an incorrect application if the wooden poles do not present an exponentially decaying life performance.

The third problem dominates and is summarized by the KM discussion on PF interval variance, where the measured PF interval transitions faster than the inspection interval of 2.5 years resulting in a high number of β1 transitions from serviceable direct to unserviceable. This seems like a program reality and thus the safety margins must be designed so that β1 transitions do not become η6 transitions.

Next, we must consider the older guidance and consider if it is still applicable. When poles are inspected before their nominal cycle of 2.5 years, for example at point X of the timeline diagram below, the next inspection may fall before the due date of the Class 2 package. This is because the existing inspection cycle tolerance is only 1 month.



This was overcome by increasing the inspection cycle tolerance to 6 months which allowed for better management of the work package.

The RCM analysis on which the inspection cycles are based allowed for the minimum inspection interval for limited life poles to be up to 3 years. Refer the attached presentation below for a summary of the 1997 RCM analysis and attached document in the Appendix for the RCM review undertaken in 2005 that confirmed a period greater than 3 years was appropriate. When we consider the percentage of poles that do not fit the noted strategy (see discussion on PF interval variance and KM estimates for the β1 transition), it is clear this advice may no longer be supportable as several β1 transitions would be expected, and possibly some η6 transitions.

[63] Wayne Nelson – Applied Life Data Analysis – General Electric Co. Corporate Research and Development – Schenectady New York – Published by John Wiley and Sons, Inc. 1982 Page 365 – Maximum Likelihood Estimate of the Exponential Mean.

Inspection Interval Recommendations/NDT

The in-scope area of this portion of the RCM study is threefold:

- The study is to provide a validation of the inspection frequency which is programmed into SAP and currently in use to maintain current pole failure rates.
- This study is also to provide a recommendation for the required inspection/assessment methods (used to detect) failure modes with an aim to reduce the current pole failure rate to within CP/PAL management expectations.
- A third consideration should include analysis of the developments associated with CP/PAL investigation into pole “Non-Destructive Techniques” (NDT) for timber poles, with a notion that future inspections must become more comprehensive and capable of predicting the end of life of a wooden pole.

The needed data and assumed sources are:

- An estimate of the PF interval for a wood pole.
    - Was determined from state transition data held in SAP PM and ranges from 1 year to 16 years (generally)
    - 2005 RCM study used fixed PF interval assumptions that are likely over estimated. (10/15/20)
- A realistic value for the probability of detection by maintenance inspection of a functional failure in a wooden pole using “Business as Usual” (BAU) maintenance inspection strategies.
    - Assumed in 1997 and 2005 to be 0.79 or 79% as per the 2005 RCM study citations.
    - Does not account for the specifics of the inspection process and most likely is higher
- A realistic value for the Probability of Detection (POD) by maintenance inspection of a functional failure in a wooden pole using a new NDT method or altered strategy is likely higher (Wood Scan results)
- An estimate of the acceptable business risk of pole failures within a given year.
    - 1/1,000,000 was used in the 2005 RCM study, but this is unrealistically low.
- An estimate of the probability that a pole is within the PF interval.
    - Estimated by the conditional probability of 0.0502 or 5.02% of 405,000 (obtained from status data).

NOTE: A reduction of pole “failure rate” will be challenged and complicated by the large “Bow-Wave” of aging poles entering a critical age where the poles experience a higher pole failure probability.

SAP PM Status Definitions

A pole is in serviceable condition and is denoted by the state (S). The start of the serviceable period begins when a new sound wood pole is placed in service and ends when the pole deteriorates into the state of limited Life (LL), having experienced a (P) potential failure. Each pole is specified to have a certain amount of deterioration allowance of wood decay or damage occur, before (P) is declared. Ideally (P) will have a defined residual strength rating as calculated by the pole calculator.

The state of (LL) is past (P) the point of detection of a potential failure. (P) and is the point where deterioration has progressed past the design allowance of extra good wood allowing a potential failure (P) is declared. During the limited life remaining the pole is still above its resistance to failure level.

When a pole no longer meets its minimum specified resistance to failure or strength it is declared (U) unserviceable. When a pole is unserviceable, a (F) functional failure is declared to have occurred before (U).

A pole may have additional reinforcement added in the form of a stake if suitable wood remains in a configuration that will allow the stake to function.

Also, important to note is the number of poles that fail within a given year is an important number to track, but it is not a failure rate, rather it is a failure count for an interval of time like a year.

Each of these subjects will be treated in the following paragraphs.

In the context of reducing pole failures caused by a missed detection there are only two levers that can be actioned.

1. Increase the frequency of inspection (over inspection) to compensate for missed detection in any single inspection.
2. Increase the probability of detection of the method or technology used to make the inspection.

It is most reasonable to consider methods that work to improve the probability of detection of a critical condition in the pole that equates to its functional failure or end of service life. If the detection probability of an inspection method can be increased, the result will be an increase of undesirable conditions that will be presented for remediation, and if actioned timely this will result in less pole failures.

Where a change in the probability of detection cannot be technically or economically accomplished, and where safety consequences are present, the number of inspections required must be calculated and balanced to meet a low probability of a pole failure. This is needed in order to design a strategy that meets the acceptable level of risk endorsed by the business.

With an over inspection strategy, we seek to reduce the likelihood of a failed pole by increasing the likelihood of detection by increasing the number of times we inspect the pole when it is likely to show signs of a potential failure. The increase in number of inspections does not guarantee zero pole failures, rather it theoretically reduces the likelihood of a potential failure reaching a functional failure, then a full pole failure undetected. The probability of this event sequence is non-zero, and over inspection allows more potential and functional failures to be detected down to an acceptable probability of missing everything resulting in a pole failure.

This strategy once designed must be programmed into the SAP work management system and executed with high percentage compliance.

Continuous Improvement (CI) & Technical Analysis Methods

Performing CI using data driven informed decision making is exciting, especially when coupled with a rather clear picture of power pole performance vs. age and the risk of a pole failure posed to the public.

In this analysis, several internationally recognized data methods of analysis have been utilized. Reliability Assessment methods included Weibull Analysis, Kaplan Meier Analysis, Expectancy Analysis, State Transition Analysis, Markov Analysis, Renewal Analysis, Failure Analysis.[64] [65]

The Weibull Analysis was guided by IEC 61649 and utilized both 2 and 3 parameter Weibull equations with regressions performed by both Ordinary Least Squares Method (OLS) and Maximum Likelihood Estimation (MLE) to ensure the highest accuracy was obtained for parameter estimates. Confidence limits of parameter estimates were checked using the 95% statistical confidence limits. Correctness of regression was checked with correlation coefficient calculations, goodness of fit calculations and the Darlington Anderson indicator.

Software utilized for the analysis included but is not limited to;

- ISOGRAPH's Availability Workbench (Weibull, Process reliability and RCMCost modules)
- ISOGRAPH's Reliability Workbench (Markov and Fault Tree Analysis modules)
- MINITAB's Reliability/Survival Distribution Analysis, Non-Parametric Analysis, Probability Plots
- SAP's Business Object Reporting
- SAP's Query Writer
- Microsoft Excel
- Microsoft's Visual Basic and Visual Basic for Applications

Where large amounts of pole data existed in good form, we have used that data in the regression routines directly.

Where low amounts of data exist in a given category, we have utilized the collective experience of the SME team to offset the low statistical confidence calculated, or we have considered the topic from the viewpoint of the process with the most safety margin using guidance from IEC 60300-3-2, IEC 62308 and Applying IEC 61649.

We have added groupings to the data set based on the experience and intuition of the SME as during the RCM workshop we found those intuitions to be supported by the data analysis on several occasions.

We have determined that the risk of catastrophic failure at any age depends on the nature of the species, its preservative treatment application of lack thereof, and its current age in service coupled with the consequence of a failure at the pole's location.

[64] IEC 62308, Equipment reliability – Reliability assessment methods
[65] IEC 61649, Weibull analysis

Action Topics from RCM Workshop

The following list of actionable topics was captured during day 1 of the RCM workshop in Melbourne on August 19, 2019.

1. An amount of bad data is being entered SAP PM is a problem that requires corrective action. Specifically pole replacement data originated due to incorrect procedure, process, and sequence timing of record keeping is a forward risk.
    a. This problem has a few variations as detected by review of the resulting data.
        i. In some cases, the pole's equipment record in SAP has been re-used instead of being properly marked for deletion and a new equipment record created and installed at the pole's functional location.
            1. The re-use of the equipment record allows the species of wood simply be changed to reflect the new pole material vs. the proper process of marking the removed pole for deletion in SAP PM and creating a new pole equipment record. Additional data fields are involved.
        ii. The net result is the pole replacement database is polluted making analysis difficult.
    b. The recommended actions are:
        i. Repair the detectable equipment record re-use cases
        ii. Install procedural and/or SAP data entry controls to prevent the problem from continuing.
        iii. Consider modification of the pole calculator data set into SAP to include data integrity controls at data input.
2. SAP PM Equipment records were reportedly set to 2009 carte blanc for records that did not have a <u>disc year date</u> (construction year) during the Y2K remediation, and not restored to their correct data post Y2K.
    a. The recommended actions are;
        i. Scour SAP data with 2009 construction year and repair to correct year.
3. There were a few temporary undocumented practices in use that have caused data to be entered SAP PM in differing ways. This affects proper analysis.
    a. One way was if the pole status had been set to Limited Life, and if the next inspection found more good wood than was reported in the prior inspection, the pole was recorded as staying in LL and the good wood datum was incorrectly lowered to a pre-determined value below the default LL threshold (usually a value of 49 or 45 mm used on a 10 mm resolution system).
    b. The recommended actions are;
        i. Install and Train proper procedure for recording the true measurements in all cases.

    Re-Consider the rest of all 49- or 45-mm datum and replace if valid data can be deduced.
4. SAP PM data entry has several different types of errors, or incorrectly recorded data.
    a. An action item should be to carefully repair the existing data, wherever data can be ascertained, of where an inspection can deduce the correct pole species or possibly age.
    b. The recommended actions are;
        i. Review the compiled list of data errors tabulated during the RCM process and view as the data to be corrected so that future reviews and management visibility operates in the forward sense from controls applied to the 2019 RCM study.
        ii. In short - Counter each data error at the source with effective controls to establish a new level of data integrity of the SAP held data.

5. Hidden failures exist in wooden poles.
    a. This is because the current inspection coverage does not extend to the entire pole.
    b. This leaves areas of the pole un-inspected if the failures occur outside the inspection zones. A specific example is 500 mm below ground line which is not subject to a Dig and Drill regiment.
    c. The recommended actions are;
        i. The inspection requirements are quite varied and depend on many factors including the position located on the pole, either below or above ground. A map of the inspected pole areas and non-inspected pole areas should be compiled.
            1. A clear revision to the inspection policy should be commissioned to produce a crystal-clear understanding of what is inspected and what parts of the pole are not inspected.
            2. SAP catalogue codes should be modified to capture modified data transmitted from the pole calculator application that clearly delineates the pole condemnation reason, and whether the pole was condemned on strength reduction, sound wood encroachment or automatics like fungal fruiting bodies observed.
        ii. Methods like the NDE test under evaluation at the University of Technology – Sydney should be considered if a commercialized effective test system emerges from their research. While it is understood there is considerable distance between hope and practical application, CP/PAL should commission active relationships with partners who can supply or show promise to supply leading edge technology.
6. Above 2 meters the inspection method is currently a visual inspection.
    a. The item is noted as there may be opportunity to improve this area.
        i. The application of Drones seems prudent.
        ii. At minimum augmentation of the inspection manual to clearly define acceptable limits is prudent.
    b. The possible future considerations actions include;
        i. Drone inspection, photograph and desk review of drone flight results.
        ii. Changes to pole condition rating system.
7. Pole failure analysis records are not complete.
    a. The root cause is because the current process does not create a pole failure record if a pole failure investigation has not been commissioned. The lack of pole failure investigation is not commissioned when the cause is so obvious, like termite infestation, that there is no need to perform an investigation. This unfortunately affects pole failure data set analysis.
    b. The desired state is a future database where (1 actual pole failure = 1 failure record). As an example of the current state - of 485 pole failures noted over a period, only about 100 were subject to a formal pole failure investigation and thus had an SAP cause associated with a failure report (94 had a location of where the failure occurred).
    c. The recommended actions are;
        i. Complete the loop and report in the failed pole database 100% of failed poles.
        ii. Complete a formal investigation on poles whose cause is not certain.
        iii. Record an accurate cause on 100% of pole failures.
        iv. Consider an approach towards a common methodology like the Apollo methodology for RCA Train all relevant team members and install a system that tracks the open action items and solution effectiveness.

8. The introduction and integration of Woodscan is in its early phases of value delivery.
    a. This is a change of practice that need to be monitored for adverse reaction - 178 Dig and Drill investigations were completed on poles within the last 12 months for poles that had termites (serviceable with previous or active termites now get DD).
    b. The activity of WS inspector adds two holes DD. The reduction in pole strength would only surface the full data set.
    c. (DD inspector condemns pole for DD straight to replace. If pole is US then goes to WS inspector as previous termites,).
    d. The recommended action is;
        i. Incorporate the Wood Scan results into the SAP PM Measurement points taken on each WS pole.
        ii. Incorporate pole calculator decisions as bona fide decisions made into SAP PM database and establish the capability to determine from future measurements the reason the pole calculator algorithm condemned a pole for replacement in SAP PM data.
        iii. Code the resultant decision in your application and interface to SAP PM and 100% establish the pole transition in SAP.
9. The Dig and Drill process has been active for just 12 months.
    a. This is a changed procedure that is likely catching poles that previously had the potential to fail that would have failed undetected with prior inspection policies. Time will tell if this is true. Asset Failure investigation is a critical function in this regard, and it has an active place in an RCM asset management program.
    b. The recommended action is;
        i. Compile statistics and use a modified failure investigation on DD poles as an active RCM age exploration investigation.
        ii. Of importance is to determine both the accuracy of the DD procedure, its practical results variance, and the impact or offset of pole failures saved by the DD program.
        iii. In order to do this, the life statistics must be complimented by a physics of failure experiment whereby some of the condemned poles are sampled to provide insight into their capability variance at the point of condemnation.
10. The effectiveness of the pole saver rod is questioned and has noted problems with application.
    a. While this is the expressed belief of subject matter experts during the RCM workshops, no factual evidence was tabled to support this. That should not be left open.
    b. If pole saver rod is not in contact with wood, or if it is inserted into the cavity and falls to the rotted bottom, it is believed to be ineffective because it is not in contact with sound wood.
    c. The extent of good chemical coverage is unknown within the sound wood and needs to be scientifically quantified from current pole retirement assets.
    d. The recommendation is;
        i. Compile evidence for the effective treatment of wood fibre with boron and fluoride analysis from removed poles by;
            1. Section cutting Pole Saver regions.
            2. Chemically testing and quantifying the amount of wood infused with chemicals and the amount of virgin wood that is untreated.
            3. Compile experimental evidence for the variance in treatment.

4. Determine the expected life of a pole saver rod using data and wood sections.

11. Pole saver rod application holes have been found drilled through centre rather than off centre as specified in the Inspection Policy.
    a. The recommendation is:
        i. CP/PAL needs to review the policy specification with an eye towards variation reduction in the drilling application of pole saver rods found in existing poles (Training and procedure review).
        ii. CP/PAL should review or audit poles at removal to determine the effectiveness of inspection and pole saver.

12. The additional safety factor concern is that pole with a hole for the pole saver rod hole, now will become LL sooner, because of ingress pathway allowing accelerated rot or termite access.
    a. At minimum, the automatic overwrite of "No Pole Saver Found" as reported today should be modified to explicitly detail when upon inspection, the pole saver rod is either;
        i. Depleted and has been fully absorbed or;
        ii. No pole saver was found – or evidence that prior inspections had installed pole saver recorded.
13. Also, important to note is that the pole saver is treating the inspection zone only, and not outside the inspection zone.
    a. Nearly every decayed pole inspected, has been treated by pole saver so there is anecdotal evidence that the product is less than effective.
    b. Creosote treated provided nice annulus of creosote.
    c. CCA treated poles have perhaps a more durable heart – but differing woods and treatments exist for the poles that have pole saver applied.
    d. Therefore, a sample of poles decommissioned should be subject to a physics of failure regiment with an aim to quantify the effectiveness of the pole saver chemicals, remaining useful life and residual timber strength.
14. Old poles purchased under a different specification (older) still exist within the network.
    a. These are not readily identifiable.
    b. The impact is some poles may be operating at a load that is not within the current safety margin system.
        i. The recommendation is to effectively review the current load of each pole, and contrast that to its residual strength and complete an evaluation within the next inspection cycle.
            1. This will require a modification and merger of pole calculator knowledge with installed base knowledge.
        ii. Wholesale replacement does not seem to be an option to remediate the out of spec poles. it is not possible to immediately remove all the non-standard poles that were within spec to an old spec.
    c. The old specification was from a different strategy process which was an engineering process.
        i. Today we know more about these assets and can make sure our design rules can produce a certain amount of reliability with low residual risk, and if the new standard is applied, the current strength and condition should drive the inspection criteria.

d. Private poles require more prescriptive inspections.

1. If pole is at original diameter, but under the current specification minimum criteria, it will stay in service until pole diameter begins to decrease further.

a. This seems to be an undeclared field procedure.

ii. The recommendation is:

1. Evaluate the undeclared field procedure.

2. If it is fit for purpose, formalize it, train the asset Inspectors and deploy it formally.

e. Used to have poles at a 5 kN rating. Today, do not have a 5 kN rating and CP/PAL is not replacing all prior A poles will eventually be replaced by an 8kN pole, but will retrospectively replace the 5kN pole because it is 3 kN rated less.

i. The recommendation is:

1. Evaluate the undeclared field procedure. If it is fit for purpose, formalize this knowledge, train the asset Inspectors and deploy it formally.

15. Training is a specific subject of concern. A broad revision and thought are needed and possibly also includes revision to the Inspection Manual should be considered for the purpose of training up and adjusting the policy to counter item 11 problems with people and procedures identified during the RCM workshop.

a. The subject of training needs its own separate investigation and recommendations.

b. The lack of an RTO regionally available and the RPL process in use does little to train the existing inspectors on the new topics considered.

16. The knowledge and education of the RCM PF interval needs to be trained and conveyed to all parts of the relevant organization:

a. The RCM process informed management that “P” starts earlier than LL (ACS). How we determine P and at what level of degrading does P really occur at is a critical measurement made by the field inspectors who must be totally in sync with the engineered approach to performance.

i. The recommendation is to establish a finite scientifically measurable acceptable limit for P for;

1. Minimum Sound wood thickness that has a derived safety factor from current data measurements.

2. The pole calculator should render a calculation or the remaining strength and bending characteristics with appropriate safety factor to prevent unassisted pole failures.

3. As the pole calculator combines 3 or 4 approaches that are competing risks for failure, there is a need to articulate P for each failure mode. (See RCM worksheets)

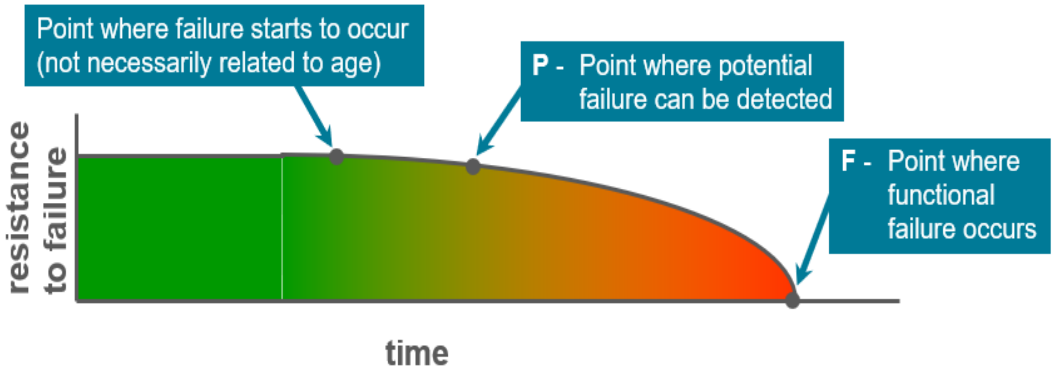


Figure 84 - PF Curve

RCM Workshop - Day Two Opportunities

1. Data Issues were unveiled with data sets that exist in the integration between SAP PM(Slave) and GIS (Master.
    a. The problem that must be examined and possibly corrected occurs when the Pole Calculator generates new set of source data, this is uploaded to SAP PM, but for some data SAP PM is not the master.
    b. The inspector's complaint is some data gets overwritten by GIS transactions negating the captured field data and causing accuracy problems.
    c. The opportunity and action item are to create a data interface document between Pole Calculator, SAP PM and the GIS system.
2. Specifically, we see problems in the following areas:
    a. There is no current data map to show what data in SAP PM goes into GIS
    b. The is no current data map to show what GIS data transacts back and updates SAP PM data.
    c. The is no data map from the pole calculator into SAP that then updates GIS if a master datum is changed.
3. SAP data Hole Score Problem is acknowledged by the team.
    a. Problems described included SAP displaying incorrect data after an update from field data sourced from the pole calculator. Inspectors have become confused and at times have zeroed out the number of holes found and only indicated new holes drilled during the current inspection as the reported hole score.
    b. Hole Reporting Procedure clarity is required.
        i. The current method to report hole scores is undocumented.
    c. Training of the Inspection team is required to sustain a procedure-based system.
    d. Periodic re-certification of the training will work to enhance retainment of knowledge.
    e. This is reportedly impaired because the inspector cannot see old holes that were drilled and then sealed with older wooden plugs.
    f. From a pole strength perspective, an inspection method is required to ensure the total number of holes in a pole is accurately observed, and then recorded into the pole calculator and then transmitted to SAP PM, and not over-written by the GIS system.
4. From a management perspective – it appears that the Asset Management function is not tied to the regulator price reset work.

   a. There are considerable economies and confidence levels achievable if this approach is considered.

5. The previous RCM in 2005 accepted the manufacturers claim that the pole chemical treatment was sustainable for 5 years after application. It is the opinion of several Subject matter experts who participated in the RCM work shop that the pole saver chemical, or its application produces less than ideal results. The workshop heard that;
   a. Pole saver only works if it is in direct contact with the sound wood.
   b. If the pole saver rod drops into the centre of a rot cavity it is thought to be completely ineffective.
      i. When the pole saver rod drops into the centre – the pole is unprotected and should be changed to LL status.
   c. The effectiveness of the pole saver chemical remains questionable and has not been scientifically tested.
   d. Expert opinion shares that the Pole saver chemical does not suppress or arrest soft rot micro fungi and recommends a different chemical should be considered for CCA treated poles whose treatment barrier is effective for White rot and brown rot but allows soft rot to pass through.
6. Stubbed poles were reported as needing to be treated as a different classification of physical characteristics.
7. Suggestion to change inspection regiment of a newly installed pole to THOR hammer test only, until such time that SAP PM data suggests the probability of S to LL transition begins. This is an RBI approach, during initial service years the inspection is THOR only, until THOR finds something OR until the pole passes the age where its species is known to begin the statistical transition to LL.
8. 2019 – 2005 is a 14-year gap between RCM refresh studies. This is typically 5 years in industry. A schedule for an RCM should be committed to occur in the 2014 timeframe.
9. There was no evidence tendered that CP/PAL or its contractor ELectix had performed a critical quality of service audit of the service delivery of the asset inspection process.
   a. The recommendation is to periodically perform an internal audit on your inspection process. Do you do what you say you do, and do you do what your procedures say you should be doing? We suggest you should look towards ISO 901 program audit structures.
10. There is no collaborative evidence to suggest the measurement data reported into SAP PM is repeatable or reliable. Therefore, the recommendation is there is a need to perform R&R test on the critical inspection measurements as a technical measurement process capability study. We would suggest you develop the mantra and ask - Does every inspector produce the same results – when given the same pole to inspect?
11. The 2005 RCM study recommended a preventative treatment for termites in termite known areas which has not been placed into service in SAP PM.
    a. The RCM produces a blend of maintenance that is prudent and thought to be the most effective combination of tasks to keep a failure mode suppressed.
    b. By executing only, the inspection portion, and with an inspection task whose task effectiveness is thought to be less than perfect, without the designated PM elements of the combined strategy this might would result in higher failure rates being observed due to unmitigated failure modes.
12. Several Data Integrity Issues have surfaced during the 2019 RCM review.
    a. We find that SAP PM data has several sources of data error that need to be controlled by;
    b. Procedural controls – Governance and oversight of data integrity

i. Specific controls regulating pole replacement data migration, old equipment number set to DLFL, New Equipment record created, time frames for all data entry and population of new asset record.

ii. Audit reporting constructed and reviewed monthly to police known data error sources not controllable by other means.

c. Training of data originator when data is to be passed through a Wide-open SAP PM system without error checking (user exits) installed.

d. Data Entry Error Checking in SAP PM by adding error checks to existing “User Exit” functionality to not allow known sources of error to be added to the SAP PM data set.

RCM Workshop - Day Three – Opportunities

Soft Rot

Soft rot is an emergent failure mode for pressure treated wood.

It is caused by a micro fungus that eats round holes into the wood cell body. The result is serious weakening of the pole strength, with extreme cases of failure or shear of pole know to occur.

1. The inspectors report they have very limited experience and no means to detect soft rot within the current wood pole population.
2. The inspectors have not been trained to detect soft rot.
3. Currently the detection method requires either a microscope procedure OR DNA testing of the wood to confirm the micro fungi are present.
4. Currently the inspectors at times under report the amount of sound wood if soft rot is suspected.
5. Soft rot found on the outer diameter is an alarm bell red flag!
6. External Diameter loss measurement is the only technically feasible measurement that can be made today.
7. Other more accurate measurements are required.

The recommendation is to holistically counter the emergent soft rot issue by changing the inspection process for o=poles susceptible to soft rot and possibly tempering the requirements based upon the significance of the consequence of failure.

Data Integrity and Data as an Asset

The data in SAP PM has the previously defined data integrity issues that can be described by several pages of know issues that were recorded during the RCM process.

In order to complete the picture of what really is happening, transactional data coupled with several data repairs were actioned and the rule applied were recorded. An additional Appendix has been created for the known data issues that would seem to be needed to be overcome poor data and raise management visibility to the level expected of a modern organization

Each issue should be treated with a mindset of elimination of this type of data error.

Variation Control

There may be too many sources of variation in the current processes.

Training of Inspectors

The training of the inspectors is a large part of the success of the inspection-based strategy.

Current qualification by RPL only. Currently cannot get cert II training. Starting to RPL new asset inspectors and using an RTO from South Australia because they are the nearest RTO.

Going through the RTO headwinds are a significant issue to fielding qualified inspectors.

The quality of inspection by RPL trained inspectors is a source of variation.

Appendix A – Assumptions

The following assumptions guide the analysis and presentation of results.

- 404554 power poles are in service. This population set is defined in the New Details of Pole in Service Life .xlsx file transmitted by Amy Boyd derived from SAP PM equipment analysis.
  - Species corrections to the SAP data are;
    - GG – GREY GUM and durability P_WOOD_CL1 are to be referenced as G1-GREY GUM.
    - GG-MOUNTAIN GREY GUM and durability P_WOOD_CL3 are to be referenced as G3-MOUNTAIN GREY GUM.
    - GG- GREY GUM and durability P_WOOD_CL2 are to be referenced as G1-GREY GUM.
    - GG- GREY MOUNTAIN GUM and durability P_WOOD_CL2 are to be referenced as G1-GREY GUM.
    - ZW-WOOD DISC UNKNOWN is to be combined with ZZ_WOOD UNKNOWN poles.
    - WS-WHITE STRINGB species are to be combined with WSB-WHITE STREINGB poles in the data set and referenced as WSB_WHITE STRINGB poles.
    - YS-YELLOW STRINGB species are to be combined with YSB-YELLOW STRINGB and referenced as YSB_YELLOW STRINGB poles.
    - All poles with a blank species are to be converted and referenced as ZZ-WOOD UNKNOWN poles.
    - STEEL and CONCRETE poles within the wood pole data set are to be ignored.
  - The AGE of the pole is as specified in the noted excel file.
- The model will be developed to predict the first replacement and will ignore replacements of replacements in each of the next 20 years.
  - SALT treated poles may become the exception to this assumption because they exhibit infant mortality the Blackbutt species (failures within the first 20 years).
- Models will be prepared based upon the species/treatment/location of failure as this allows clear vision into the characteristics of each combination.
  - Allocation of poles in service for each species and treatment type of the in-service poles will be performed based upon a mixed sub population of failures by failure location, treating each failure location as a distinct sub population.
  - For in-service poles that do not have a corresponding failure profile taken from data (2009 to 2019), the failure parameters will be subject to facilitation. Examples are treatment types (BLANK and WOOD OTHER)

Appendix B – Inspection Zones

The following graphic is indicative of the current inspection policy.

Above 2 meters above nominal ground line. Designated in data as "-2" receives Visual Inspection only.

Above Ground to 2 meters above nominal ground line. Designated in data as "-2" receives Visual Inspection, Thor's Hammer and Woodscan.

Under Ground – Designated as UG in data files. Dig at inspection is down 300 mm. Beyond 300 mm inspection is not possible.

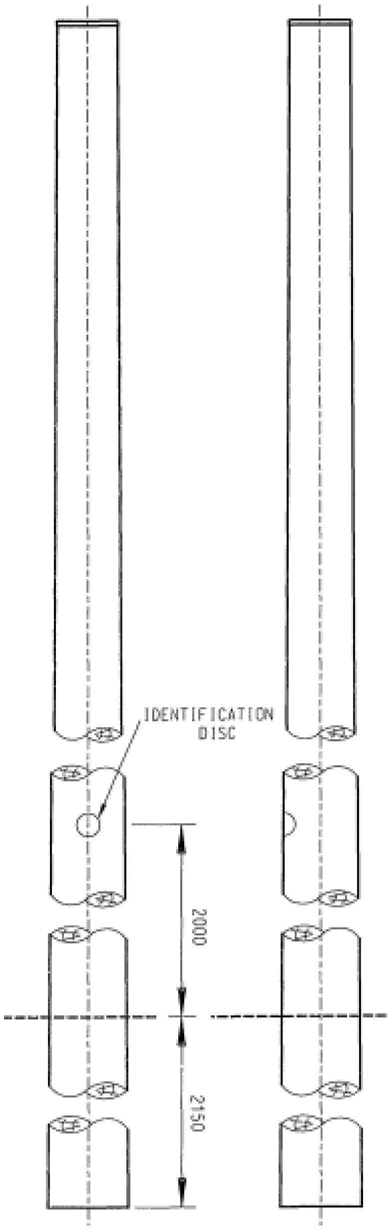


Figure 85 - Pole Inspection Process map

Appendix C – Natural Durability – Probable Life Expectancy

TABLE 1

NATURAL DURABILITY—PROBABLE LIFE EXPECTANCY*

Class	Probable in-ground life expectancy (years)	Probable above-ground life expectancy (years)
1	Greater than 25	Greater than 40
2	15 to 25	15 to 40
3	5 to 15	7 to 15
4	0 to 5	0 to 7

* The ratings in this Table are based on expert opinions and the performance of the following test specimens:

(a) In-ground: 50 × 50 mm test specimens at four sites around Australia.

(b) Above-ground: 35 × 35 mm test specimens at eleven sites around Australia.

Timber Species		Treatment Type					Durability Class	Strength Group
		Wood Untreated Round	Wood Untreated Dressed	Wood Creosote Impregnated	Wood Salt Impregnated (Green) CCA	Unknown		
BB	Black Butt	✓		✓	✓		2	2
BI	Broad leaf red ironbark				✓		1	1
BS	Brown Stringybark			✓			3	3
BG	Southern Blue Gum				✓		3	3
BW	Red Bloodwood	✓	✓	✓	✓		1	3
CB	Coastal Grey Box				✓		1	1
CG	Mountain Grey Gum			✓	✓		3	3
GB	Grey Box	✓	✓	✓	✓		1	2
GG	Grey Gum	✓	✓	✓	✓		1	1
GG	Mountain Grey Gum [1]			✓	✓		3	3
GI	Grey Ironbark	✓	✓	✓	✓		1	1
IB	Ironbark	✓	✓	✓			1	2
MA	Mountain Ash			✓			4	4
MM	Messmate Stringybark			✓	✓		3	3
MS	Messmate Stringybark			✓	✓		3	3
MS	Messmate [2]				✓		3	3
MT	Mountain Grey Gum			✓	✓		3	3
NA	Blackbutt, New England				✓		2	3
NI	Narrow leaf red ironbark				✓		1	2
P	Pinus Radiata			✓	✓		4	6
PR	Pinus Radiata [3]			✓	✓		4	6
QB	White-topped box		✓				2	2
RI	Red Ironbark	✓	✓	✓	✓		1	2

Timber Species		Treatment Type					Durability Class	Strength Group
		Wood Untreated Round	Wood Untreated Dressed	Wood Creosote Impregnated	Wood Salt Impregnated (Green) CCA	Unknown		
RM	Red Mahogany	✓	✓	✓	✓		2	3
RS	Red Stringybark [4]			✓			3	3
RW	Red Bloodwood	✓	✓	✓	✓		1	3
SG	Spotted Gum	✓		✓	✓		2	2
SL	Blue-Leaved Stringybark				✓		3	3
SS	Silvertop Stringybark [5]			✓			3	3
ST	Silvertop Ash			✓			3	3
SY	Sydney Blue Gum [6]		✓				3	3
TP	Turpentine		✓				1	3
TW	Tallowwood	✓	✓	✓	✓		1	2
WM	White Mahogany	✓	✓	✓	✓		1	2
WS	White Stringybark	✓	✓	✓			2	3
WSB	White Stringybark	✓	✓	✓			2	3
WT	White-topped box		✓				2	2
YS	Yellow Stringybark	✓	✓	✓			2	3
YSB	Yellow Stringybark	✓	✓	✓			2	3
ZZ	Unknown Species [7]					✓		

CP/PAL Timber Type Designations – Influenced by AS-5604 – 2005 Timber—Natural durability ratings with CP/PAL indexed by treatment types in Service

Appendix D – Terms, definitions and abbreviations

For the purposes of this document, the terms and definitions of IEC 60050-191 apply, together with the following and are taken from the Australian Standard AS IEC 60300.3.11—2011 or the international equivalent IEC 60300.3.11, Ed.2.0 (2009)

RCM Key Definitions

age exploration

systematic evaluation of an item based on analysis of collected information from in-service experience to determine the optimum maintenance task interval

NOTE The evaluation assesses the item's resistance to a deterioration process with respect to increasing age or usage.

criticality

severity of effect of a deviation from the specified function of an item, with respect to specified evaluation criteria

NOTE 1 The extent of effects considered may be limited to the item itself, to the system of which it is a part, or range beyond the system boundary.

NOTE 2 The deviation may be a fault, a failure, a degradation, an excess temperature, an excess pressure, etc.

NOTE 3 In some applications, the evaluation of criticality may include other factors such as the probability of occurrence of the deviation, or the probability of detection.

damage-tolerant

capable of sustaining damage and continuing to function as required, possibly at reduced loading or capacity

failure (of an item)

loss of ability to perform as required

failure effect

consequence of a failure mode on the operation, function or status of the item

failure management policy

maintenance activities, operational changes, design modifications or other actions in order to mitigate the consequences of failure

function

intended purpose of an item as described by a required standard of performance

failure mode

way failure occurs

NOTE A failure mode may be defined by the function lost or the state transition that occurred.

failure-finding task

scheduled inspection or specific test used to determine whether a specific hidden failure has occurred

functional failure

reduction in function performance below desired level

hidden failure mode

failure mode whose effects do not become apparent to the operator under normal circumstances

indenture level
level of subdivision of an item from the point of view of a maintenance action

NOTE 1 Examples of indenture levels could be a subsystem, a circuit board, a component.

NOTE 2 The indenture level depends on the complexity of the item's construction, the accessibility to sub items, skill level of maintenance personnel, test equipment facilities, safety considerations, etc.

inspection
identification and evaluation of the actual condition against a specification

maintenance action
maintenance task

sequence of elementary maintenance activities carried out for a given purpose

NOTE Examples include diagnosis, localization, function check-out, or combinations thereof.

item
part, component, device, subsystem, functional unit, equipment or system that can be individually considered

NOTE 1 An item may consist of hardware, software or both, and may also, cases, include people.

Elements of a system may be natural or man-made material objects, as well as modes of thinking and the results thereof (e.g. forms of organization, mathematical methods and programming languages).

NOTE 2 In French the term "entité" is preferred to the term "dispositif" due to its more general meaning. The term "dispositif' is also the common equivalent for the English term "device".

NOTE 3 In French the term "individu" is used mainly in statistics.

NOTE 4 A group of items, e.g. a population of items or a sample, may itself be considered as an item.

NOTE 5 A software item may be a source code, an object code, a job control code, control data, or a collection of these.

maintenance concept
interrelationship between the maintenance echelons, the indenture levels and the levels of maintenance to be applied for the maintenance of an item

maintenance echelon
position in an organization where specified levels of maintenance are to be carried out on an item

NOTE 1 Examples of maintenance echelons are: field, repair shop, and manufacturer.

NOTE 2 The maintenance echelon is characterized by the level of skill of the personnel, the facilities available, the location, etc.

maintenance policy
general approach to the provision of maintenance and maintenance support based on the objectives and policies of owners, users and customers

maintenance programme
list of all the maintenance tasks developed for a system for a given operating context and maintenance concept

operating context
circumstances in which an item is expected to operate

potential failure
identifiable condition that indicates that a functional failure is either about to occur or is in the

process of occurring

potential failure – functional failure (P-F) interval

interval between the point at which a potential failure becomes detectable and the point at which it degrades into a functional failure

reliability centred maintenance

method to identify and select failure management policies to efficiently and effectively achieve the required safety, availability and economy of operation.

safe life

age before which no failures are expected to occur

system

set of interrelated or interacting elements

NOTE 1 In the context of dependability, a system will have:

a) a defined purpose expressed in terms of required functions;

b) stated conditions of operation/use;

c) defined boundaries.

NOTE 2 The structure of a system may be hierarchical.

useful life

time interval to a given instant when a limited state is reached

NOTE 1 Limited state may be a function of failure intensity, maintenance support requirement, physical condition,

age, obsolescence, etc.

NOTE 2 The time interval may start at first use, at a subsequent instant, i.e. remaining useful life.

Appendix E - Abbreviations

The following Industry accepted abbreviations are used throughout the report.

FMEA	Failure mode and effects analysis
FMECA	Failure mode, effects and criticality analysis
ILS	Integrated logistic support
HUMS	Health usage management systems
LORA	Level of repair analysis
NDI	Non-destructive inspection
RCM	Reliability Centered Maintenance

Appendix F – Wood Species Cross Reference

Original species in SAP	Consolidated species	Durability class
BB-BLACKBUTT	BB-BLACKBUTT	P_WOOD_CL2
BI-BROAD LEAF IBARK	BI-BROAD LEAF IBARK	P_WOOD_CL1
BS-STRINGB BROWN	BS-STRINGB BROWN	P_WOOD_CL3
BW-RED BLOODWOOD	RW-RED BLOODWOOD	P_WOOD_CL1
CB-COSTAL GREY BOX	CB-COSTAL GREY BOX	P_WOOD_CL1
CG-MOUNTAIN GREY GUM	G3-MOUNTAIN GREY GUM	P_WOOD_CL3
GB-GREY BOX	GB-GREY BOX	P_WOOD_CL1
GG-GREY GUM	G1-GREY GUM	P_WOOD_CL1
GG-MOUNTAIN GREY GUM	G3-MOUNTAIN GREY GUM	P_WOOD_CL3
GI-GREY IRONBARK	GI-GREY IRONBARK	P_WOOD_CL1
IB-IRONBARK	IB-IRONBARK	P_WOOD_CL1
MA-MOUNTAIN ASH	MA-MOUNTAIN ASH	P_WOOD_CL4
MESSMATE STRINGYBARK	MM-MESSMATE STRINGB	P_WOOD_CL3
MM-MESSMATE STRINGB	MM-MESSMATE STRINGB	P_WOOD_CL3
MS-MESSMATE STRINGB	MM-MESSMATE STRINGB	P_WOOD_CL3
MT-MOUNTAIN GREY GUM	G3-MOUNTAIN GREY GUM	P_WOOD_CL3
P-PINUS RADIATA	P-PINUS RADIATA	P_WOOD_CL1
PR-PINUS RADIATA	P-PINUS RADIATA	P_WOOD_CL1
QB-WHITE TOPPED BOX	QB-WHITE TOPPED BOX	P_WOOD_CL2
RI-RED IRONBARK	RI-RED IRONBARK	P_WOOD_CL1
RM-RED MAHOGANY	RM-RED MAHOGANY	P_WOOD_CL2
RS-RED STRINGB	RS-RED STRINGB	P_WOOD_CL3
RW-RED BLOODWOOD	RW-RED BLOODWOOD	P_WOOD_CL1
SG-SPOTTED GUM	SG-SPOTTED GUM	P_WOOD_CL2
SS-SILVERTOP STRINGB	SS-SILVERTOP STRINGB	P_WOOD_CL3
ST-SILVERTOP ASH	ST-SILVERTOP ASH	P_WOOD_CL3
SY-SYDNEY BLUE GUM	SY-SYDNEY BLUE GUM	P_WOOD_CL3
TW-TALLOWWOOD	TW-TALLOWWOOD	P_WOOD_CL1
WM-WHITE MAHOGANY	WM-WHITE MAHOGANY	P_WOOD_CL1
WSB-WHITE STRINGB	WSB-WHITE STRINGB	P_WOOD_CL2
WS-WHITE STRINGB	WSB-WHITE STRINGB	P_WOOD_CL2
YSB-YELLOW STRINGB	YSB-YELLOW STRINGB	P_WOOD_CL2
YS-YELLOW STRINGB	YSB-YELLOW STRINGB	P_WOOD_CL2
ZW-WOOD DISC UNKNOWN	ZZ-WOOD UNKNOWN	P_WOOD_CL3
ZZ-WOOD UNKNOWN	ZZ-WOOD UNKNOWN	P_WOOD_CL3
Unknown	ZZ-WOOD UNKNOWN	P_WOOD_CL3
G3-MOUNTAIN GREY GUM	G3-MOUNTAIN GREY GUM	P_WOOD_CL3
G1-GREY GUM	G1-GREY GUM	P_WOOD_CL1
G3-MOUNTAIN GREY GUM	G3-MOUNTAIN GREY GUM	P_WOOD_CL3

[66]

[66] File Copy of Reference - species treatment class consolidation.xlsx from Amy Boyd - Powercor Transmitted on August 28, 2019

Appendix G – Outlier Treatment – Data Consolidations

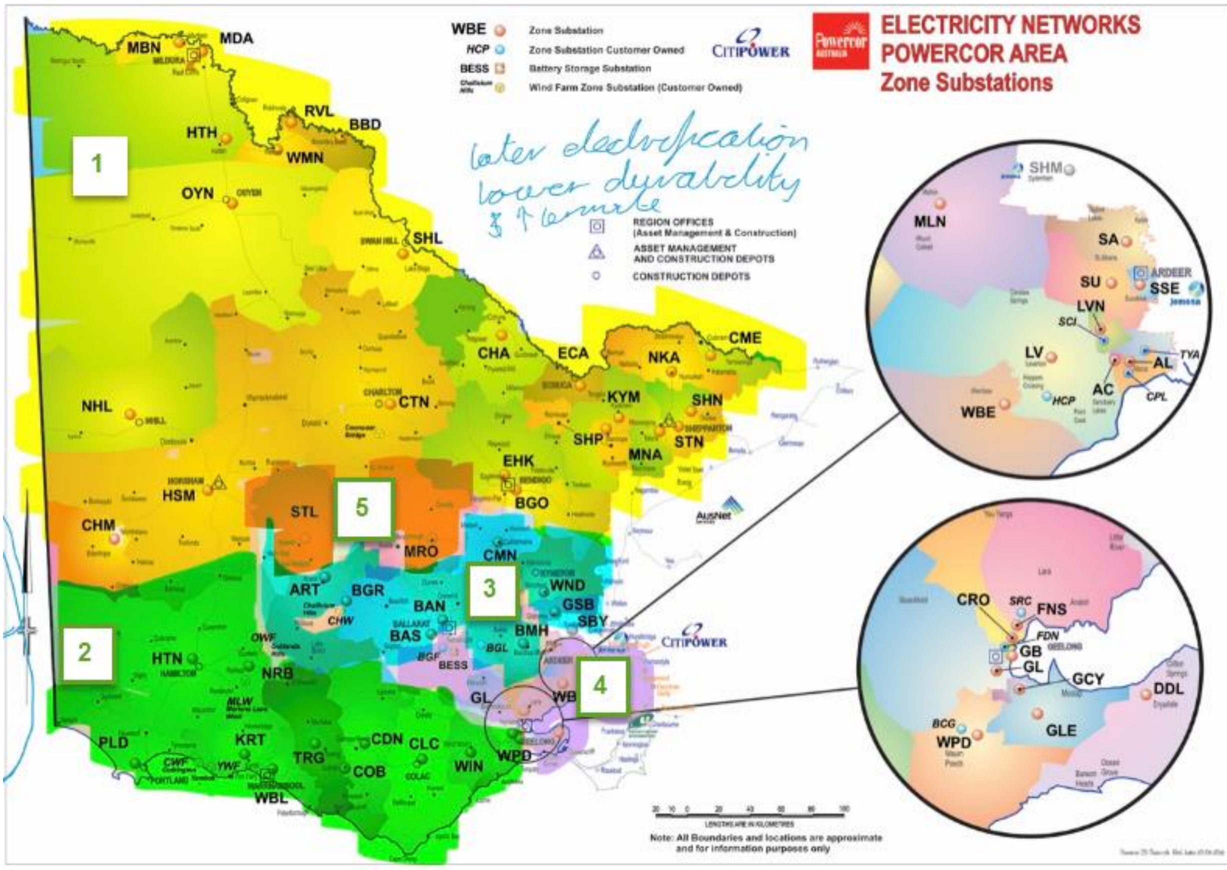
Install year range				
min	**max**	**Typical Treatment**	**Class**	**Comments for outliers**
<1947	1947	WOOD UNTREATED ROUND	P_WOOD_CL1	ch cl3 to cl1
		WOOD UNTREATED ROUND	P_WOOD_CL2	creos to untr dress
		WOOD UNTREATED DRESSED	P_WOOD_CL1	
		WOOD UNTREATED DRESSED	P_WOOD_CL2	
1947	1956	WOOD UNTREATED ROUND	P_WOOD_CL1	
		WOOD UNTREATED ROUND	P_WOOD_CL2	ch to untr round, cl2
		WOOD UNTREATED DRESSED	P_WOOD_CL1	
		WOOD UNTREATED DRESSED	P_WOOD_CL2	
1956	1971	WOOD CREOS IMPREGNATED	P_WOOD_CL3	ch to creos imp
		WOOD CREOS IMPREGNATED	P_WOOD_CL1	
		WOOD UNTREATED DRESSED	P_WOOD_CL1	P-PINUS RADIATA
		WOOD CREOS IMPREGNATED	P_WOOD_CL4	
		WOOD PENTA IMPREGNATED		
1972	1984	WOOD CREOS IMPREGNATED	P_WOOD_CL3	either untreated or creos imp
		WOOD CREOS IMPREGNATED	P_WOOD_CL1	
		WOOD UNTREATED DRESSED	P_WOOD_CL1	
		WOOD PENTA IMPREGNATED		
1984	1999	WOOD UNTREATED DRESSED	P_WOOD_CL1	
1999	2019	WOOD SALT IMP (GREEN)	P_WOOD_CL1	
		WOOD SALT IMP (GREEN)	P_WOOD_CL2	
			P_WOOD_CL3	Few
			P_WOOD_CL4	Few

The SAP equipment database was scrubbed using the rules noted above to treat the small amount of obvious data, as detected by Powercor experts during the RC process that had been miss-recorded in SAP PM over the last several years.[67] Given that SAP PM has only been in use since 1990, prior records were less accurate and the corrections above adjust the base data set to be the most accurate, using the noted changes.

[67] Data file: Copy of Reference - species treatment class consolidation.xlsx transmitted August 28, 2019 from Amy Boyd – Powercor

Appendix H – Regional Scenario Analysis – Region Grouping

The following grouping was agreed upon by the RCM SME during the RCM analysis to be the most likely to be insightful.



Electricity Network Zone Substation Grouped by RCM Analysis Group

The following feeders originating from the identified substations make up each regional group. These regional differences reflect the historical and environmental differences likely to affect statistical analysis of the performance of the wooden power pole.

North Region 1 was only electrified during the Victorian state electrification initiative, which largely used MM-MESSMATE Durability Class 3 wooden power poles treated with creosote.

Feeder	Zone Substation	Regional Mapping	Geo split
AC031	AC	4	Central
ACCPL	Subtrans	4	Central
AL002	AL	4	Central
AL006	AL	4	Central
AL007	AL	4	Central
AL011	AL	4	Central
AL012	AL	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
AL014	AL	4	Central
AP001	AP	4	Central
AP003	AP	4	Central
AP005	AP	4	Central
AP006	AP	4	Central
AP007	AP	4	Central
AP008	AP	4	Central
AP009	AP	4	Central
AP011	AP	4	Central
AP013	AP	4	Central
AP014	AP	4	Central
AP015	AP	4	Central
AP017	AP	4	Central
AP018	AP	4	Central
AP019	AP	4	Central
AP-MG	Subtrans	4	Central
AR002	AR	4	Central
AR003	AR	4	Central
AR004	AR	4	Central
AR005	AR	4	Central
AR006	AR	4	Central
AR007	AR	4	Central
AR009	AR	4	Central
AR010	AR	4	Central
AR011	AR	4	Central
AR012	AR	4	Central
AR013	AR	4	Central
AR-BC	Subtrans	4	Central
ART023	ART	3	South
ART031	ART	3	South
ART033	ART	3	South
ART034	ART	3	South
ARTSTL	Subtrans	3	South
ATSHCP	Subtrans	4	Central
ATSLV1	Subtrans	4	Central
ATSLV2	Subtrans	4	Central
ATSWBE	Subtrans	4	Central
B002	B	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
B003	B	4	Central
B004	B	4	Central
B011	B	4	Central
B012	B	4	Central
B014	B	4	Central
B016	B	4	Central
B021	B	4	Central
B023	B	4	Central
B026	B	4	Central
BAN001	BAN	3	South
BAN002	BAN	3	South
BAN003	BAN	3	South
BAN004	BAN	3	South
BAN005	BAN	3	South
BAN006	BAN	3	South
BAN007	BAN	3	South
BAN008	BAN	3	South
BAN009	BAN	3	South
BAN011	BAN	3	South
BAN013	BAN	3	South
BAN015	BAN	3	South
BANBGR	Subtrans	3	South
BAS011	BAS	3	South
BAS012	BAS	3	South
BAS013	BAS	3	South
BAS014	BAS	3	South
BAS021	BAS	3	South
BAS022	BAS	3	South
BAS023	BAS	3	South
BAS024	BAS	3	South
BAS034	BAS	3	South
BATBAN1	Subtrans	3	South
BATBAN2	Subtrans	3	South
BATBAS1	Subtrans	3	South
BATBAS2	Subtrans	3	South
BATSBMH	Subtrans	3	South
BATSYDW	Subtrans	3	South
BBD013	BBD	1	North

Feeder	Zone Substation	Regional Mapping	Geo split
BBD014	BBD	1	North
BBD021	BBD	1	North
BBD022	BBD	1	North
BC003	BC	4	Central
BC006	BC	4	Central
BC007	BC	4	Central
BC011	BC	4	Central
BC012	BC	4	Central
BC013	BC	4	Central
BC014	BC	4	Central
BC015	BC	4	Central
BC019	BC	4	Central
BC020	BC	4	Central
BC022	BC	4	Central
BC024	BC	4	Central
BCGWPD	Subtrans	4	Central
BC-TK	Subtrans	4	Central
BET001	BET	1	North
BET002	BET	1	North
BET003	BET	1	North
BET004	BET	1	North
BET005	BET	1	North
BET006	BET	1	North
BET007	BET	1	North
BET008	BET	1	North
BETSBGO	Subtrans	1	North
BETSCMN	Subtrans	1	North
BETSCTN	Subtrans	1	North
BETSEHK	Subtrans	1	North
BETSMRO	Subtrans	1	North
BGO011	BGO	1	North
BGO012	BGO	1	North
BGO013	BGO	1	North
BGO021	BGO	1	North
BGO022	BGO	1	North
BGO023	BGO	1	North
BGO024	BGO	1	North
BGRART	Subtrans	3	South

Feeder	Zone Substation	Regional Mapping	Geo split
BK002	BK	4	Central
BK003	BK	4	Central
BK004	BK	4	Central
BK006	BK	4	Central
BK007	BK	4	Central
BK009	BK	4	Central
BK011	BK	4	Central
BLT016	BLT	4	Central
BLT017	BLT	4	Central
BLT019	BLT	4	Central
BLT020	BLT	4	Central
BLT021	BLT	4	Central
BLT022	BLT	4	Central
BLT030	BLT	4	Central
BLT030	BLT	4	Central
BLT031	BLT	4	Central
BLTSAL	Subtrans	4	Central
BLTSATS	Subtrans	4	Central
BLTSBMH	Subtrans	4	Central
BLTSHCP	Subtrans	4	Central
BLTSLVN	Subtrans	4	Central
BLTSSCI	Subtrans	4	Central
BLTSTH1	Subtrans	4	Central
BLTSTYA	Subtrans	4	Central
BMH003	BMH	3	South
BMH004	BMH	3	South
BMH005	BMH	3	South
BMH006	BMH	3	South
B-NR	Subtrans	4	Central
BQ003	BQ	4	Central
BQ008	BQ	4	Central
BQ012	BQ	4	Central
BQ015	BQ	4	Central
BQ022	BQ	4	Central
BQ030	BQ	4	Central
BQ041	BQ	4	Central
BQ047	BQ	4	Central
BSBQ-J324	Subtrans	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
BTS-BK185	Subtrans	4	Central
BTS-BK187	Subtrans	4	Central
BTS-F179	Subtrans	4	Central
BTS-F189	Subtrans	4	Central
BTS-FF181	Subtrans	4	Central
BTS-NS176	Subtrans	4	Central
C020	C	4	Central
C022	C	4	Central
C022	C	4	Central
C023	C	4	Central
C024	C	4	Central
C028	C	4	Central
C029	C	4	Central
CDN001	CDN	2	South
CDN002	CDN	2	South
CDN003	CDN	2	South
CDN004	CDN	2	South
CDN006	CDN	2	South
CFD021	CFD	4	Central
CFD023	CFD	4	Central
CHA003	CHA	1	North
CHA005	CHA	1	North
CHA006	CHA	1	North
CHM011	CHM	1	North
CL011	CL	4	Central
CL013	CL	4	Central
CL014	CL	4	Central
CL016	CL	4	Central
CL016	CL	4	Central
CL021	CL	4	Central
CL022	CL	4	Central
CL023	CL	4	Central
CL026	CL	4	Central
CL027	CL	4	Central
CL033	CL	4	Central
CL035	CL	4	Central
CL036	CL	4	Central
CL037	CL	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
CL038	CL	4	Central
CLC001	CLC	2	South
CLC002	CLC	2	South
CLC002	CLC	2	South
CLC003	CLC	2	South
CLC003	CLC	2	South
CLC004	CLC	2	South
CLC006	CLC	2	South
CLC013	CLC	2	South
CLC014	CLC	2	South
CLCCDN	Subtrans	2	South
CL-K	Subtrans	4	Central
CME014	CME	1	North
CME014	CME	1	North
CME015	CME	1	North
CME016	CME	1	North
CME021	CME	1	North
CME022	CME	1	North
CMN001	CMN	3	South
CMN002	CMN	3	South
CMN003	CMN	3	South
CMN004	CMN	3	South
CMN005	CMN	3	South
CMNMRO	Subtrans	1	North
COB011	COB	2	South
COB012	COB	2	South
COB021	COB	2	South
COBWSD	Subtrans	2	South
CRO013	CRO	4	Central
CRO013	CRO	4	Central
CRO014	CRO	4	Central
CRO014	CRO	4	Central
CRO021	CRO	4	Central
CRO022	CRO	4	Central
CRO023	CRO	4	Central
CRO031	CRO	4	Central
CRO032	CRO	4	Central
CRO033	CRO	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
CRO034	CRO	4	Central
CTN001	CTN	1	North
CTN001	CTN	1	North
CTN002	CTN	1	North
CTN003	CTN	1	North
CTN004	CTN	1	North
CTN005	CTN	1	North
CTN006	CTN	1	North
CW004	CW	4	Central
CW005	CW	4	Central
CW006	CW	4	Central
CW007	CW	4	Central
CW008	CW	4	Central
CW009	CW	4	Central
CW011	CW	4	Central
CW012	CW	4	Central
CW013	CW	4	Central
CW014	CW	4	Central
CW015	CW	4	Central
CW-B	Subtrans	4	Central
DA008	DA	4	Central
DA015	DA	4	Central
DA016	DA	4	Central
DA028	DA	4	Central
DDL011	DDL	4	Central
DDL012	DDL	4	Central
DDL013	DDL	4	Central
DDL014	DDL	4	Central
DDL014	DDL	4	Central
DDL021	DDL	4	Central
DDL022	DDL	4	Central
DDL022	DDL	4	Central
DDL023	DDL	4	Central
DDL024	DDL	4	Central
DPTSSU1	Subtrans	4	Central
E022	E	4	Central
E033	E	4	Central
E035	E	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
ECA001	ECA	1	North
ECA003	ECA	1	North
ECA005	ECA	1	North
ECA005	ECA	1	North
ECA010	ECA	1	North
ECA012	ECA	1	North
EHK021	EHK	1	North
EHK022	EHK	1	North
EHK023	EHK	1	North
EHK024	EHK	1	North
EHK031	EHK	1	North
EHK032	EHK	1	North
EHK033	EHK	1	North
EHK034	EHK	1	North
EL009	EL	4	Central
EL011	EL	4	Central
E-PM	Subtrans	4	Central
ETSA001	ETSA	1	North
F026	F	4	Central
F027	F	4	Central
F028	F	4	Central
F029	F	4	Central
F030	F	4	Central
F032	F	4	Central
F033	F	4	Central
F033	F	4	Central
F034	F	4	Central
F035	F	4	Central
F035	F	4	Central
F037	F	4	Central
FB004	FB	4	Central
FB005	FB	4	Central
FB014	FB	4	Central
FB015	FB	4	Central
FB023	FB	4	Central
FBTS-AP	Subtrans	4	Central
FBTS-E	Subtrans	4	Central
FBTS-FB	Subtrans	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
FBTS-MG	Subtrans	4	Central
FBTS-PM	Subtrans	4	Central
FBTS-SB	Subtrans	4	Central
FBTS-SO	Subtrans	4	Central
FBTS-WG	Subtrans	4	Central
FF084	FF	4	Central
FF085	FF	4	Central
FF086	FF	4	Central
FF086	FF	4	Central
FF091	FF	4	Central
FF092	FF	4	Central
FF097	FF	4	Central
FNS011	FNS	4	Central
FNS012	FNS	4	Central
FNS021	FNS	4	Central
FNS022	FNS	4	Central
FNS032	FNS	4	Central
FR014	FR	4	Central
FR016	FR	4	Central
GB011	GB	4	Central
GB012	GB	4	Central
GB014	GB	4	Central
GB031	GB	4	Central
GB032	GB	4	Central
GBGL	Subtrans	4	Central
GCY012	GCY	4	Central
GCY013	GCY	4	Central
GCY014	GCY	4	Central
GCY021	GCY	4	Central
GCY022	GCY	4	Central
GCY023	GCY	4	Central
GCY023	GCY	4	Central
GCY024	GCY	4	Central
GCY024	GCY	4	Central
GL011	GL	4	Central
GL012	GL	4	Central
GL013	GL	4	Central
GL014	GL	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
GL015	GL	4	Central
GL015	GL	4	Central
GL021	GL	4	Central
GL021	GL	4	Central
GL022	GL	4	Central
GL023	GL	4	Central
GL024	GL	4	Central
GLE011	GLE	4	Central
GLE012	GLE	4	Central
GLE013	GLE	4	Central
GLE021	GLE	4	Central
GLE024	GLE	4	Central
GLE031	GLE	4	Central
GLE032	GLE	4	Central
GLE033	GLE	4	Central
GLEDDL1	Subtrans	4	Central
GLEDDL2	Subtrans	4	Central
GLGCY	Subtrans	4	Central
GSB011	GSB	3	South
GSB012	GSB	3	South
GSB013	GSB	3	South
GSB014	GSB	3	South
GSBWND1	Subtrans	3	South
GSBWND2	Subtrans	1	North
GTSBCG	Subtrans	4	Central
GTSCRO	Subtrans	4	Central
GTSFDN	Subtrans	4	Central
GTSFNS	Subtrans	4	Central
GTSGB	Subtrans	4	Central
GTSGCY	Subtrans	4	Central
GTSGLE1	Subtrans	4	Central
GTSGLE2	Subtrans	4	Central
GTSSRC	Subtrans	4	Central
GTSWIN	Subtrans	4	Central
GTSWPD	Subtrans	4	Central
HB-Q	Subtrans	4	Central
HCPWBE	Subtrans	4	Central
HOTHSM1	Subtrans	1	North

Feeder	Zone Substation	Regional Mapping	Geo split
HOTHSM2	Subtrans	1	North
HOTSCHM	Subtrans	1	North
HOTSKWF	Subtrans	1	North
HOTSTL2	Subtrans	1	North
HSM001	HSM	1	North
HSM002	HSM	1	North
HSM003	HSM	1	North
HSM004	HSM	1	North
HSM005	HSM	1	North
HSM006	HSM	1	North
HSM009	HSM	1	North
HSM010	HSM	1	North
HTN001	HTN	2	South
HTN001	HTN	2	South
HTN002	HTN	2	South
HTN003	HTN	2	South
HTN004	HTN	2	South
HTN005	HTN	2	South
HTN006	HTN	2	South
HYT011	HYT	4	Central
JA041	JA	4	Central
J-LS325	Subtrans	4	Central
K003	K	4	Central
K004	K	4	Central
K007	K	4	Central
K008	K	4	Central
K011	K	4	Central
K011	K	4	Central
KGT002	KGT	1	North
KGT003	KGT	1	North
KGT004	KGT	1	North
KGTSCHA	Subtrans	1	North
KGTSHL1	Subtrans	1	North
KGTSHL2	Subtrans	1	North
KRT012	KRT	2	South
KRT013	KRT	2	South
KRT022	KRT	2	South
KRT023	KRT	2	South

Feeder	Zone Substation	Regional Mapping	Geo split
KRT031	KRT	2	South
KRTPLD1	Subtrans	2	South
KRTPLD2	Subtrans	2	South
KSFRVL	Subtrans	1	North
KTSSA1	Subtrans	4	Central
KTSSA2	Subtrans	4	Central
KTSSBY1	Subtrans	4	Central
KTSSBY2	Subtrans	4	Central
KTSSSE1	Subtrans	4	Central
KTSSU1	Subtrans	4	Central
KWFNHL	Subtrans	1	North
KYM001	KYM	1	North
KYM002	KYM	1	North
KYM003	KYM	1	North
KYM004	KYM	1	North
KYM005	KYM	1	North
KYM006	KYM	1	North
KYMECA1	Subtrans	1	North
KYMECA2	Subtrans	1	North
L001	L	4	Central
L002	L	4	Central
L004	L	4	Central
L005	L	4	Central
L006	L	4	Central
L009	L	4	Central
L010	L	4	Central
L013	L	4	Central
L014	L	4	Central
L015	L	4	Central
L018	L	4	Central
L019	L	4	Central
L020	L	4	Central
L022	L	4	Central
LS003	LS	4	Central
LS005	LS	4	Central
LS006	LS	4	Central
LS009	LS	4	Central
LS010	LS	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
LS012	LS	4	Central
LS016	LS	4	Central
LS020	LS	4	Central
LS024	LS	4	Central
LS025	LS	4	Central
LS027	LS	4	Central
LV001	LV	4	Central
LV002	LV	4	Central
LV003	LV	4	Central
LV004	LV	4	Central
LV006	LV	4	Central
LV007	LV	4	Central
LV008	LV	4	Central
LV009	LV	4	Central
LV010	LV	4	Central
LVN022	LVN	4	Central
LVN023	LVN	4	Central
LVN032	LVN	4	Central
LVN033	LVN	4	Central
LVN034	LVN	4	Central
MBN012	MBN	1	North
MBN013	MBN	1	North
MBN014	MBN	1	North
MBN021	MBN	1	North
MBN023	MBN	1	North
MBN031	MBN	1	North
MBN032	MBN	1	North
MDA022	MDA	1	North
MDA022	MDA	1	North
MDA023	MDA	1	North
MDA024	MDA	1	North
MDA031	MDA	1	North
MDA032	MDA	1	North
MDA033	MDA	1	North
MDA034	MDA	1	North
MG001	MG	4	Central
MG002	MG	4	Central
MG004	MG	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
MG006	MG	4	Central
MG009	MG	4	Central
MG014	MG	4	Central
MG015	MG	4	Central
MG018	MG	4	Central
MG019	MG	4	Central
MG020	MG	4	Central
MG022	MG	4	Central
MLN011	MLN	4	Central
MLN012	MLN	4	Central
MLN013	MLN	4	Central
MLN014	MLN	4	Central
MLN021	MLN	4	Central
MLN022	MLN	4	Central
MLN023	MLN	4	Central
MLN024	MLN	4	Central
MLN032	MLN	4	Central
MNA013	MNA	1	North
MNA014	MNA	1	North
MNA021	MNA	1	North
MNA021	MNA	1	North
MNA022	MNA	1	North
MNA024	MNA	1	North
MNA034	MNA	1	North
MNASTN	Subtrans	1	North
MP021	MP	4	Central
MP030	MP	4	Central
MP050	MP	4	Central
MP055	MP	4	Central
MRO002	MRO	1	North
MRO004	MRO	1	North
MRO005	MRO	1	North
MRO006	MRO	1	North
MRO007	MRO	1	North
MRO008	MRO	1	North
NC001	NC	4	Central
NC002	NC	4	Central
NC004	NC	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
NC005	NC	4	Central
NC006	NC	4	Central
NC009	NC	4	Central
NC010	NC	4	Central
NC013	NC	4	Central
NC014	NC	4	Central
NC015	NC	4	Central
NC-WB	Subtrans	4	Central
NHL015	NHL	1	North
NHL016	NHL	1	North
NHL031	NHL	1	North
NKA001	NKA	1	North
NKA002	NKA	1	North
NKA003	NKA	1	North
NKA004	NKA	1	North
NKA005	NKA	1	North
NKA006	NKA	1	North
NKACME	Subtrans	1	North
NR002	NR	4	Central
NR003	NR	4	Central
NR006	NR	4	Central
NR007	NR	4	Central
NR015	NR	4	Central
NR016	NR	4	Central
NR020	NR	4	Central
NR021	NR	4	Central
NR022	NR	4	Central
NR024	NR	4	Central
NR025	NR	4	Central
NRBHTN	Subtrans	4	Central
NS010	NS	4	Central
NS013	NS	4	Central
NT-TP278	Subtrans	4	Central
NT-TP81	Subtrans	4	Central
OYN001	OYN	1	North
OYN003	OYN	1	North
OYN005	OYN	1	North
OYN007	OYN	1	North

Feeder	Zone Substation	Regional Mapping	Geo split
PLD001	PLD	2	South
PLD002	PLD	2	South
PLD003	PLD	2	South
PLD004	PLD	2	South
PLD005	PLD	2	South
PLD006	PLD	2	South
PM001	PM	4	Central
PM002	PM	4	Central
PM003	PM	4	Central
PM004	PM	4	Central
PM005	PM	4	Central
PM006	PM	4	Central
PM008	PM	4	Central
PM009	PM	4	Central
PM012	PM	4	Central
PR018	PR	4	Central
PR021	PR	4	Central
PR022	PR	4	Central
Q001	Q	4	Central
Q002	Q	4	Central
Q004	Q	4	Central
Q005	Q	4	Central
Q006	Q	4	Central
Q009	Q	4	Central
Q010	Q	4	Central
Q013	Q	4	Central
Q014	Q	4	Central
Q015	Q	4	Central
Q019	Q	4	Central
Q-L	Subtrans	4	Central
R022	R	4	Central
R023	R	4	Central
R024	R	4	Central
R031	R	4	Central
R032	R	4	Central
R033	R	4	Central
R034	R	4	Central
R035	R	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
R093	R	4	Central
RCT011	RCT	1	North
RCT013	RCT	1	North
RCT014	RCT	1	North
RCT015	RCT	1	North
RCT021	RCT	1	North
RCT022	RCT	1	North
RCT023	RCT	1	North
RCT023	RCT	1	North
RCTSMBN	Subtrans	1	North
RCTSMDA1	Subtrans	1	North
RCTSMDA2	Subtrans	1	North
RCTSYSF	Subtrans	1	North
RD001	RD	4	Central
RD002	RD	4	Central
RD004	RD	4	Central
RD005	RD	4	Central
RD006	RD	4	Central
RD009	RD	4	Central
RD010	RD	4	Central
RD013	RD	4	Central
RD014	RD	4	Central
RD015	RD	4	Central
R-PR127	Subtrans	4	Central
R-SM114	Subtrans	4	Central
RTS-AR	Subtrans	4	Central
RTS-CL	Subtrans	4	Central
RTS-CW	Subtrans	4	Central
RTS-EW	Subtrans	4	Central
RTS-FR1	Subtrans	4	Central
RTS-NR	Subtrans	4	Central
RTS-PR129	Subtrans	4	Central
RTS-R134	Subtrans	4	Central
RTS-RP124	Subtrans	4	Central
RTS-SK	Subtrans	4	Central
RTS-SM152	Subtrans	4	Central
RTS-SM153	Subtrans	4	Central
RTS-TK	Subtrans	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
RVL001	RVL	1	North
RVL004	RVL	1	North
RVL006	RVL	1	North
RVL008	RVL	1	North
RVLHTH	Subtrans	1	North
SA001	SA	4	Central
SA002	SA	4	Central
SA003	SA	4	Central
SA004	SA	4	Central
SA005	SA	4	Central
SA006	SA	4	Central
SA007	SA	4	Central
SA009	SA	4	Central
SA010	SA	4	Central
SB012	SB	4	Central
SB015	SB	4	Central
SB021	SB	4	Central
SB045	SB	4	Central
SB056	SB	4	Central
SB-SO	Subtrans	4	Central
SBYGSB1	Subtrans	3	South
SBYGSB2	Subtrans	3	South
SBYMLN	Subtrans	4	Central
SHL001	SHL	1	North
SHL001	SHL	1	North
SHL002	SHL	1	North
SHL004	SHL	1	North
SHL005	SHL	1	North
SHL007	SHL	1	North
SHL008	SHL	1	North
SHN011	SHN	1	North
SHN012	SHN	1	North
SHN014	SHN	1	North
SHN021	SHN	1	North
SHN022	SHN	1	North
SHN023	SHN	1	North
SHN024	SHN	1	North
SHP011	SHP	1	North

Feeder	Zone Substation	Regional Mapping	Geo split
SHP012	SHP	1	North
SHP014	SHP	1	North
SHP021	SHP	1	North
SHTKYM1	Subtrans	1	North
SHTKYM2	Subtrans	1	North
SHTNKA1	Subtrans	1	North
SHTNKA2	Subtrans	1	North
SHTSHN1	Subtrans	1	North
SHTSMNA	Subtrans	1	North
SHTSNSF	Subtrans	1	North
SHTSSHP	Subtrans	1	North
SHTSSTN	Subtrans	1	North
SK001	SK	4	Central
SK002	SK	4	Central
SK004	SK	4	Central
SK005	SK	4	Central
SK006	SK	4	Central
SK009	SK	4	Central
SK013	SK	4	Central
SK014	SK	4	Central
SK019	SK	4	Central
SK020	SK	4	Central
SK022	SK	4	Central
SK023	SK	4	Central
SK024	SK	4	Central
SK-EW	Subtrans	4	Central
SO001	SO	4	Central
SO002	SO	4	Central
SO005	SO	4	Central
SO006	SO	4	Central
SO013	SO	4	Central
SO018	SO	4	Central
SO019	SO	4	Central
SO022	SO	4	Central
SRCCRO	Subtrans	4	Central
SSE011	SSE	4	Central
SSE012	SSE	4	Central
SSE013	SSE	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
SSE014	SSE	4	Central
SSE031	SSE	4	Central
SSE032	SSE	4	Central
SSE033	SSE	4	Central
SSE034	SSE	4	Central
STL004	STL	1	North
STL005	STL	1	North
STL006	STL	1	North
STL007	STL	1	North
STN011	STN	1	North
STN012	STN	1	North
STN014	STN	1	North
STN021	STN	1	North
STN022	STN	1	North
STN023	STN	1	North
STN024	STN	1	North
STN024	STN	1	North
SU011	SU	4	Central
SU012	SU	4	Central
SU015	SU	4	Central
SU021	SU	4	Central
SU022	SU	4	Central
SU034	SU	4	Central
SU035	SU	4	Central
SUSSE	Subtrans	4	Central
SVTS-RD	Subtrans	4	Central
TGTKRT1	Subtrans	2	South
TGTSCDN	Subtrans	2	South
TGTSHTN	Subtrans	2	South
TGTSNRB	Subtrans	2	South
TK001	TK	4	Central
TK002	TK	4	Central
TK004	TK	4	Central
TK005	TK	4	Central
TK006	TK	4	Central
TK009	TK	4	Central
TK010	TK	4	Central
TK011	TK	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
TK014	TK	4	Central
TK015	TK	4	Central
TK015	TK	4	Central
TK017	TK	4	Central
TK025	TK	4	Central
TK025	TK	4	Central
TNA021	TNA	4	Central
TNA023	TNA	4	Central
TRG001	TRG	2	South
TRG002	TRG	2	South
TRG003	TRG	2	South
TRG004	TRG	2	South
TRG005	TRG	2	South
TRGWBL1	Subtrans	2	South
TRGWBL2	Subtrans	2	South
TSTS-L	Subtrans	4	Central
VM002	VM	4	Central
VM004	VM	4	Central
VM005	VM	4	Central
VM006	VM	4	Central
VM009	VM	4	Central
VM014	VM	4	Central
VM020	VM	4	Central
VM025	VM	4	Central
VM026	VM	4	Central
VM030	VM	4	Central
VM034	VM	4	Central
VM035	VM	4	Central
VM038	VM	4	Central
VM040	VM	4	Central
WA034	WA	4	Central
WB001	WB	4	Central
WB002	WB	4	Central
WB004	WB	4	Central
WB005	WB	4	Central
WB006	WB	4	Central
WB009	WB	4	Central
WB010	WB	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
WB011	WB	4	Central
WB013	WB	4	Central
WB014	WB	4	Central
WB015	WB	4	Central
WBE011	WBE	4	Central
WBE012	WBE	4	Central
WBE013	WBE	4	Central
WBE014	WBE	4	Central
WBE021	WBE	4	Central
WBE022	WBE	4	Central
WBE023	WBE	4	Central
WBE024	WBE	4	Central
WBE031	WBE	4	Central
WBE032	WBE	4	Central
WBE033	WBE	4	Central
WBE034	WBE	4	Central
WBL002	WBL	2	South
WBL003	WBL	2	South
WBL004	WBL	2	South
WBL005	WBL	2	South
WBL006	WBL	2	South
WBL008	WBL	2	South
WBL010	WBL	2	South
WBL012	WBL	2	South
WBLKRT	Subtrans	2	South
WD011	WD	4	Central
WD013	WD	4	Central
WD021	WD	4	Central
WD021	WD	4	Central
WD022	WD	4	Central
WD031	WD	4	Central
WD032	WD	4	Central
WETSHTH	Subtrans	1	North
WETSRVL	Subtrans	1	North
WG014	WG	4	Central
WG024	WG	4	Central
WIN011	WIN	2	South
WIN012	WIN	2	South

Feeder	Zone Substation	Regional Mapping	Geo split
WIN013	WIN	2	South
WIN022	WIN	2	South
WINMGW	Subtrans	2	South
WMN013	WMN	1	North
WMN014	WMN	1	North
WMN021	WMN	1	North
WMTS-ARD1	Subtrans	4	Central
WMTS-JA3	Subtrans	4	Central
WMTS-LS226	Subtrans	4	Central
WMTS-NC	Subtrans	4	Central
WMTS-VM1	Subtrans	4	Central
WMTS-VM2	Subtrans	4	Central
WMTS-VM3	Subtrans	4	Central
WMTS-WB	Subtrans	4	Central
WND011	WND	3	South
WND012	WND	3	South
WND013	WND	3	South
WND014	WND	3	South
WND021	WND	3	South
WND022	WND	3	South
WND023	WND	3	South
WND024	WND	3	South
WND024	WND	3	South
WPD011	WPD	2	South
WPD012	WPD	2	South
WPD013	WPD	3	South
WPD014	WPD	2	South
WPD021	WPD	2	South
WPD022	WPD	2	South
WPD024	WPD	2	South
WPD031	WPD	2	South
WPD032	WPD	2	South
WPD033	WPD	2	South
YSWBMH	Subtrans	3	South
SA011	SA	4	Central
TK001	TK	4	Central
BC012	BC	4	Central
RD014	RD	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
BC003	BC	4	Central
TK010	TK	4	Central
SA005	SA	4	Central
NR002	NR	4	Central
NR020	NR	4	Central
BC024	BC	4	Central
BC007	BC	4	Central
SU035	SU	4	Central
SU021	SU	4	Central
SA003	SA	4	Central
SA007	SA	4	Central
SA010	SA	4	Central
SU034	SU	4	Central
SA001	SA	4	Central
SU022	SU	4	Central
SA004	SA	4	Central
RD013	RD	4	Central
WD021	WD	4	Central
CW011	CW	4	Central
TK015	TK	4	Central
CW006	CW	4	Central
TK004	TK	4	Central
CW012	CW	4	Central
WD032	WD	4	Central
WD011	WD	4	Central
RD005	RD	4	Central
RD004	RD	4	Central
RD006	RD	4	Central
RD009	RD	4	Central
WD022	WD	4	Central
NR003	NR	4	Central
WD013	WD	4	Central
WD031	WD	4	Central
NR025	NR	4	Central
NR015	NR	4	Central
NR016	NR	4	Central
NR024	NR	4	Central
NR006	NR	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
TK006	TK	4	Central
CW013	CW	4	Central
TK014	TK	4	Central
BC020	BC	4	Central
BC013	BC	4	Central
BC022	BC	4	Central
SA009	SA	4	Central
SA012	SA	4	Central
RD015	RD	4	Central
CW014	CW	4	Central
SA006	SA	4	Central
SA002	SA	4	Central
SK005	SK	4	Central
TK025	TK	4	Central
SU023	SU	4	Central
TK009	TK	4	Central
RD002	RD	4	Central
BC015	BC	4	Central
CW009	CW	4	Central
CW015	CW	4	Central
SK006	SK	4	Central
NR007	NR	4	Central
BC019	BC	4	Central
BC006	BC	4	Central
TK005	TK	4	Central
CW004	CW	4	Central
SK013	SK	4	Central
RD010	RD	4	Central
DLF005	DLF	4	Central
SK009	SK	4	Central
SK014	SK	4	Central
TK024	TK	4	Central
TK017	TK	4	Central
SK024	SK	4	Central
BC014	BC	4	Central
SK001	SK	4	Central
CW007	CW	4	Central
NR022	NR	4	Central

Feeder	Zone Substation	Regional Mapping	Geo split
RD001	RD	4	Central
SK020	SK	4	Central
CW008	CW	4	Central
SK002	SK	4	Central
TK011	TK	4	Central
J068	J	4	Central
NR021	NR	4	Central
TK002	TK	4	Central
BC011	BC	4	Central
SK023	SK	4	Central
BC023	BC	4	Central
TK013	TK	4	Central
SK022	SK	4	Central
SK004	SK	4	Central
SK015	SK	4	Central
NR004	NR	4	Central
SK019	SK	4	Central
RP026	RP	4	Central
NR013	NR	4	Central
J063	J	4	Central
LQ001	LQ	4	Central

Appendix I – Powercor Species Designations

The following listing is the RCM studies base list of wood species in service in Victoria under the control of CP/PAL as used in the 2019 RCM Study. G1 is Grey Gum Durability Class 1, G3 is Grey Gum Durability Class 3 poles.

BB-BLACKBUTT

BI-BROAD LEAF IBARK

BS-STRINGB BROWN

RW-RED BLOODWOOD

CB-COSTAL GREY BOX

G3-MOUNTAIN GREY GUM

GB-GREY BOX

G1-GREY GUM

GI-GREY IRONBARK

IB-IRONBARK

MA-MOUNTAIN ASH

MM-MESSMATE STRINGB

P-PINUS RADIATA

QB-WHITE TOPPED BOX

RI-RED IRONBARK

RM-RED MAHOGANY

RS-RED STRINGB

SG-SPOTTED GUM

SS-SILVERTOP STRINGB

ST-SILVERTOP ASH

SY-SYDNEY BLUE GUM

TW-TALLOWWOOD

WM-WHITE MAHOGANY

WSB-WHITE STRINGB

YSB-YELLOW STRINGB

ZZ-WOOD UNKNOWN

Appendix J – Inspection Task Effectiveness

The following inspection task effectiveness or probability of detection value used in the 2005 RCM study of 79.7% was obtained from the study noted below.[68]

2/03/01 - 10:28 UTS rating analysis NDE ver 2 - inspector.xls

EANSW NDE Project - Analysis of NDE systems Prediction of Section Properties at GL

Summary Report for: Inspector - Section Modulus
(analysis template ver: 2.1)
February - 2001

	Comparative Analysis with Digital Ref.					Relative Distributions / Grouping Analysis					Rating Assessments (and weighting factors)							
											1.0	2.0	2.0	2.0	1.0	2.0		
	ratio NDE / digital	ratio NDE / digital		75% confidence	95% confidence	ratio <= 70%	>70% & <= 90%	>90% & <=110%	>110% & <140%	ratio >= 140%	average accuracy (95% confidence)	variability index	R^2 co-efficient	reliability index (normalised)	rogue detection	cost index (reliability)	TOTAL RATING (unweighted)	TOTAL RATING (weighted)
Section above GL	average	std dev	COV	+/-	+/-	A	B	C	D	E	1	2	3	4	5	6	7	8
Z average																		
Z xx																		
Z yy																		
MOI average																		
MOI xx																		
MOI yy																		
Section below GL																		
Z average	103.4%	22.2%	21.4%	1.4%	2.5%	4.2%	13.2%	53.5%	24.8%	4.2%	94%	79%	75%	80%	73%	81%	80.4%	79.7%
Z xx	106.0%	24.6%	23.2%	1.6%	2.7%	4.2%	17.1%	40.6%	30.6%	7.4%	91%	77%	73%	74%	66%	75%	75.9%	75.4%
Z yy	103.1%	26.6%	25.8%	1.7%	3.0%	5.2%	20.3%	41.3%	29.7%	3.5%	94%	74%	74%	76%	69%	79%	77.6%	76.9%
MOI average	105.5%	26.6%	25.2%	1.7%	3.0%	5.5%	15.2%	46.1%	26.8%	6.5%	92%	75%	77%	75%	70%	78%	77.7%	77.1%
MOI xx	107.1%	27.8%	26.0%	1.8%	3.1%	5.8%	16.1%	39.7%	30.3%	8.1%	90%	74%	77%	72%	66%	74%	75.4%	75.0%
MOI yy	105.1%	29.4%	28.0%	1.9%	3.3%	4.8%	18.7%	41.6%	29.0%	5.8%	92%	72%	77%	75%	68%	77%	76.8%	76.1%
AVERAGE Ixx:	107.1%	27.8%		1.8%	3.1%	5.8%	16.1%	39.7%	30.3%	8.1%	90%	74%	77%	72%	66%	74%	75%	75.0%
AVERAGE Zave:	**103.4%**	**22.2%**		**1.4%**	**2.5%**	**4.2%**	**13.2%**	**53.5%**	**24.8%**	**4.2%**	**94%**	**79%**	**75%**	**80%**	**73%**	**81%**	**80%**	**79.7%**
AVERAGE Zxx:	**106.0%**	**24.6%**		**1.6%**	**2.7%**	**4.2%**	**17.1%**	**40.6%**	**30.6%**	**7.4%**	**91%**	**77%**	**73%**	**74%**	**66%**	**75%**	**76%**	**75.4%**

Notes on Rating Assessments Factors

1) ave. accuracy	*Equal to the upper bound average ratio of the NDE value divided by the reference value determined from the digital images; equation = ABS [1- (average + 95% confidence interval)]*
2) variability index	*Equals (1 - COV), expressed as a percentage*
3) R^2 regression	*Equals the least squares R^2 co-efficient for the relevant plot of NDE vs Digital*
4) reliability index	*Reflects the grouping of ratios, weighted to a normal distribution as follows: 0.7*B + C + 0.7*D and discounting A & E where: A, B, C, D & E are the relative percentages in each respective ratio group*
5) rogue detection	*Indicates the percentage of readings where the ratio is less than or equal to 110%, with a partial weighting of 0.5 on the "D" group The rating for rogue detection is determined as follows: (1.0 - 0.5*D - E) - a value of 100% indicates that all potential rogues are identified*
6) cost index	*Based on Cost model described in the main report. Reflects the cost of both conservative results (where a pole is removed prematurely) and unconservative assessments where the cost of failure is not just pole replacement, but loss of service, damage to property, injury or death*
7) TOTAL (unweighted)	*The total rating is the average of all indices*
8) TOTAL (weighted)	*The total rating is based on weighting the indicies by the factors indicated at the top of the table.*

Figure 86 - EANSW NDE Project - Analysis of NDE Systems - Prediction of Section Properties

[68] EANSW NDE Project - Analysis of NDE Systems - Prediction of Section Properties. February 2001 File UTS rating analysis NDE version 2 – inspector.xls using the Weighted average Zave total rating of 79.7%.

Appendix K – RCM II Worksheets

The RCM II worksheets are found in this file: RCM II Decision Worksheet Final - (DMPS).xlsx

Appendix L – Weibull Sub-Population & Key results

See File: Weibull Sub-Population Results - Appendix L.docx

Appendix M – Scenario Analysis

The various scenario analysis and sensitivity studies are found in these two files.

1. PF Interval Analysis - HBRA vs LBRA using KM CDF 09132019 v1.pptx
2. Replacement Pole Distribution Analysis 09062019.pptx

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