Crossarms

AMS Electricity Distribution Network

Document number	**AMS 20-57**
Issue number	11
Status	Approved
Approver	Paul Ascione
Date of approval	28/05/2019

ISSUE/AMENDMENT STATUS

Issue Number	Date	Description	Author	Approved by
1	1995/96	Initial document	D Postlethwaite	G Towns
2	27 Aug 2008	Revision – added RCM models	D Postlethwaite	G Towns
3	10 Sep 2008	Editorial by technical writer	J Kenyon	G Towns
4	11 Dec 2008	Revision of replacement forecast	D Postlethwaite	G Towns
5	27 Feb 2009	Update of failures and replacements	D Postlethwaite	G Towns
6	21 Apr 2009	Amended strategy for high consequence circuits	D Postlethwaite	G Towns
7	12 Oct 2009	Update of RCM models following ARMs Reliability Engineers review	D Postlethwaite	G Towns
8	25 Nov 2009	Added replacement forecasts to executive summary	D Postlethwaite	G Towns
9	15 Jul 2010	Update 2009 failures and replacement and proposed addition BFM replacements	D Postlethwaite	D Postlethwaite
10	30 Mar 2015	Major revision including Dependability management	D Erzetic-Graziani D Meade T Gowland	J Bridge
11	28 May 2019	Major revision to the content and format of the document.	F Lirios	P Ascione

Disclaimer

Contact

This document is the responsibility of the Network Assets, Regulated Energy Services Division of AusNet Services. Please contact the indicated owner of the document with any inquiries.

AusNet Services
Level 31, 2 Southbank Boulevard
Melbourne Victoria 3006
Ph: (03) 9695 6000

Table of Contents

1 Executive Summary....4
1.1 Strategies 4
2 Introduction....6
2.1 Purpose 6
2.2 Scope 6
2.3 Asset Management Objectives 6
3 Asset Description 7
3.1 Asset Function 7
3.2 Asset Population 7
3.3 Asset Age Profile 8
3.4 Asset Condition.... 12
3.5 Asset Criticality 14
3.6 Asset Performance.... 17
4 Other Issues 20
4.1 Inspection 20
4.2 Maintenance 20
4.3 Replacements.... 21
4.4 Codified Areas 21
4.5 Low clearance conductors 22
5 Risk and Options Analysis....23
5.1 Overview 23
5.2 Risk assessment methodology 23
5.3 Options.... 24
5.4 Summary Forecast.... 24
6 Asset Strategies....26
6.1 New Assets.... 26
6.2 Inspection 26
6.3 Replacements.... 26

1 Executive Summary

This document is part of the suite of Asset Management Strategies relating to AusNet Services' electricity distribution network. The purpose of this strategy is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of crossarms in AusNet Services' Victorian electricity distribution network.

This crossarm population is comprised of approximately 200,000 steel high voltage (HV) crossarms, 23,000 wood HV crossarms, 155,000 wood low-voltage (LV) crossarms and 30,000 steel sub-transmission crossarms.

Since 1991, low-voltage aerial bundled cable (LVABC) programs have resulted in retirement of crossarms however; the majority of LV circuits are still supported by Australian hardwood crossarms. The LV wood crossarm population is stable as most of the new LV circuits are underground cable or LVABC.

In the early 1970s, steel crossarms were introduced with concrete poles and became standard construction for 66kV lines in the late 1970s and for 22kV, 11kV and 6.6kV circuits following the 1983 bushfires. Accordingly, the number of steel crossarms in service continues to rise, and the number of HV wood crossarms is declining.

Since 2011/12, the replacement rate of wood crossarms was increased significantly and between 2011 and 2014 more than 39,000 wood crossarms were replaced to match increasing deterioration rates and reduce limited life crossarm volumes. This volume included 10,000 replacements targeted in extreme bushfire risk areas as part of the approved Electricity Safety Management Scheme. This has had the effect of since 2015, the number of wood crossarm failures has decreased from 164 to 88 failures per annum.

Crossarm risk mitigation forecasts suggest that an average of 4,135 wood crossarms will need to be replaced each year to address deterioration and failures over the period 2022-26.

Ongoing proactive management of crossarm application, inspection, maintenance, and replacement practice is required to ensure AusNet Services meet stakeholder expectations of cost, safety, reliability and environmental performance.

1.1 Strategies

1.1.1 New Assets

- Install insulated cable systems for new 22kV, 11kV and 6.6kV circuits in codified areas[1] eliminating need to install crossarms.
- Install insulated underground cable or LVABC for new LV aerial circuits eliminating need to install crossarms.
- Install steel crossarms on new 66kV, 22kV, 11kV and 6.6kV circuits.
- Continue to use and monitor the performance of fibre glass crossarms as a replacement for LV wood crossarms

1.1.2 Inspection

- Inspect crossarms in accordance with criteria in the Asset Inspection Manual (4111).

1.1.3 Replacements

- Replace deteriorated 66kV, 22kV, 11kV and 6.6kV wood crossarms with steel crossarms

[1] Areas designated by Energy Safe Victoria as extreme fire risk areas that was introduced via the amendments to the Electricity Safety (Bushfire Mitigation) Regulations 2013

- Reclaim serviceable steel crossarms, where practicable, from deteriorated poles for installation at other locations
- Replace individual deteriorated LV wood crossarms with wood or fibre glass crossarms
- On a case-by-case basis, use insulated underground cable and LVABC to replace groups of deteriorated LV wood crossarms.

2 Introduction

2.1 Purpose

The purpose of this document is to outline the inspection, maintenance, replacement and monitoring activities identified for the economic life cycle management of crossarm in AusNet Services' Victorian electricity distribution network. This document is intended to be used to inform asset management decisions and communicate the basis for activities.

In addition, this document forms part of our Asset Management System for compliance with relevant standards and regulatory requirements. This document demonstrates responsible asset management practices by outlining economically justified outcomes.

2.2 Scope

This asset management strategy applies to the all crossarms used to support conductors operating at 66kV, 22kV, 11kV, 6.6kV and below.

The other related assets are described in;.

- AMS 20-52 Conductor
- AMS 20-70 Poles
- AMS 20-66 Insulators – High and Medium Voltage

2.3 Asset Management Objectives

As stated in *AMS 01-01 Asset Management System Overview*, the high-level asset management objectives are:

- Comply with legal and contractual obligations;
- Maintain safety;
- Be future ready;
- Maintain network performance at the lowest sustainable cost; and
- Meet customer needs.

As stated in *AMS 20-01 Electricity Distribution Network Asset Management Strategy*, the electricity distribution network objectives are:

- Improve efficiency of network investments
- Maintain long-term network reliability
- Implement REFCL within prescribed timeframes
- Reduce risks in highest bushfire risk areas
- Achieve top quartile operational efficiency
- Prepare for changing network usage

3 Asset Description

3.1 Asset Function

Crossarms primarily support the conductors, which operate at various levels throughout the network.

The crossarms are installed along the upper part of the pole to assure the energised conductors are operating at a safe elevation from the ground – away from members of the public, vehicles and mobile plant, animals and vegetation.

3.2 Asset Population

The AusNet Services electricity distribution network has 405,074[2] crossarms consisting of:

- 199,253 steel HV crossarms;
- 22,905 wood HV crossarms;
- 154,679 wood LV crossarms; and
- 28,237 sub-transmission (ST) and other types of crossarms.

Overall, approximately 38% of the crossarm fleet are wood crossarms supporting LV circuits, 6% are wood crossarms supporting HV circuits, 1% are wood crossarms supporting 66kV circuits, 49% are steel crossarms supporting HV circuits, and the remaining 6% are steel crossarms that support 66kV circuits. This is illustrated in Figure 1.

[2] 2018 AusNet Services (distribution) Category Analysis

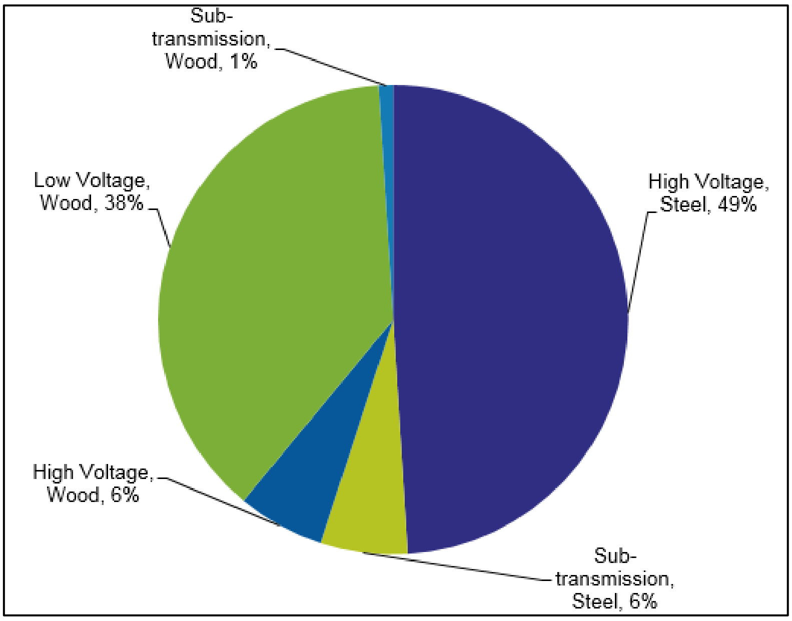

Figure 1: Crossarms by type

In terms of geographical location, the network is subdivided into Hazardous Bushfire Risk Areas (HBRA) and Low Bushfire Risk Areas (LBRA)[3].

The 58%of the crossarm population are located in HBRA region while 42% are located in the LBRA region.

Table 1 shows the breakdown of the crossarm fleet in terms of material, type and location.

Table 1: Crossarm by type, material and location

	XARMGRP	XARMSTEEL			XARMWOOD			Grand Total	%
Area	**LV**	**HV**	**LV**	**ST**	**HV**	**LV**	**ST**		
HBRA	5	146,106	66	19,781	11,644	56,622	725	234,948	58%
LBRA	0	53,148	33	7,476	11,261	98,057	150	170,126	42%
Grand Total	5	199,253	99	27,257	22,905	154,679	875	405,074	

3.3 Asset Age Profile

Electrification of rural Victoria between the late 1950s and early 1970s required the installation of large numbers of HV and LV wood crossarms of varying species and quality.

In the early 1970s, HV galvanized steel crossarms and aerodynamic post insulators were introduced along with concrete poles.

Steel crossarms and post insulators became standard construction for 66kV lines in the late 1970s and for 22kV, 11kV and 6.6kV feeders following the 1983 bushfires.

In 1990, the use of highly durable wood species was first specified for crossarms. Since 1991, only high-quality wood has been installed.

[3] This is based on the HBRA and Non-HBRA region as of the writing for this AMS

Since 2003, steel crossarms fitted with porcelain post type insulators have become a standard for HV construction on both concrete and wood poles.

The number of LV wood crossarms is steadily decreasing as a majority of new LV circuits are fashioned from underground cable or from LVABC coupled with steel crossarms.

Since 1991, small groups of deteriorated LV crossarms in coastal areas have been replaced by LVABC, but the majority of LV aerial circuits are still supported by crossarms manufactured from Australian hardwood.

Steel is not appropriate for LV crossarms as birds and animals can easily short-circuit the small LV pin insulators, causing supply outages.

3.3.1 Steel Crossarms

In the 1970s, galvanized steel crossarms became standard construction for 66kV lines and 22kV, 11kV and 6.6kV feeders. There has been minimal change in the technical specification of galvanized steel crossarms resulting in a homogenous population.

Steel crossarms make up 55% of the crossarm population.

The galvanised steel crossarm service age profile is illustrated in Figure 2. The spike at 44 years is due to assets lacking a confirmed installation date.

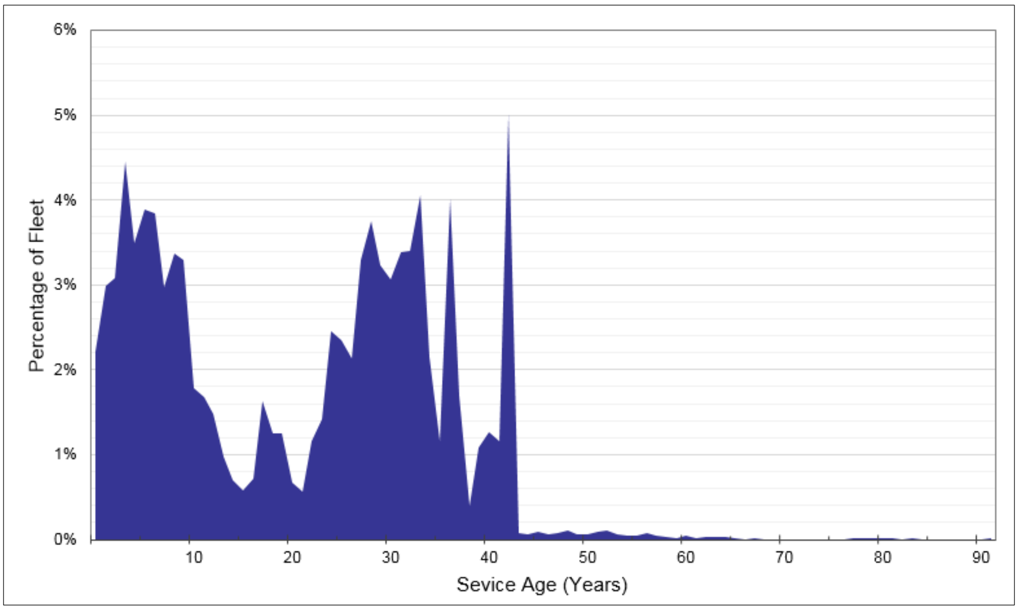

Figure 2: Steel Crossarm Service Age

The mean technical life of a steel crossarm in the eastern Victorian environment is expected to exceed 60 years.

3.3.2 Wood Crossarms

The volume of wood crossarms replaced by steel units over the last two decades has significantly reduced the total volume of wood crossarms supporting HV circuits.

By contrast, the volume of wood crossarms on the LV network has remained relatively stable at 38% of the crossarm population, even though there is the growth in the LV ABC network and continued introduction of LV UG cables.

Figure 3 shows that more than half of the wood crossarm population has a service age less than 25 years due to the impact of accelerating replacement rates over the last decade. The proportion of variable quality wood, installed before 1990, is now estimated to be less than 15% of the crossarm population.

Since 1991, only high-quality wood has been installed in the distribution network. The mean expected technical life of wood crossarms ranges from 40 to 50 years.

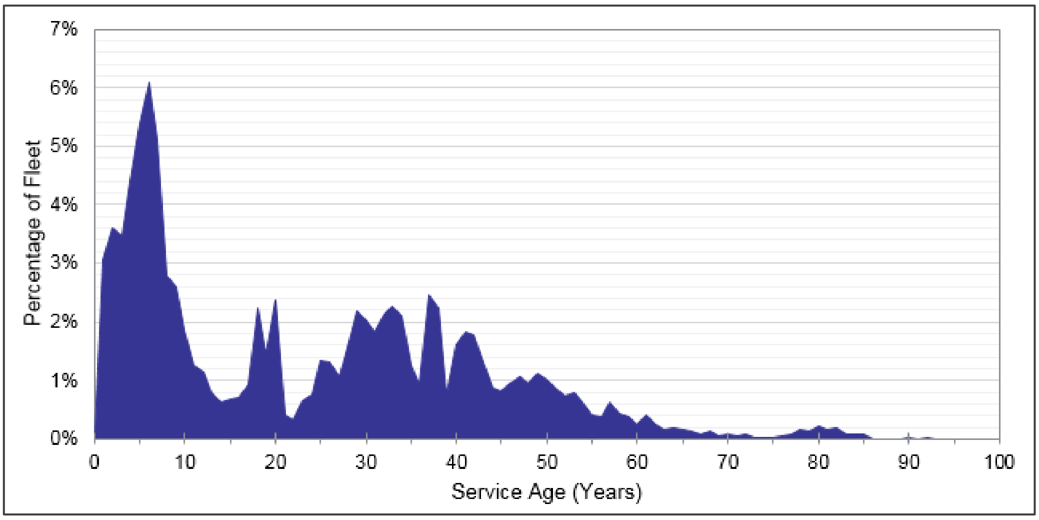

Figure 3: Wood Crossarm Service Age

Sub-transmission

The prevailing focus on replacing sub-transmission wood crossarms with galvanised steel units over the last decade has reduced the population of wood crossarms supporting 66kV circuits to less than 1% of the crossarm population.

At the current rate of replacement, it is expected that variable quality wood crossarms will be eliminated from 66kV circuits by 2020. The service age of this small population is illustrated in Figure 4.

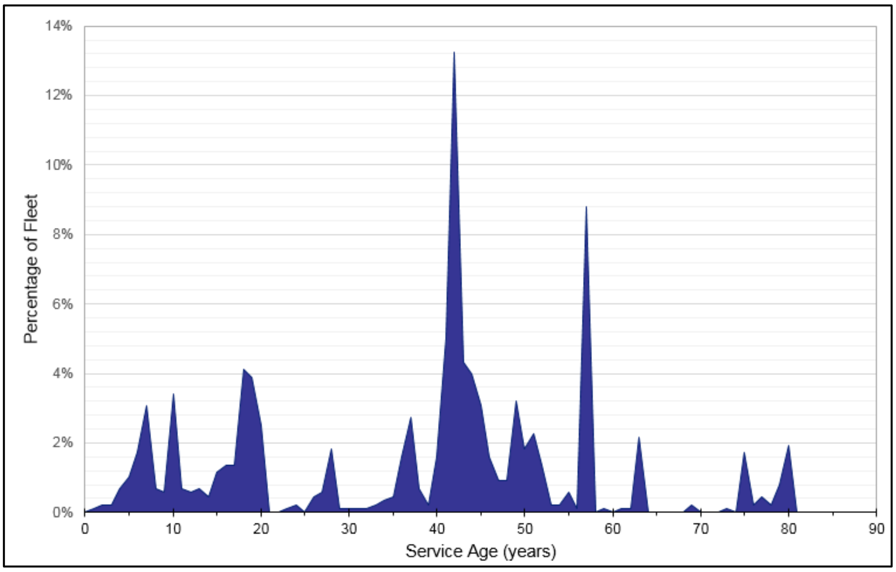

Figure 4: 66kV Wood Crossarm Service Age

High Voltage

The prevailing focus on replacing HV wood crossarms with galvanised steel units over the last decade has reduced the population of wood crossarms supporting 22kV, 11kV and 6.6kV feeders to less than 6% of the crossarm population.

The service age of this fleet is illustrated below in Figure 5.

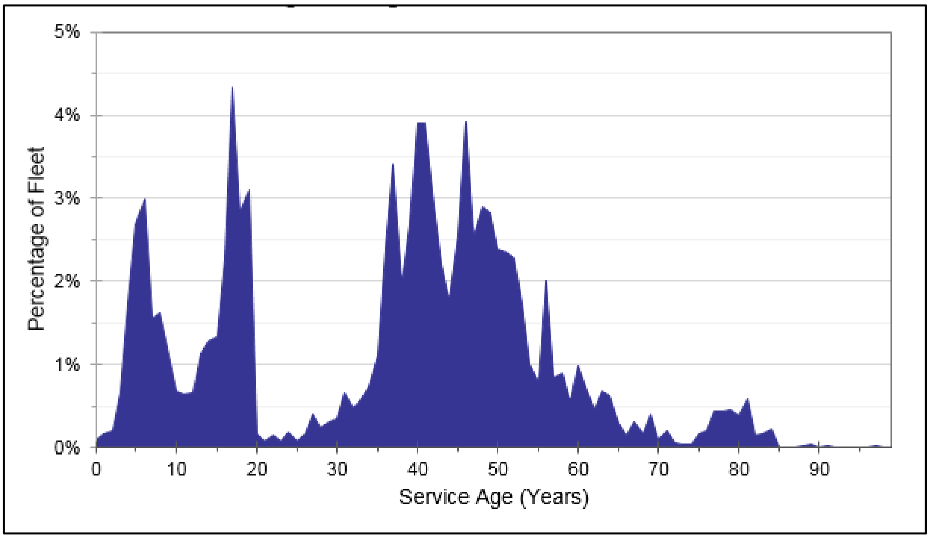

Figure 5: HV Wood Crossarm Service Age

At the current rate of replacement, it is expected that HV wood crossarms will be replaced by steel crossarms within the next 15 to 20 years.

Low Voltage

Low voltage wood arms supporting LV circuits contribute approximately 38% of the crossarm population. The service age of this fleet is illustrated in Figure 6.

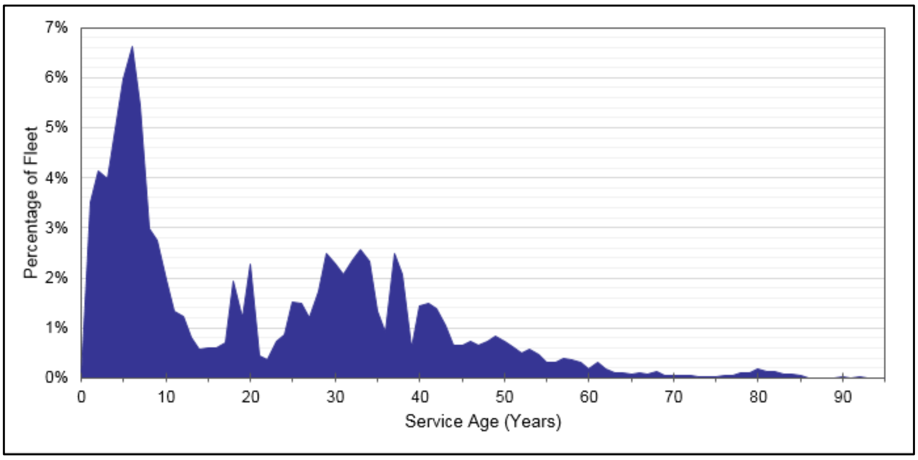

Figure 6: LV Wood Crossarm Service Age

3.4 Asset Condition

AusNet Services undertakes crossarm inspection according to 30-4111, Asset Inspection Manual using image-stabilised binoculars. Additionally, if the crossarm is situated in a HBRA then it will be subjected to an aerial based inspection (helicopter or Hi mast photography).

In order to ascertain the overall condition of all crossarms, a common condition rating criteria has been developed and applied to the crossarm population. There are five different condition scores that have been applied to each distribution crossarm, ranging from ‘as-new’ condition (C1) to advanced deterioration (C5).

Table 2 describes the typical attributes, which determine the condition score rating.

Table 2: Condition Score Methodology[4]

Condition Score	Condition Description	Summary of details of condition score	Remaining Life
C1	Very Good	Assets are generally in good operating condition with no history of significant defects or failures. Routine inspection and condition monitoring is recommended	95%
C2	Good	Assets in better than average condition that neither require intervention between scheduled inspections nor show any trends of serious deterioration in condition or performance.	70%
C3	Average	Includes assets, which typically require some maintenance activity. The assets are showing signs of deterioration in condition or performance.	50%

[4] Age does not dictate whether a crossarm must be replaced; this decision is reached through defect identification and prioritisation.

Condition Score	Condition Description	Summary of details of condition score	Remaining Life
C4	Poor	Assets which are in worse than average condition. Specialised work may be required to manage specific defects.	25%
C5	Very Poor	This category includes assets, which are typically inspection and maintenance intensive. These assets are approaching the end of their economic life. The crossarm is being managed through to the 'Unserviceable' condition and replacement.	5%

3.4.1 Steel Crossarms

Approximately 10% of the steel crossarm population are considered to be in a "below average" condition (8% HV crossarms and 2% sub-transmission crossarms) these crossarms are currently assessed as C4 and C5 condition as shown in Figure 7.

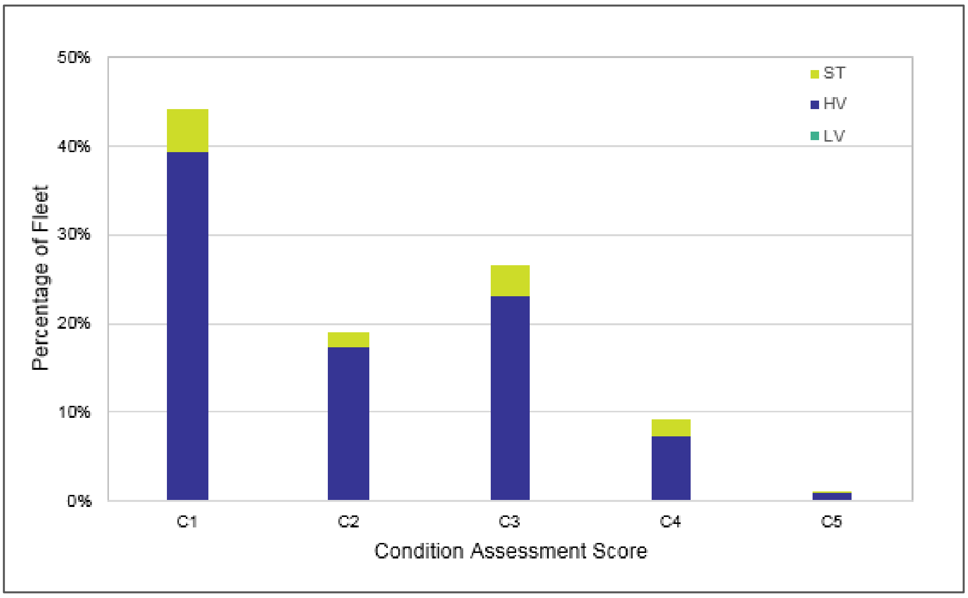

Figure 7: Condition Assessment for Steel Crossarms

Overall, it is expected that steel crossarms will deliver long service lives as 63% of steel crossarms are assessed as "Good" or "Very Good" condition (C1 and C2), 26% are in "Average" condition (C3), 9% have been assessed as in "Poor" condition (C4) and 1% in "Very Poor" condition (C5).

There have been two minor issues with steel crossarms:

- Poor galvanising – This issue has now been addressed and was identified as a manufacturing defect, caused by poor cleaning of the bare steel crossarms prior to the application of the zinc coating.
- A number of HV crossarm end caps were incorrectly welded by the manufacturer and this issue has been rectified.

AusNet Services has recorded damage to steel crossarms, which have buckled and bent due to abnormal loading e.g. a tree falling onto the overhead line, rather than deterioration of base materials.

3.4.2 Wood Crossarms

Issues such as rotting, splitting and insect infestation determine the service life of a wood crossarm.

Figure 8 shows that approximately 56% of wood crossarms are assessed as “Good” or “Very Good” condition (C1 and C2), 14% are in “Average” condition (C3) and 30% have been assessed as in “Poor” (C4) or “Very Poor” condition (C5).

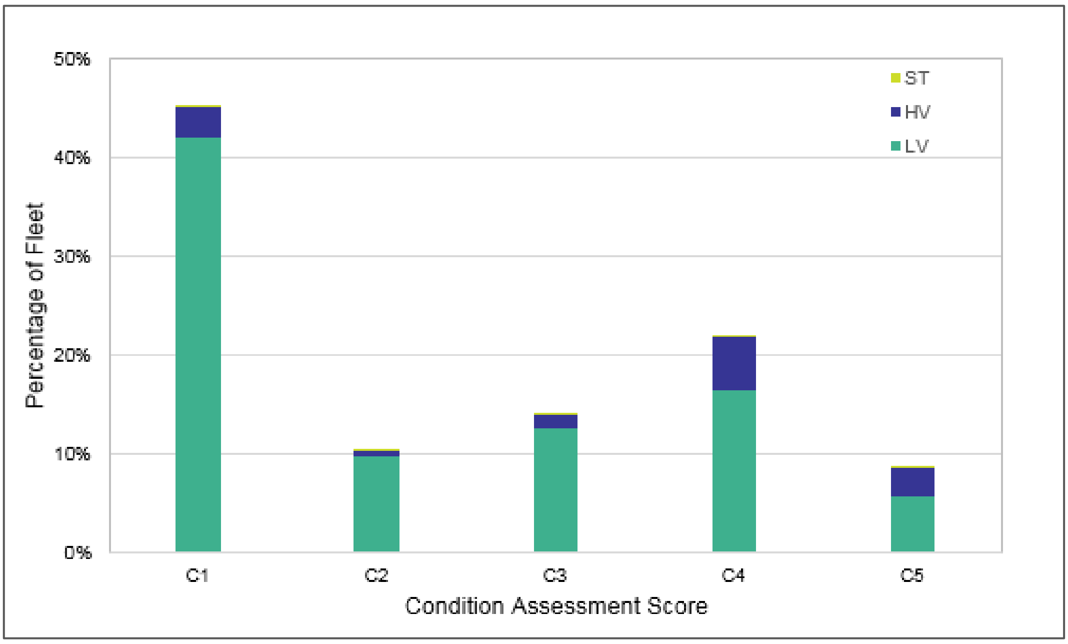

Figure 8: Wood Crossarm Condition

3.5 Asset Criticality

3.5.1 Failure Mode Effects Criticality Analysis (FMECA)

Failure Mode, Effects Criticality Analysis (FMECA) is a technique for analysing and evaluating a life cycle strategy to ensure that the function has the desired reliability characteristics by managing critical failure modes through redundancy, maintenance, refurbishment or replacement.

FMECA includes a criticality analysis, which charts the probability of failure modes against the severity of their consequences. The result highlights failure modes with relatively high probability and severity of consequences, allowing remedial effort to be directed where it will produce the greatest value.

3.5.2 Failure Modes

The failure modes of crossarms include:

- Mechanical failure;

- Wood rot; and
- Termites

Eighty percent of wood crossarm failures are due to wood rot and to a lesser extent termite infestation. This reduces the cross-sectional area of wood at a stress concentration point. Random failures such as tree and vehicle damage account for the remaining 20% of wood crossarm failures.

Failures of galvanized steel crossarms have been rare. To date, inspections have revealed very little deterioration in galvanized steel.

3.5.2.1 Mechanical failure

Figure 9 shows a steel crossarm, which has suffered corrosion. The corrosion which can only be seen from the underside of the crossarm, has been exacerbated by the presence of the animal cover as the moisture is retained after being wetted by rain.

Figure 9: Steel Crossarm rusting under an animal cover

Mechanical damage due to external factors such as trees or vehicles is occasionally responsible for a bending failure, as illustrated in Figure 10.

Figure 10: Steel Crossarm Bending Failure

The predominant failure mode for wood crossarms is a fracture at a stress concentration point such as the kingbolt or insulator mounting; when mechanical loadings of conductors exceed the strength of deteriorating wood, as illustrated in Figure 11 and Figure 12.

Figure 11: Wood Crossarm Fracture

Figure 12: Wood crossarm fracture at kingbolt

3.5.2.2 Wood Rot

Wood rot is usually detectable and failure is largely predictable as shown in Figure 13.

Figure 13: Wood Rot

3.5.2.3 Termites

East of Bairnsdale, Wodonga and Benalla districts have relatively high termite infestation rates and some wood pole assets have required termite treatment. Termite attack is difficult to predict in crossarms and early detection is challenging for asset inspectors. Structural failure can occur within months of infestation and often well within a single routine inspection cycle.

3.5.3 Failure Effects

The economic impact of a crossarm failure consists of the following four components:

- Bushfire start impact;
- Health and safety impact;
- Value of unserved energy impact; and
- Replacement cost.

3.5.3.1 Bushfire

Crossarm failures can cause a fire start, which may result into a bushfire during a hot day. The risk associated with a bushfire is calculated by applying the probability of fire ignition, probability of unfavourable weather conditions, expected house loss consequence and house loss value. Data has been sourced from the Victorian Bushfires Royal Commission findings, Government departs, Bureau of Meteorology and CSIRO.

3.5.3.2 Health and Safety Impact

Crossarm failure may result to injury to members of the public. The effect is highest for crossarms that support conductors going across roads while spans that follow the roadside have a much lower effects cost.

3.5.3.3 Unserved Energy

Value of expected unserved energy is calculated by using the value of customer reliability (VCR) and the expected outage time. Mean time to restore (MTTR) is used to estimate the expected outage time. The approach taken is consistent with AEMO's energy forecasting approach as detailed in paper by AEMO and in AusNet Services Distribution Annual Planning Report (DARP)[5]

3.5.3.4 Replacement cost

This refers to the material, plan hire and labour cost associated with replacing a crossarm. The cost of replacement, although not material, has some dependency on the voltage of the line – as larger crossarms are needed to support higher voltages.

3.6 Asset Performance

3.6.1 Failures

The rate of failures peaked in 2010 with an average reduction of 14% per annum, as shown in Figure 14.

[5] Distribution Annual Planning Report – AusNet Services 2018-2022

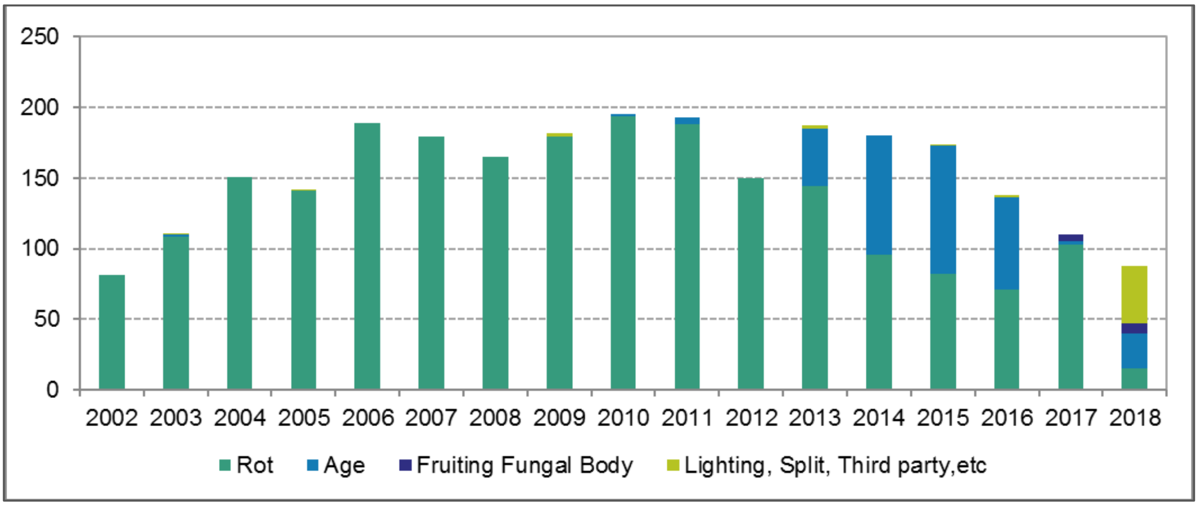

Figure 14: Crossarms Failures 2002–2018

In 2018, 88 crossarm failures occurred with 17% of crossarm failures caused by rot, 28% caused by age deterioration, 8% caused by Fruiting fungal infection and 47% from other causes, i.e. lighting, split & third party, as shown in Figure 15.

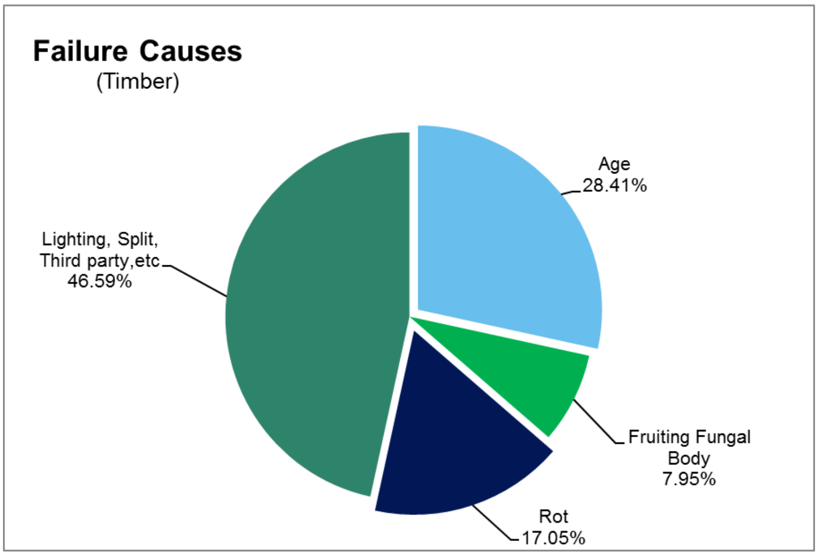

Figure 15: Wood Crossarm Failure Causes, 2018

3.6.2 Customer Impact

The failure of a crossarm affects the customer by two main ways, which is supply outages and the risk of starting an asset fire or ground fire. The introduction of aerial inspections on the crossarm fleet has been instrumental in lowering the number of failures in the fleet with positive outcomes.

3.6.2.1 Supply outages

Analysis of 390 HV crossarm failures occurring between 2008 and 2013 reveals a total of 26.2 minutes USAIDI; an average of 0.07 minutes USAIDI and a reliability incentive scheme penalty of $42,000 per HV failure. Over the same period, a total of 467 LV crossarm failures averaged 0.01 minutes USAIDI and a STPIS[6] penalty of $5,800 per LV failure.

The latest analysis done for 105 HV crossarm failures occurring between 2014 until 2017 identified a total of 7.16 minutes USAIDI; an average of 0.7 minutes USAIDI and a reliability incentive scheme penalty of $32,000 per HV failure. Over the same period, a total of 218 LV crossarm failures reveals a total of 2.31 minutes USAIDI; an average of 0.1 minutes USAIDI and a STPIS[7] penalty of $4,900 per LV failure.

3.6.2.2 Fire ignition

Approximately 55% of all poles are located in declared 'fire risk' areas and the use of HV steel crossarms is specifically mentioned in the insurance underwriters' submission as a bushfire mitigation technique.

A crossarm failure can cause a fire ignition to occur. In 2011, "F-Factor" was introduced as a scheme to incentivise Distribution Businesses to reduce the number of asset failures causing fire ignitions. AusNet Services has implemented programs targeting fire ignitions; this has resulted in a decline in Asset Fires as shown in Figure 16.

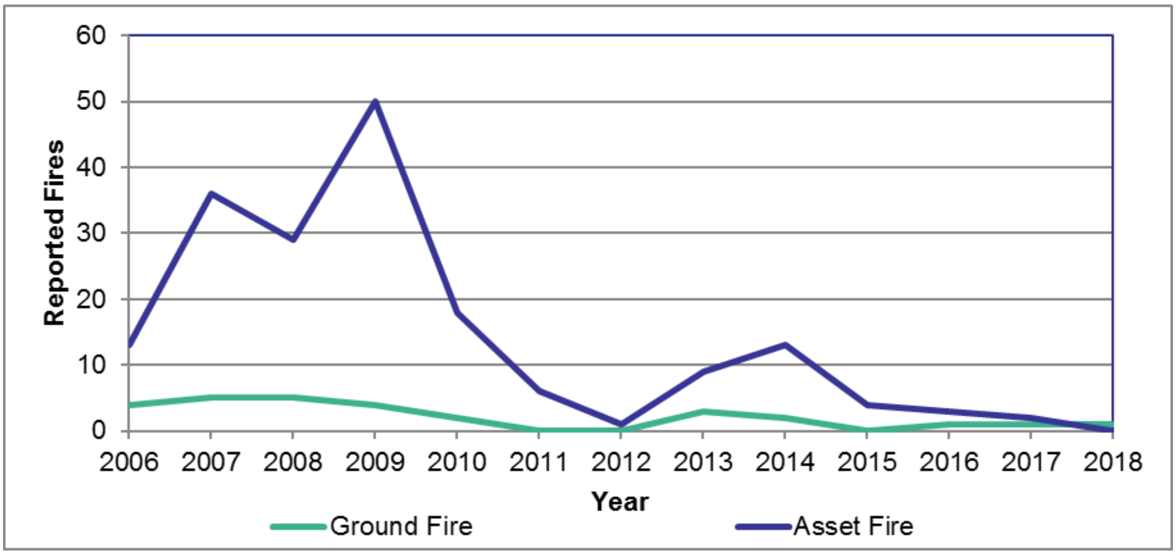

Figure 16: Fire Starts Attributed to Crossarm Failures

[6] Service Target Performance Incentive Scheme

[7] Reliability Impact.xls provided by Asset Analytics Team

4 Other Issues

4.1 Inspection

Inspection contractors assess crossarms at regular intervals and assign one of the following categories based on their assessment:

- Serviceable (until the next inspection cycle); or
- Limited Life – Prioritised for replacement at:
  - PT30 (within <30 days);
  - PT90 (<90 days);
  - PT180 (<180 days); or
  - PT912 (re-inspection within 912 days)

HV wood crossarms are difficult to inspect from ground level as defects often occur on the upper face; consequently, the accuracy of inspection is limited and re-inspection from an elevated platform vehicle (EPV) or helicopter is often necessary to establish the true condition.

LV wood crossarms are more readily visible from ground level and the top face can be probed with an implement mounted on an operating stick.

To improve the assessment accuracy, image-stabilized binoculars, remote-controlled aircraft-mounted cameras and mast-mounted cameras have been introduced and regular training of asset inspectors is undertaken.

Any defective crossarm observed are recorded in the asset database and entered upon the work plan and prioritised for remedial action.

Please refer to 30-4111, Asset Inspection Manual for further information.

4.2 Maintenance

Inspections have revealed little deterioration in galvanized steel HV crossarms except for rare cases of broken welds and insulator mountings arising from manufacturing defects or caused by mechanical damage by trees or vehicles.

Accordingly, steel crossarms have not required significant maintenance or replacement to date.

Defect issues that have arisen were generally caused by the manufacturer or third party interference.

Currently, the only potential deterioration issue with steel crossarms is corrosion and to mitigate this risk, the material specification requires the supplier to galvanise all steel crossarms.

Wood crossarms are subject to shrinkage, twisting and warping in the Victorian environment.

Spiral spring washers and spiked bonding plates have reduced the need for tightening kingbolts and other fastenings on a universal basis.

However, some maintenance is carried out on wood crossarms as a by-product of other works; for example; radio frequency interference maintenance and anti-split bolts are used to rectify splitting defects in otherwise sound crossarms.

Planned replacement is the principal maintenance technique employed on wood crossarms and is expected to become the principal technique for steel crossarms.

4.3 Replacements

Inspections have thus far revealed a small number of deteriorated galvanized steel HV crossarms and thus replacements have mostly been limited to rare cases of damage because of third party intervention.

Significant variations occur in the number of wood crossarms replaced on a year-to-year basis due to variable deterioration rates in different geographic environments, the cyclic nature of the asset inspection process and changes in asset management strategies.

In 2004, AusNet Services began increasing replacement rates to reduce the number of limited life wood crossarms. In 2006, the replacement rate was further accelerated in response to changes in the reliability incentive scheme. In 2008 the replacement of wood crossarms was again accelerated to match increasing deterioration due to the higher rainfalls associated with the conclusion of the 2000 to 2009 drought.

In 2009, AusNet Services introduced an aerial inspection program to increase the effectiveness of asset inspection. The aerial inspections are carried out on a 5-year cycle to cover all crossarms in HBRA areas, which is approximately 55% of the network. There was an expectation that aerial inspections would identify deteriorated wood crossarms that traditional ground inspections could not identify. Therefore, the volumes of crossarm replacements were forecast to increase, and the actual number of replacements did increase starting from 2010, which can be seen in Figure 117.

The replacement rate of deteriorated wood crossarms peaked at approximately 14,000 units per annum in the period 2012 to 2013. Since then, the replacement rate has steadily declined after required replacements identified from the first 5-year cycle of the aerial inspection program has been completed.

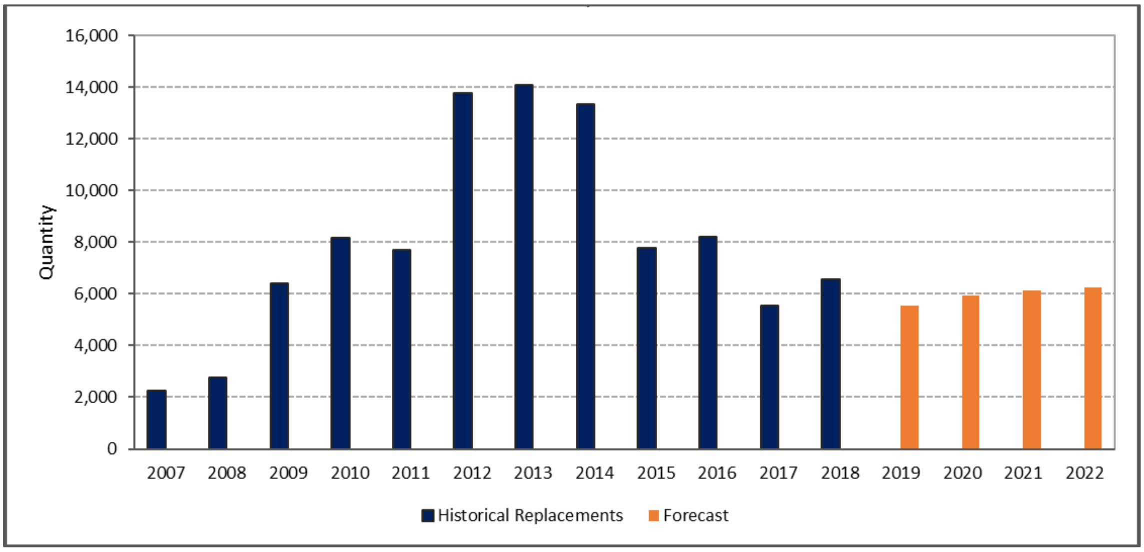

Figure 17: Crossarm Replacements, Actual and Forecast

4.4 Codified Areas

Amendments to the Electricity Safety (Bushfire Mitigation) Regulations 2013 introduced the use of codified areas, which are prescribed geographical areas of highest file loss consequence where replacement or construction of powerlines (1kV to 22kV) of four or more consecutive spans must be with insulated or covered conductor. This resulted in the removal of in-service crossarms, which further decreased the crossarm fleet population.

4.5 Low clearance conductors

The failure of a crossarm can create substandard clearances between conductors, the ground, trees and buildings. On most occasions, electrical protection disconnects the affected circuit. However, there have been occasions when the electrical protection has not disconnected the conductors in a timely fashion, which in urban areas allows the possibility for vehicles and pedestrians to contact energised conductors with subsequent property damage, injuries and the potential risk for loss of life. In rural areas, substandard clearances may result in motor vehicle accidents, personal injuries, stock losses and wildfire ignitions.

5 Risk and Options Analysis

5.1 Overview

The failure of a wood crossarm has a variety of consequences depending on the mode of failure, the surrounding physical environment and the location of the crossarm within the distribution network.

In an urban environment, HV crossarms support three-phase circuits with relatively high electrical loads and high customer densities. Hence, a failure usually inconveniences many customers and incurs a relatively high reliability incentive scheme penalty.

There are also more motorists and pedestrians in an urban environment and a failure may create a safety hazard due to low clearance conductors in public places.

Most LV crossarms are installed in urban environments. The failure of a LV crossarm has a lower reliability incentive scheme impact, as fewer customers are disadvantaged, but the public safety hazard is similar to that of a HV or MV wood crossarm failure.

A rural environment has a much lower customer density than the urban environment. However, rural HV feeders are considerably longer than urban feeders and thus the failure of a crossarm supporting a three-phase circuit near the source will disadvantage many customers and incur a high reliability incentive scheme penalty.

Many crossarms in the rural environment are located on single-phase spurs with few downstream customers and hence failures incur a low reliability incentive scheme penalty.

The public safety risk in rural areas arises from the potential for a wildfire ignition following a crossarm failure as well as from low clearance conductors.

5.2 Risk assessment methodology

A quantitative risk assessment was undertaken, which considers the following items:

Crossarm probability of failure

- Calculate the asset's remaining service potential based on its condition score
- Calculate the probability of failure
    - o From historical failures, Isograph's Availability Workbench (AWB)[8] software was used to determine the shape parameter β and scale parameter η for each crossarm type and condition

Criticality values (aka Failure Effects)

- Bushfire criticality
- Value of Unserved Energy (VUE)
- Health and Safety

Cost of replacement

- Replacement cost in today's $ value
- Replacement costs NPV for each option considered
- Cumulated criticality and replacement cost NPV for each option

Benefit of replacement

[8] AWB uses actual failures as well as suspended failures in the crossarm fleet to determine the failure probability density function.

- Determine the benefit as a difference between the consequence NPV and cost of replacement
- Identify the preferred option as the maximum NPV benefit among the options

The actual failures and suspended failures recorded in the Asset Management System were used to determine the shape parameter β and scale parameter η for each crossarm type and condition using Isograph's Availability Workbench (AWB) software.

The failure characteristics was then used to calculate the remaining service potential (RSP) for each crossarm condition using the criteria as described in section 3.4 Asset Condition. This information was used in formulating the best way of managing the crossarm fleet.

5.3 Options

The optimal quantity of crossarm replacement is determined using a combination of risk-based replacement, where the benefits of replacement outweighs the cost for the replacement; and condition-based/ end of life replacement, which targets the assets that are in the "Very Poor" condition.

5.3.1 Risk-Based Replacement

Risk-based replacement compares the benefits gained by replacing the crossarm against the risk of failure for that particular asset. The probability of failure is determined by the condition of the crossarm (i.e. remaining service potential as discussed in Section 3.4) while the consequence of failure is reliant on the location of the crossarm in the network as well as the feeder it is supporting.

As the business had implemented an aggressive replacement program in the 2011-15 EDPR period, the probability – and therefore, the risks associated with the crossarm fleet has gone down drastically. Due to this, the number of crossarms forecasted to be replaced proactively due to risks is lower compared to other periods.

5.3.2 End of Life Replacement

End of life replacements are forecasts based on observed condition at the time of inspection. The possible result of an inspection is that a crossarm may fail and made unserviceable, or it remains as serviceable. Using historical failure data, this have been analysed in Isograph's Availability Workbench (AWB) software to obtain a Weibull probability distribution.

Based on the result of this statistical analysis in AWB, crossarms that may become unserviceable in the next inspection can be predicted.

5.3.3 Efficiency Replacement

Wood crossarms are replaced together with a pole that is deemed unserviceable[9]. This policy exists so maximum service life is assured when a new pole is erected on site, as well as saving the need to revisit the pole when the wood crossarm becomes unserviceable. This number was obtained in the analysis and represents 30% of the crossarm forecast for replacement but is excluded from the summary table in the succeeding section.

5.4 Summary Forecast

Table 3 summarises the economic contribution of crossarms for replacement over the 2022-26 period. This excludes crossarms replaced as part of pole replacement program.

[9] Steel crossarms can be reused if deemed serviceable

Table 3: Crossarm Risk Mitigation Summary

Identifier	Justification	Contribution Per Annum
End of Life Replacements	Condition Assessment forecast	3,902
Pro-active Replacement	Risk of failure	233
	Total Crossarms	4,135

6 Asset Strategies

6.1 New Assets

- Install insulated cable systems for new 22kV, 11kV and 6.6kV circuits in codified areas[10] eliminating need to install crossarms.
- Install insulated underground cable or LVABC for new LV I circuits eliminating need to install crossarms.
- Install steel crossarms on new 66kV, 22kV, 11kV and 6.6kV circuits.
- Continue to use and monitor the performance of fibre glass crossarms as a replacement for LV wood crossarms

6.2 Inspection

- Inspect crossarms in accordance with criteria in the Asset Inspection Manual (4111).

6.3 Replacements

- Replace deteriorated 66kV, 22kV, 11kV and 6.6kV wood crossarms with steel crossarms
- Reclaim serviceable steel crossarms, where practicable, from deteriorated poles for installation at other locations
- Replace individual deteriorated LV wood crossarms with wood or fibre glass crossarms
- On a case-by-case basis, use insulated underground cable and LVABC to replace groups of deteriorated LV wood

[10] Areas designated by Energy Safe Victoria as extreme fire risk areas