Festival Hydro Inc.

Appendix I

FHI 2022 Reliability Report

2022 SYSTEM RELIABILITY

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prepared by:

Jordan Murray, P. Eng.
Distribution Engineer

This report reviews the reliability of the distribution system owned and operated by Festival Hydro for the year 2022. Comparisons are made to provincial and international standards. Root causes are identified and recommendations made to improve the system reliability. This report is an annual report presented to Festival Hydro management and the Board of Directors. Comments or questions should be directed to the author.

BACKGROUND

Festival Hydro is required by the Ontario Energy Board (OEB) to achieve minimum performance standards regarding customer service and system reliability. The standards for reliability are not prescriptive, but the OEB expects utilities to maintain their systems to prevent degradation in reliability. The OEB anticipates requiring minimum acceptable levels of reliability as part of the second generation of performance-based rates. For the present time, a 5-year rolling average is used and five years' worth of data is presented in this report.

Data regarding outages is collected daily and reported every year to the OEB. For system reliability, five indicators are used, and the first two are reported to the OEB. The information that is submitted to the OEB includes outage duration and frequency for the entire year. The same information is also submitted to the OEB with outages due to Loss of Supply and outages that occurred during Major Events excluded.

The standard reliability indices are weighted by customer and presented as averages. For example, a System Average Interruption Duration Index (SAIDI) of 2.0 means the average customer was off for 2 hours during the entire year. Not all customers on that feeder or in that area were off for 2 hours – some were off for more; some were off for less. Likewise, with the System Average Interruption Frequency Index (SAIFI) – a SAIFI of 3.2 means some customers had more than 3 outages while some had less. This concept is particularly important when looking at feeder specific data – it is still an average value. The way the indices are calculated means that a 15-minute outage to 5000 customers will have a much greater impact than a 15-minute outage to only 10 customers, even though both outages may have been caused by a tree contact. With a relatively small customer base, it only takes one or two outages to a main feeder in any given year to push the reliability indices higher than average. This could give the impression that the reliability is getting worse, when in reality the actual number of outages is declining and the increase in the reliability indices is more related to chance than poor performance. To account for this, data regarding the number of outages and causes of the outages is also examined and summarized on the following pages.

For this report's purposes, the total number of FHI customers that was used to calculate the system averages was 22,261. This number was calculated using the monthly average customer counts for 2022.

The Festival MTS1 8051M3 feeder is a dedicated circuit for one large customer and there are no other customers on it. The Festival MTS1 8051M6 feeder is also a dedicated feeder for the Wright Blvd battery storage facility. Those 2 circuits are not included as part of this report as any outages on those circuits have practically no impact on the overall statistics.

1. RELIABILITY INDICIES

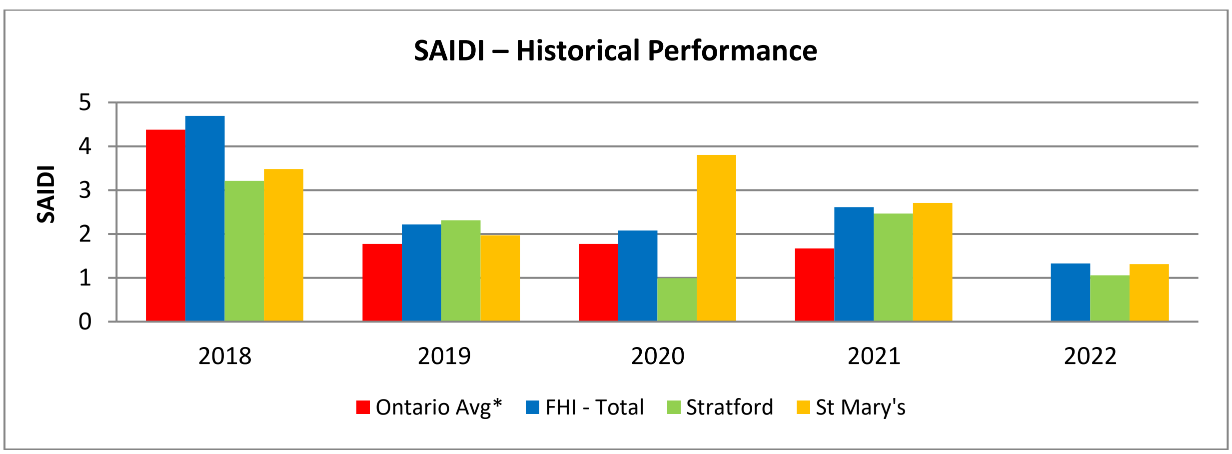
A) System Average Interruption Duration Index (SAIDI) – This is the length of time in hours during the year that power was not available to the average customer.

SAIDI – Historical Performance

Outage Hours/Year

Area	2018	2019	2020	2021	2022	Avg
Ontario Avg*	4.38	1.77	1.77	1.67		2.40
FHI - Total	4.69	2.22	2.08	2.61	1.33	2.59
Stratford	3.21	2.31	0.99	2.47	1.06	2.01
68M2	2.57	0.29	0.16	0.30	1.95	1.05
68M3	2.68	3.73	1.18	4.38	0.47	2.49
68M4	2.27	0.26	2.92	1.31	0.92	1.53
68M5	5.15	2.17	0.81	2.77	0.50	2.28
68M8	7.96	3.00	2.52	0.31	1.99	3.16
8051M1	1.05	1.83	0.13	1.12	2.01	1.23
8051M2	0.62	0.66	0.00	0.38	0.00	0.33
8051M4	0.65	0.03	0.54	0.57	6.67	1.69
St Mary's	3.48	1.97	3.80	2.70	1.31	2.65
9M1	2.17	1.33	2.65	0.10	1.26	1.50
9M2	0.08	1.04	2.44	1.26	2.44	1.45
9M3	1.77	0.06	2.69	6.48	0.47	2.29
9M4	5.47	2.82	6.48	0.01	1.58	3.27

In 2022, the average Festival Hydro customer would have been without power for a total of 1.33 hours over the course of the entire year. Stratford customers would have been without power for an average of approximately 1 hour, while St. Mary's customers would have been without power for an average of 1.3 hours.



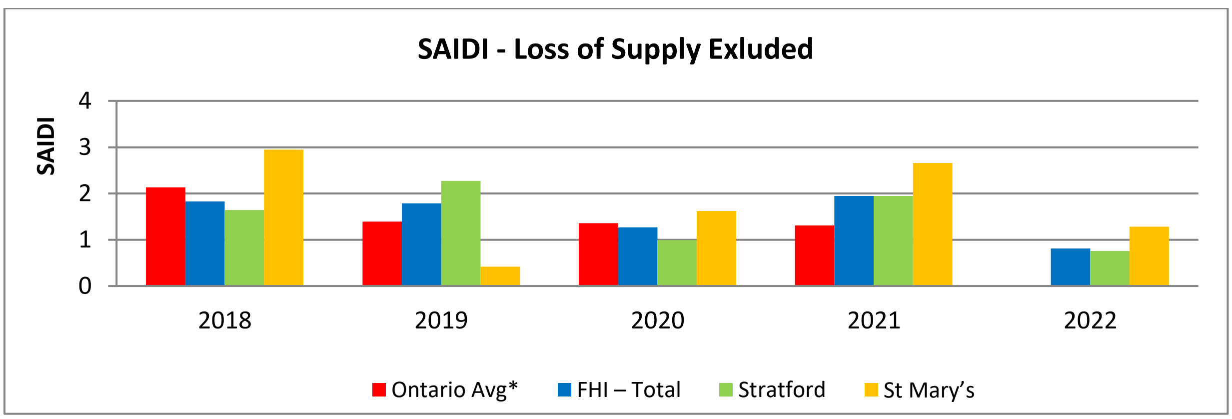
* Ontario average does not include Hydro One Networks

SAIDI – Excluding Loss of Supply

Outage Hours/Year

Area	2018	2019	2020	2021	2022	Avg
Ontario Avg*	2.13	1.39	1.36	1.31		1.55
FHI – Total	1.83	1.79	1.27	1.95	0.81	1.53
Stratford	1.64	2.27	0.99	1.95	0.76	1.52
68M2	0.48	0.18	0.16	0.30	1.63	0.55
68M3	0.6	3.62	1.18	3.66	0.14	1.84
68M4	0.22	0.26	2.92	1.22	0.56	1.04
68M5	3.25	2.17	0.81	1.72	0.17	1.62
68M8	5.88	2.90	2.52	0.26	1.51	2.61
8051M1	0.85	1.83	0.13	1.12	2.01	1.19
8051M2	0.43	0.66	0.00	0.38	0.00	0.29
8051M4	0.46	0.03	0.52	0.57	0.04	0.32
St Mary's	2.95	0.42	1.62	2.66	1.26	1.78
9M1	0.17	1.28	0.51	0.00	1.26	0.64
9M2	0.08	0.82	0.16	1.26	2.32	0.93
9M3	1.59	0.01	0.04	6.39	0.47	1.70
9M4	5.13	0.06	4.83	0.01	1.48	2.30

Loss of Supply did not have a significant impact for customers in St. Mary's, however it did impact customers within the rest of our system. Loss of Supply in Stratford (16%) and the remaining 5 communities (23%) accounted for 39% of outage minutes, system wide. At a community level, Loss of Supply was responsible for 28% of all Stratford outage minutes and 81% of all outage minutes in the remaining communities, excluding St. Mary's.



* Ontario average does not include Hydro One Networks

RELIABILITY INDICIES – Cont'd

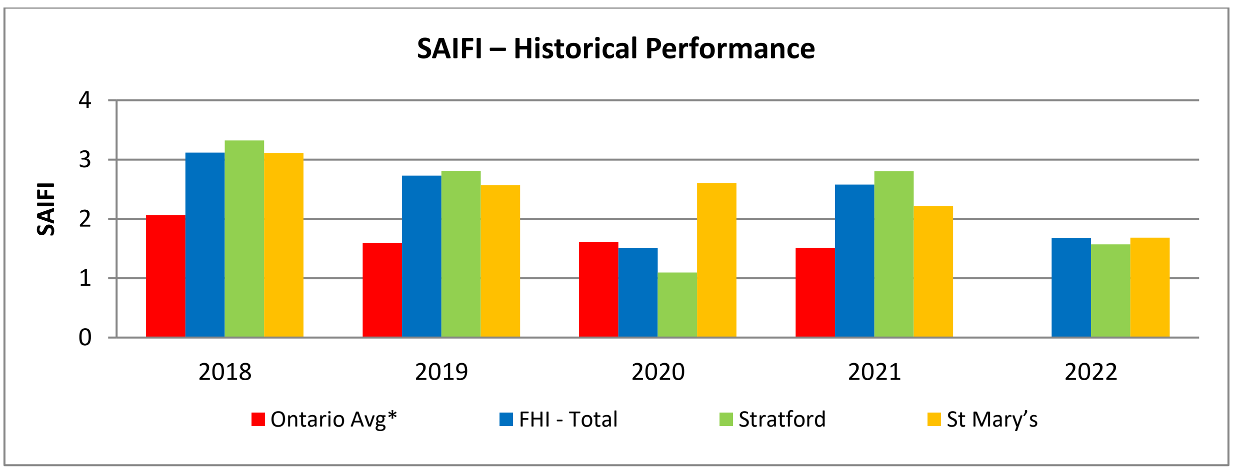
B) System Average Interruption Frequency Index (SAIFI) – This is the number of outages (greater than 1 minute) during the year that affects the average customer.

SAIFI – Historical Performance

Number of Outages/Year

Area	2018	2019	2020	2021	2022	Avg
Ontario Avg*	2.06	1.59	1.61	1.51		1.69
FHI - Total	3.12	2.73	1.50	2.58	1.68	2.32
Stratford	3.32	2.81	1.09	2.80	1.57	2.32
68M2	3.73	1.13	0.10	0.31	2.15	1.49
68M3	3.57	4.93	1.11	4.42	1.07	3.02
68M4	2.1	0.19	1.22	3.11	1.40	1.60
68M5	4.02	2.35	2.08	3.18	1.13	2.55
68M8	3.52	1.71	0.69	0.22	3.45	1.92
8051M1	2.37	2.28	0.09	1.38	2.14	1.65
8051M2	2	1	0	0.08	0.00	0.62
8051M4	2.03	0.03	1.07	0.06	8.14	2.27
St Mary's	3.11	2.57	2.61	2.22	1.68	2.44
9M1	1.11	1.44	1.17	1.02	0.98	1.14
9M2	0.04	2.87	2.30	1.41	2.33	1.79
9M3	2.06	1.02	1.31	4.64	0.86	1.98
9M4	5.08	3.03	4.90	0.01	2.90	3.18

In 2022, the average Festival Hydro customer would have experienced 1.68 outages greater than 1 minute in length. Customers outside of Stratford and St. Mary's were affected the most, followed by those in St. Mary's and Stratford.



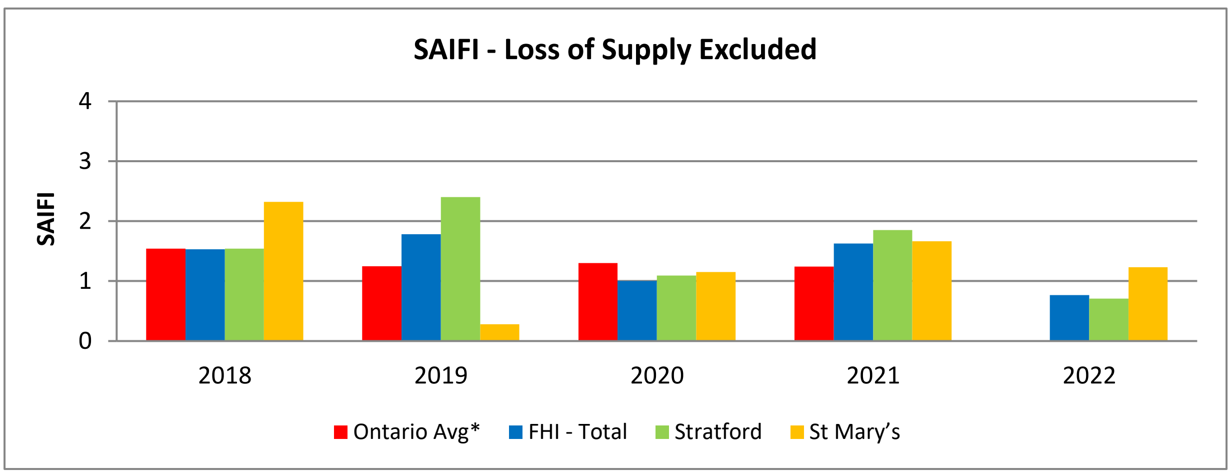
* Ontario average does not include Hydro One Networks

SAIFI – Excluding Loss of Supply

Number of Outages/Year

Area	2018	2019	2020	2021	2022	Avg
Ontario Avg*	1.54	1.25	1.3	1.24		1.33
FHI - Total	1.53	1.78	1.00	1.63	0.77	1.34
Stratford	1.54	2.40	1.09	1.85	0.71	1.52
68M2	1.72	0.16	0.10	0.31	1.15	0.69
68M3	1.58	3.93	1.11	3.42	0.07	2.02
68M4	0.1	0.19	1.22	2.11	0.40	0.80
68M5	2.1	2.35	2.08	1.18	0.14	1.57
68M8	1.52	0.71	0.69	0.20	1.45	0.91
8051M1	1.27	2.28	0.09	1.38	2.14	1.43
8051M2	1	1	0.00	0.08	0.00	0.42
8051M4	1.03	0.03	1.06	0.06	0.01	0.44
St Mary's	2.32	0.28	1.15	1.66	1.23	1.33
9M1	0.11	0.46	0.16	0.00	0.98	0.34
9M2	0.04	0.87	0.27	1.41	1.35	0.79
9M3	1.06	0.02	0.06	3.63	0.86	1.13
9M4	4.08	0.03	3.40	0.01	1.90	1.88

Loss of Supply had a considerable impact on frequency of outages in 2022, as system wide the SAIFI is reduced by 54% with loss of supply outages excluded which equates to nearly 1 additional outage experienced by the average customer.



* Ontario average does not include Hydro One Networks

RELIABILITY INDICIES – Cont'd

C) Customer Average Interruption Duration Index (CAIDI) – This is the average length of an outage in hours seen by the average customer and is calculated as SAIDI divided by SAIFI.

CAIDI – Historical Performance

Average Length of Outage in Hours

Area	2018	2019	2020	2021	2022	Avg
Ontario Avg*	2.13	1.11	1.1	1.10		1.36
FHI - Total	1.5	0.81	1.38	1.01	0.79	1.10
Stratford	0.97	0.82	0.91	0.88	0.67	0.85
68M2	0.69	0.26	1.55	0.95	0.91	0.87
68M3	0.75	0.76	1.07	0.99	0.44	0.80
68M4	1.08	1.34	2.40	0.42	0.65	1.18
68M5	1.28	0.92	0.39	0.87	0.44	0.78
68M8	2.26	1.75	3.65	1.42	0.58	1.93
8051M1	0.44	0.8	1.42	0.81	0.94	0.88
8051M2	0.31	0.66	0	4.50	0.00	1.09
8051M4	0.32	1.03	0.50	10.03	0.82	2.54
St Mary's	1.12	0.77	1.46	1.22	0.78	1.07
9M1	1.96	0.92	2.28	0.09	1.28	1.31
9M2	1.98	0.36	1.06	0.89	1.05	1.07
9M3	0.86	0.06	2.06	1.40	0.54	0.98
9M4	1.08	0.93	1.32	2.16	0.54	1.21

In 2022 the average length of an outage for FHI customers was 0.79 hours, the lowest in the past 5 years.

CAIDI – Excluding Loss of Supply

Average Length of Outage in Hours

Area	2018	2019	2020	2021	2022	Avg
Ontario Avg*	1.39	1.11	1.05	1.06		1.15
FHI - Total	1.19	1.00	1.26	1.20	1.06	1.14
Stratford	1.07	0.94	0.91	1.05	1.07	1.01
68M2	0.28	1.16	1.56	0.95	1.42	1.07
68M3	0.38	0.92	1.06	1.07	2.10	1.11
68M4	2.16	1.34	2.40	0.58	1.40	1.57
68M5	1.55	0.92	0.39	1.46	1.23	1.11
68M8	3.86	4.09	3.65	1.31	1.05	2.79
8051M1	0.67	0.8	1.42	0.81	0.94	0.93
8051M2	0.43	0.66	0.00	4.50	0.00	1.12
8051M4	0.45	1.03	0.49	10.03	2.68	2.94
St Mary's	1.27	1.5	1.41	1.60	1.02	1.36
9M1	1.56	2.78	3.16	0	1.28	1.76
9M2	1.98	0.95	0.59	0.89	1.72	1.23
9M3	1.49	0.57	0.66	1.76	0.54	1.00
9M4	1.26	1.88	1.42	2.16	0.78	1.50

Loss of Supply impacted the average outage duration in 2022 system wide with CAIDI increasing by 34% when loss of supply is excluded. This can be attributed to Loss of Supply outages having a greater effect on SAIFI as compared to SAIDI and therefore the remaining outages result in fewer customers being affected for a longer duration.

* Ontario average does not include Hydro One Networks

RELIABILITY INDICIES – Cont'd

D) Index of Reliability – This identifies the percentage of the time that service was available during a given year. There are 8760 hours in one year; therefore, 1 hour is equal to 0.011%.

Index of Reliability – Historical Performance

Percentage of Time Available

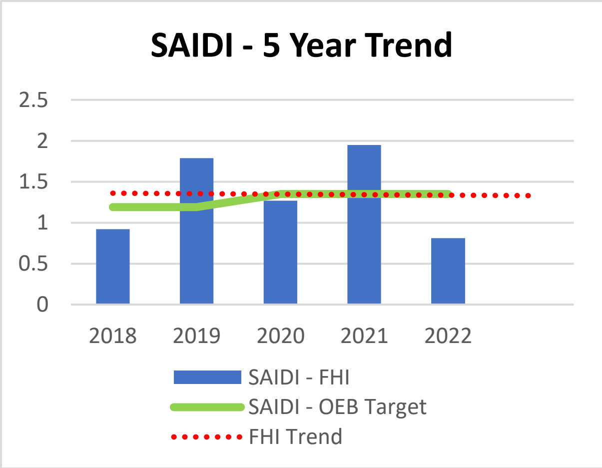
Area	2018	2019	2020	2021	2022	Avg
Ontario Avg*	99.950	99.98	99.98	99.98		99.980
FHI - Total	99.945	99.974	99.976	99.970	99.985	99.970
Stratford	99.962	99.973	99.989	99.972	99.988	99.977
68M2	99.97	99.997	99.998	99.997	99.978	99.988
68M3	99.969	99.956	99.986	99.950	99.995	99.971
68M4	99.973	99.997	99.967	99.985	99.990	99.982
68M5	99.94	99.975	99.991	99.968	99.994	99.974
68M8	99.907	99.965	99.971	99.996	99.977	99.963
8051M1	99.988	99.979	99.999	99.987	99.977	99.986
8051M2	99.993	99.992	100	99.996	100.000	99.996
8051M4	99.992	99.999	99.994	99.993	99.924	99.980
St Mary's	99.959	99.977	99.957	99.969	99.985	99.969
9M1	99.975	99.985	99.970	99.999	99.986	99.983
9M2	99.999	99.988	99.972	99.986	99.972	99.983
9M3	99.979	99.999	99.969	99.926	99.995	99.974
9M4	99.936	99.967	99.926	99.999	99.982	99.962

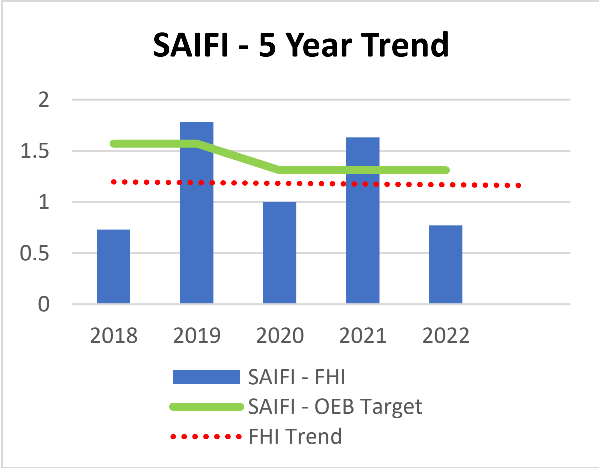
In 2022, the average FHI customer could expect the power to be available 99.985% of the time, which is above the 5-year average. By excluding Loss of Supply Index of Reliability would increase to 99.991%.

E) Major Event and Loss of Supply Excluded – 5 Year Trend – The table below shows the SAIDI and SAIFI values over the last 5 years for the entire Festival Hydro system, with both loss of supply and major event causes excluded as well as the OEB Scorecard targets for these same indices. 2022 was the fourth year in a row year in which no major events occurred.

A major event is an interruption or group of interruptions caused by conditions that exceed the design and operational limits of the system. A major event occurs when the daily SAIDI exceeds a threshold value, T_{MED}, as calculated per IEEE Standard 1366. For 2022 our T_{MED} value was 54.61 which correlates to 1,215, 673 total customer outage minutes (20,261 hours).

Index	2018	2019	2020	2021	2022	Avg.
SAIDI - FHI	0.92	1.79	1.27	1.95	0.81	1.35
SAIDI - OEB Target	1.19	1.19	1.35	1.35	1.35	1.29
SAIFI - FHI	0.73	1.78	1	1.63	0.77	1.18
SAIFI - OEB Target	1.57	1.57	1.31	1.31	1.31	1.41





RELIABILITY INDICIES – Cont'd

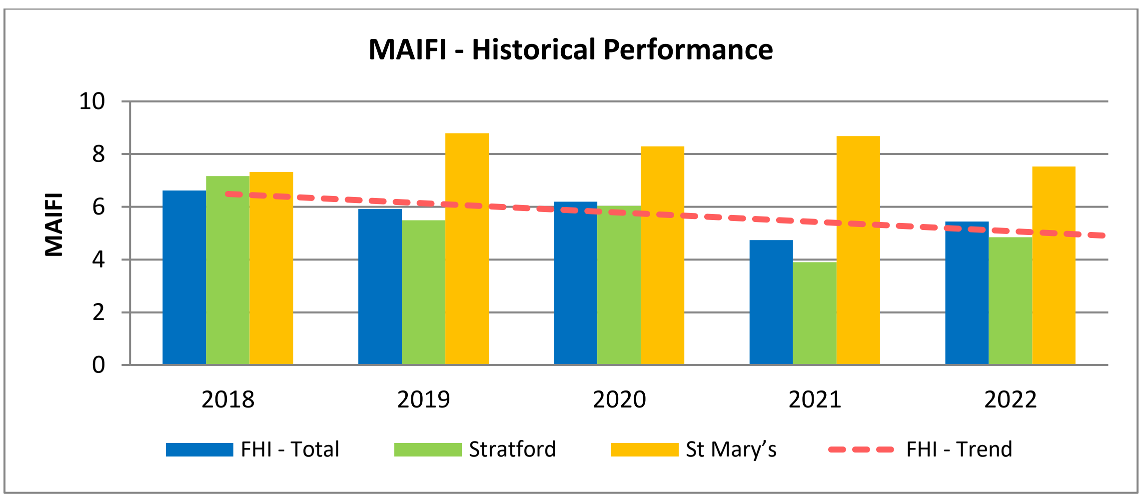
F) Momentary Average Interruption Frequency Index (MAIFI) – This is the average number of momentary interruptions (less than 1 minute) seen by the average customer in one year.

MAIFI – Historical Performance

Average Number of Momentary Interruptions/Year

Area	2018	2019	2020	2021	2022	Average
FHI - Total	6.62	5.91	6.20	4.74	5.44	5.8
Stratford	7.17	5.49	6.04	3.90	4.84	5.5
68M2	2	1.05	0.99	2.00	3.00	1.8
68M3	3.9	2.00	3.01	3.00	1.00	2.6
68M4	4	1.00	2.97	2.00	9.00	3.8
68M5	10.8	12.62	10.00	6.00	6.99	9.3
68M8	4.9	1.00	1.07	3.00	9.01	3.8
8051M1	9.4	5.00	9.00	4.02	4.97	6.5
8051M2	1	1.00	0.00	0.00	0.00	0.4
8051M4	0	3.00	2.99	0.99	16.25	4.6
St Mary's	7.32	8.79	8.30	8.68	7.53	8.1
9M1	3.9	5.77	10.03	4.98	3.00	5.5
9M2	10.3	12.00	9.01	10.43	7.05	9.8
9M3	3	9.00	10.66	7.36	9.73	7.9
9M4	8.1	8.43	4.52	12.01	7.99	8.2

In 2022, the average Festival Hydro customer would have experienced nearly 5.5 outages of less than 1 minute in length, which is slightly below the 5-year average. St. Mary's customers experienced about 7.5 momentary outages which is just below the 5-year average and the second lowest level in the past 5 years.



2. DATA ANALYSIS

To get a better understanding of what is happening to the distribution system, the data is analyzed excluding the number of affected customers from Loss of Supply Outages (which are upstream of the distribution system) and from Scheduled Outages (which are not a result of problems with the distribution system).

A) Number Of Outages – The quantity of outages greater than 1 minute each year, excluding Loss of Supply and Scheduled causes. It should be noted that the number of outages does not mean the entire feeder experienced an outage, only that an outage occurred somewhere on that feeder.

Number of Outages/Year

Area	2018	2019**	2020**	2021**	2022**	Average
FHI - Total	82	92	75	91	74	82.8
Stratford	49	52	44	56	40	48.2
68M2	2	4	2	2	5	3.0
68M3	16	20	10	22	6	14.8
68M4	3	3	6	4	3	3.8
68M5	11	17	14	12	12	13.2
68M8	5	1	0	4	3	2.6
8051M1	11	5	10	12	10	9.6
8051M2	1	1	0	0	0	0.4
8051M4	1	1	2	0	1	1.0
St Mary's	20	17	17	23	21	19.6
9M1	1	3	3	0	0	1.4
9M2	3	8	3	6	4	4.8
9M3	1	2	2	15	7	5.4
9M4	15	4	9	2	10	8.0

B) Number Of Outages by Cause – The quantity of outages greater than 1 minute for each cause each year, excluding Loss of Supply and Scheduled outage causes.

Number of Outages/Year

Cause	2018	2019**	2020**	2021**	2022**	Average
Adverse Environment	0	2	0	0	0	0.4
Adverse Weather	14	15	3	10	8	10.0
Defective Equipment	39	35	23	33	31	32.2
Foreign Interference	19	28	30	29	23	25.8
Human Error	2	3	1	0	1	1.4
Lightning	0	0	3	4	0	1.4
Tree Contacts	4	1	10	8	9	6.4
Unknown	4	8	5	7	2	5.2
Total	82	92	75	91	74	82.8

**Only initial outages are shown. When restoration of the same outage event occurs in stages until service is restored to all customers it will be considered a single outage rather than multiple outages.

DATA ANALYSIS – Cont'd

C) Number Of Feeder Lockouts – The quantity of outages greater than 1 minute each year that affected the entire feeder, excluding Loss of Supply causes (Feeder Lockout).

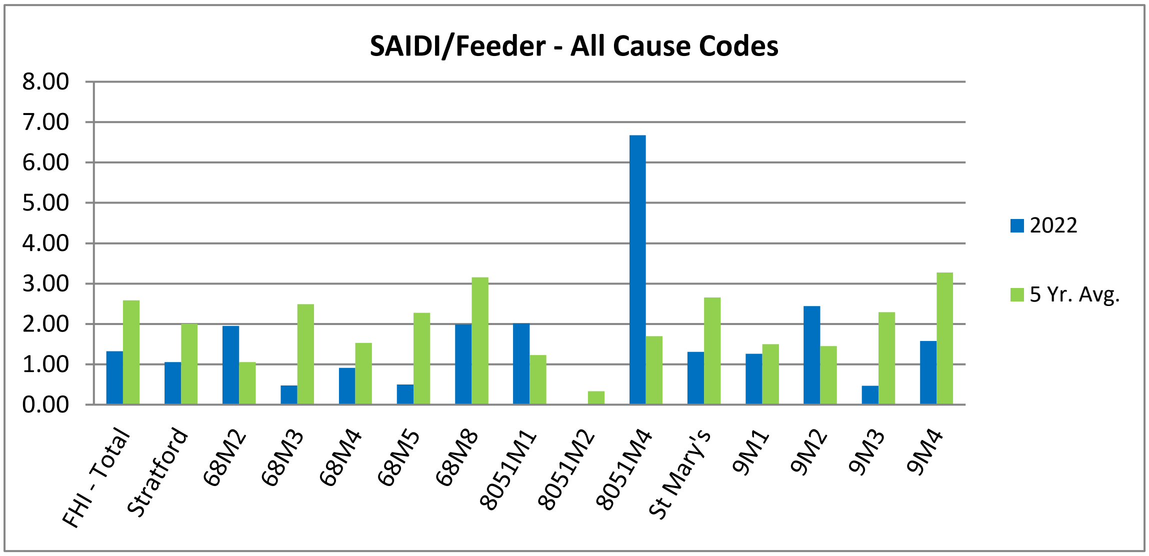
Number of Feeder Lockouts/Year

Area	2018	2019	2020	2021	2022	Average
FHI - Total	15	5	8	9	5	8.4
Stratford	10	5	5	7	3	6.0
68M2	1	0	0	0	0	0.2
68M3	1	2	1	3	0	1.4
68M4	0	0	1	2	0	0.6
68M5	2	1	2	1	0	1.2
68M8	1	0	0	0	1	0.4
8051M1	1	2	0	1	2	1.2
8051M2	1	1	0	0	0	0.4
8051M4	1	0	1	0	0	0.4
St Mary's	4	0	3	1	1	1.8
9M1	0	0	0	0	0	0.0
9M2	0	0	0	0	0	0.0
9M3	1	0	0	1	0	0.4
9M4	3	0	3	0	1	1.4

3. TREND ANALYSIS

It should be noted that 2021 was the first full year with the St. Mary's 9M3 and 9M4 feeders reconfigured. The reconfiguration balanced customer counts by shifting approximately 785 customers from the 9M4 to the 9M3 including the Victoria and Thomas Street reclosers. As a result, the 5-year averages for the 9M3 and 9M4 are not representative of their current configuration.

SAIDI (duration)



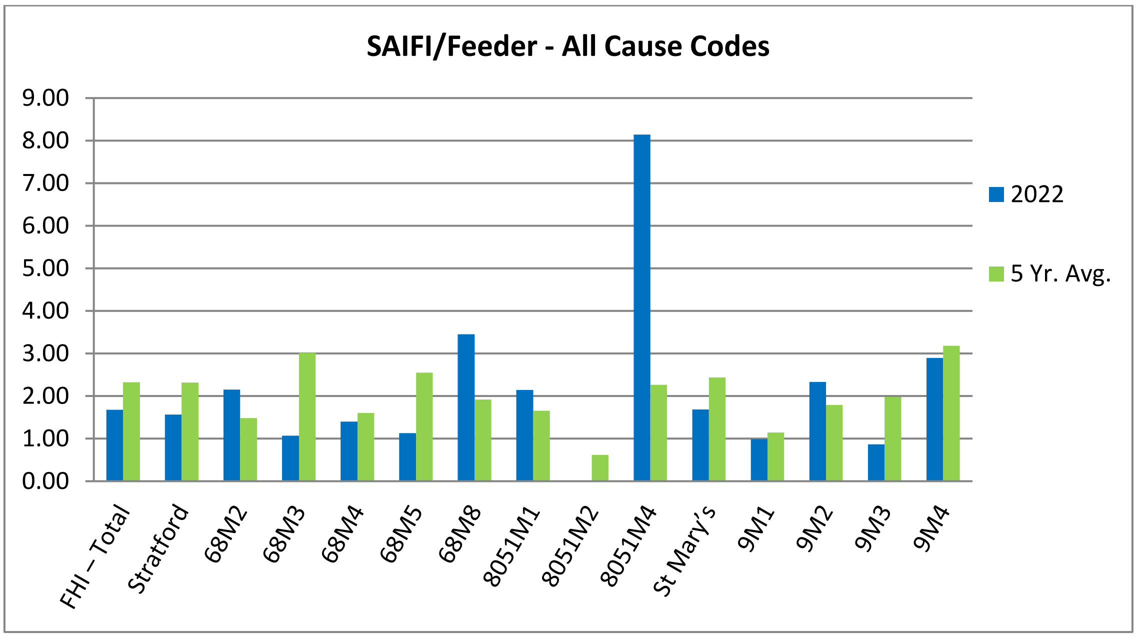
With Loss of Supply included the average outage duration for the entire FHI territory is well below the 5-year average and is the lowest in the past 5 years. With Loss of Supply excluded the outage durations are also the lowest in the past 5 years. Loss of Supply did not have an impact in St. Mary's however in Stratford, Loss of Supply accounted for 28% of outage minutes (16% system wide) affecting the 8051M4, 68M3 and 68M5 feeders. Loss of supply also had a significant impact on the other 5 communities causing 81% of those outage minutes (23% system wide).

TREND ANALYSIS – Cont'd

The 8051M4 had 1 outage caused by Loss of Supply which accounted for 99% of all outage minutes on this feeder causing it to have the highest SAIDI of the entire system. This value, however, is overstated due to the outage occurring while the 8051M4 was supplying part of the 68M2 during the Romeo St capital job, resulting in more customer outage minutes than otherwise would have occurred.

The high average outage duration on the 9M2 was due to a Foreign Interference outage caused by a squirrel that resulted in 81% of outage minutes for this feeder while 2 outages on the 8051M1 caused by Foreign Interference (vehicle accident, 48%) and Tree Contacts (47%) accounted for 95% of its outage minutes.

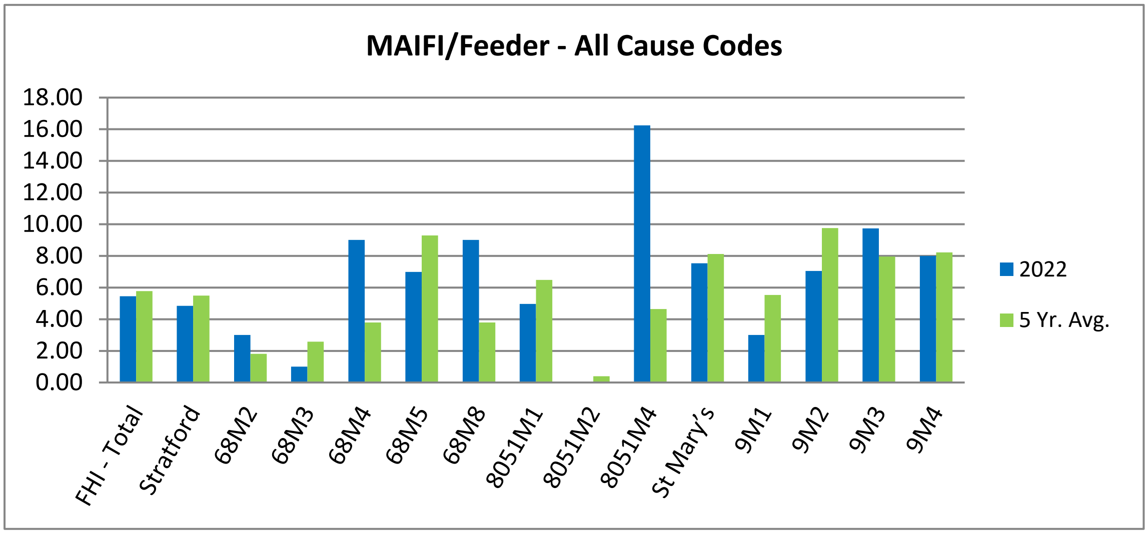
SAIFI (frequency)



Outage frequencies in 2022 were below the 5-year average with and without Loss of Supply included. Outage frequencies for the system are second lowest in the past 5 years.
Outages in Stratford on the 8051M1 (20%), 68M3 (13%) and the 68M5 (13%) together with the were the main contributors to the entire system's outage frequency.

TREND ANALYSIS – Cont'd

MAIFI (frequency of momentary outages)

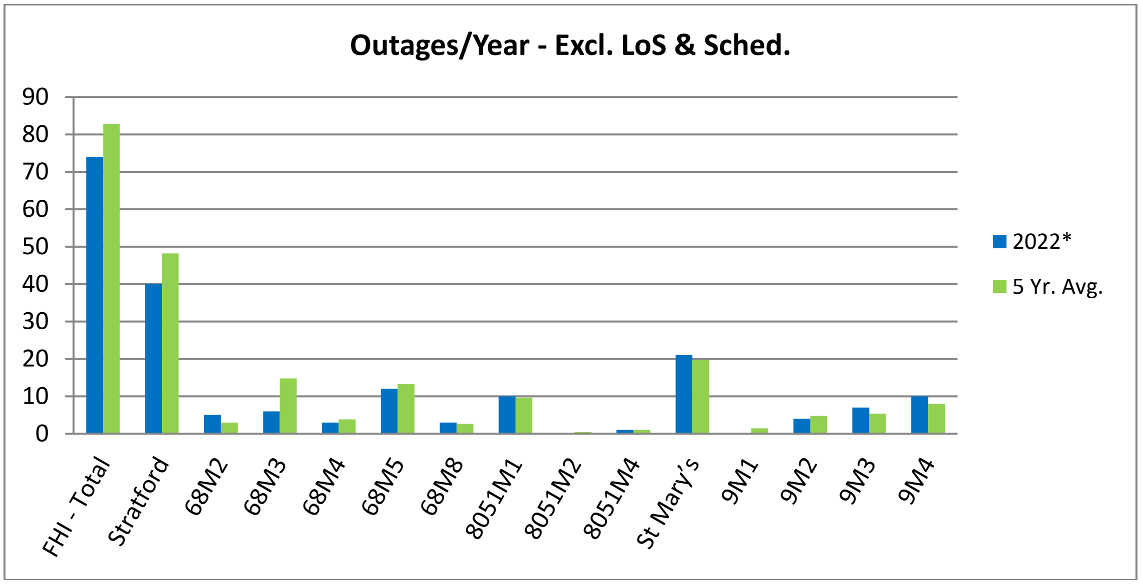


The number of customers that experienced momentary outages for the entire system is slightly below average this year and is the second lowest level in the last 5 years. Most feeders in St. Mary's saw momentary outages below their 5-year average, however 4 Stratford feeders had a notably higher MAIFI than their historical 5-year averages. Momentary outage causes for these feeders include Foreign Interference, Unknown causes, Defective Equipment and Loss of Supply while the remaining communities were caused by Loss of Supply.

Like SAIDI and SAIFI, the 8051M4 is inflated due to the momentary outages occurring while the feeder supplied a portion of the 68M2 as part of the Romeo St capital job, resulting in significantly more customers connected than usual.

TREND ANALYSIS – Cont'd

Number of Outages (excluding Loss of Supply and Scheduled)

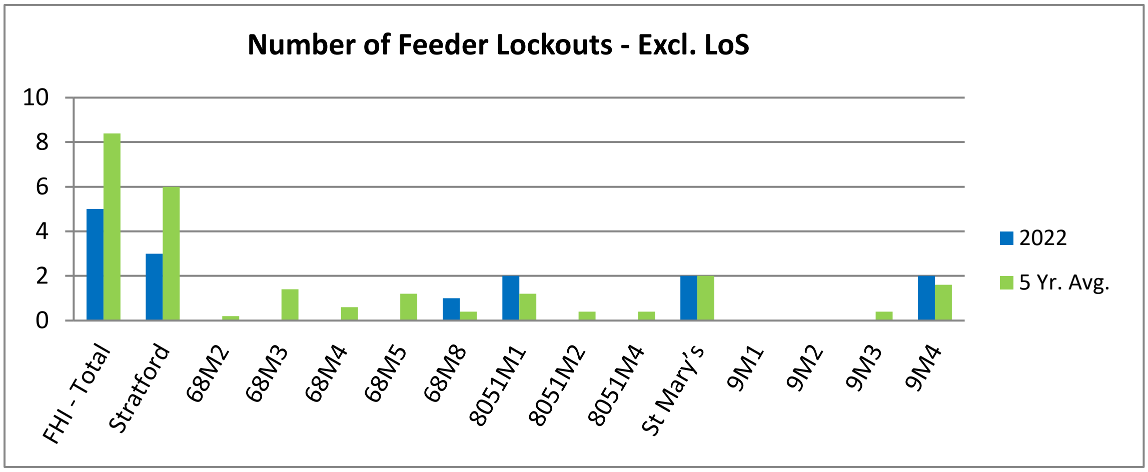


The number of outages in 2022 was below the 5-year average. As in previous years, most of the outages occurred in Stratford and St. Mary's on the feeders with more exposure. The 68M3 feeder in Stratford experienced outages significantly below its average with all other feeders in Stratford experiencing their average number of outages. St. Mary's experienced a similar number of outages compared to previous years, with most occurring on the 9M4 as opposed to the 9M3 in 2021.

It should be noted that the process of restoration may require restoring service in stages to small sections of the system until service has been restored to all customers. As required by the OEB, each of these individual stages is tracked, collecting the start time, end time and number of affected customers for each stage. This philosophy allows the Utility to restore power more quickly to some of the affected customers however as a result, the total number of outages may be misleading. To provide a more accurate representation of the system's performance only the initial outage has been counted rather than each individual stage (where applicable). This change has been applied retroactively to 2019 to better represent the 5 year averages.

TREND ANALYSIS – Cont'd

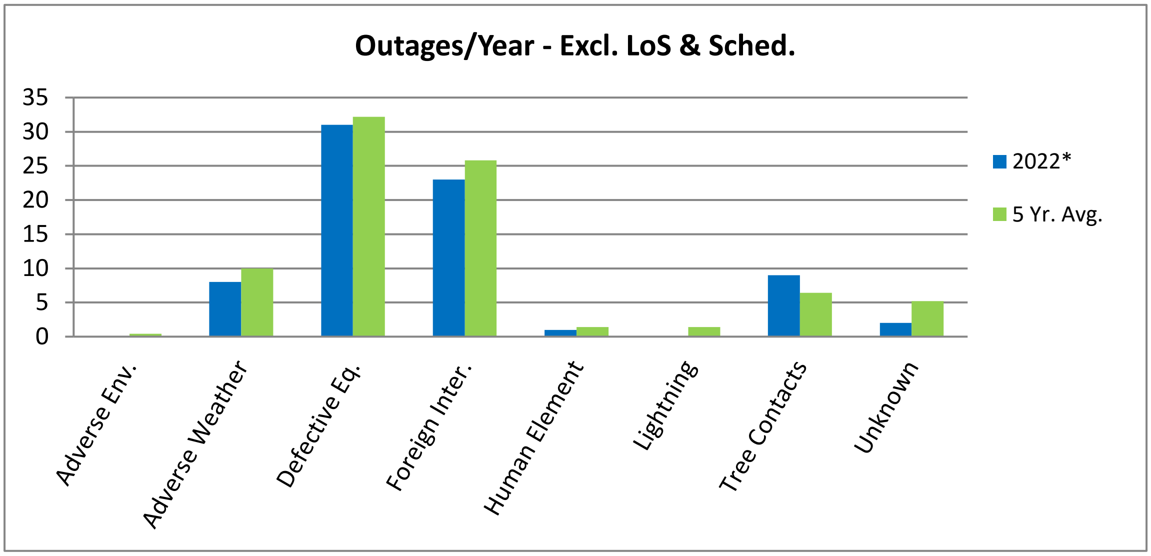
Number of Feeder Lockouts (outages to entire feeder, excluding Loss of Supply)



The number of feeder lockouts in 2022 was 40% below the 5-year average with all lockouts occurring on Stratford feeders 68M8 and 8051M1 as well as the 9M4 in St. Mary's. Multiple lockouts were experienced by 8051M1 due to Tree Contacts and Foreign Interference (vehicle accident). Defective Equipment, Foreign Interference (animal) and Unknown were causes for the remaining lockouts.

TREND ANALYSIS – Cont'd

Number of Outages by Cause (excluding Loss of Supply and Scheduled)



It is worth noting that only the initial outage will be counted rather than each individual restoration stage (when applicable) which will provide a more accurate representation of the system's performance. To maintain the 5-year average as best as possible, this change was applied retroactively to 2019.

Adverse Weather was attributed to 8 outages in 2022, which is below the 5-year average despite significant weather events occurring throughout the year.

The number of outages that occurred because of Defective Equipment was slightly below the 5-year average and very comparable to the previous year. Of all the outages, 42% were due to Defective Equipment (excluding Loss of Supply and Scheduled). Defective switches and connections were responsible for 18 of the 31 outages.

Foreign interference outages (animals, vehicles) were marginally lower compared the 5-year average. 14 of the 23 outages were caused by animal contacts, 7 were caused by motor vehicle accidents and 2 from contractor dig-ins.

Tree Contacts were attributed to 9 outages in 2022, which is similar to the previous year and above the 5-year average. 2 of 9 outages affected only a single customer.

There were 2 outages in 2022 for which no cause was found, which is about half the 5-year average. All outages occurred in St. Mary's on the 9M3 feeder.

There was 1 sustained outage in 2022 attributed to Human Element that occurred in Seaforth.

There were no sustained outages in 2022 that were attributed to Adverse Environment or Lightning.

Overall, the number of outages greater than 1 minute was 11% below the 5-year average. Nearly three quarters of outages were due to Foreign Interference or Defective Equipment, which is consistent with the 5-year trend.

4. DETAILED ANALYSIS

DURATION:

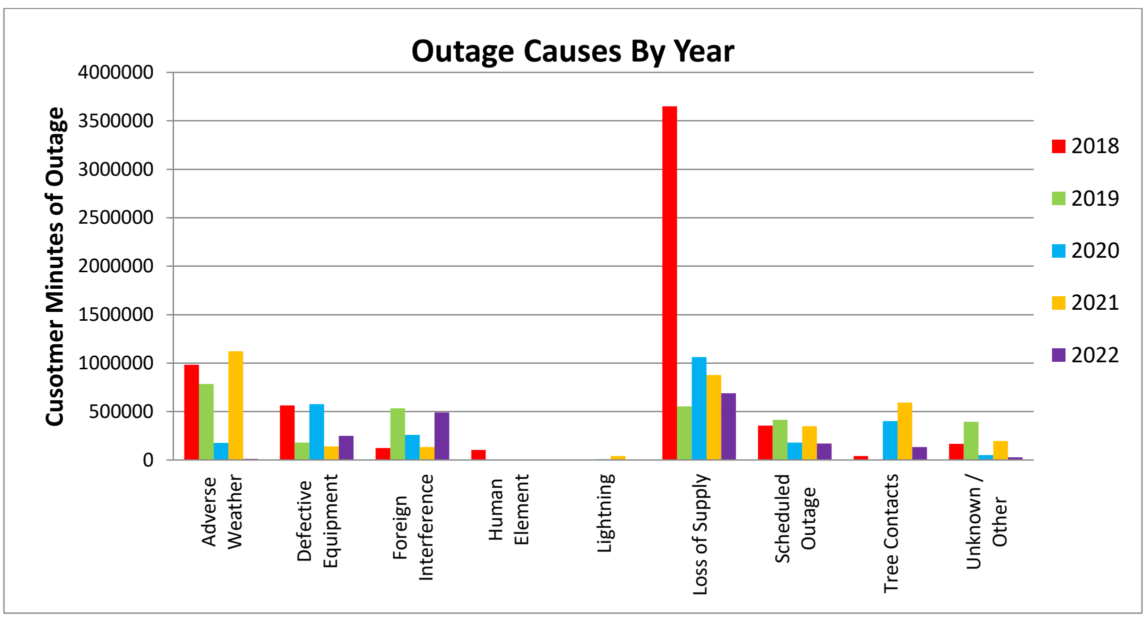
The 6 longest outages in terms of customer minutes accounted for about 33% of the total customer minutes in 2022 occurring in Stratford on the 8051M1, 68M3 and 68M5 feeders and in Zurich/Dashwood on the 6102F1. Of these 6 outages, 4 occurred because of Hydro One station issues (Loss of Supply), 1 occurred because of a vehicle accident (Foreign Interference) and 1 was caused by a fallen branch (Tree Contact). The 10 longest outages, accounting for 49% of the total customer minutes, occurred in Stratford (26%), St. Mary's (8%) and Zurich/Dashwood (15%). Of these 10 outages, Loss of Supply (25%), Foreign Interference (18%) and Tree Contacts (6%) were the common cause codes.

FREQUENCY:

The SAIFI numbers for the entire system were below the 5-year average since the larger Stratford feeders experienced fewer outages in 2022 compared to the 5-year average. The 8 outages that affected most customers in 2022 accounted for 50% of all customers that experienced an outage throughout the year. For all outages, Loss of Supply (54%) and Foreign Interference (17%) were responsible for impacting most customers in 2022.

OUTAGE CAUSES:

The total number of outages remained nearly the same as in 2021 however, the number of affected customers decreased by 34% while total customer minutes decreased by over 48% when compared to 2021.



Weather = outage caused by high winds, blowing debris, ice, flooding
Equipment = outage caused by failure of distribution equipment
Foreign Interference = outage caused by animals, vehicles, vandalism
Human Element = outage caused by human error
Lightning = outage caused by lightning strike
Loss of Supply = Outages on Hydro One System Supplying Festival Hydro
Scheduled = planned outage by Festival Hydro needed to upgrade system
Tree Contact = outage caused by contact with tree or tree limb
Unknown = no cause could be found

DETAILED ANALYSIS – Cont'd

Loss of Supply outages had a significant impact for customers in Stratford and our outlying communities where 98% of these outage minutes occurred (40% from Stratford and 58% from remaining 5 communities) in 2022. Loss of Supply accounted for 39% of all outage minutes system wide.

Adverse Weather had a minor impact in 2022, contributing to only 1% of all outage minutes.

Foreign Interference outage minutes were the second highest level in the past 5 years, responsible for roughly 28% of all outage minutes system wide. The largest 4 of 28 outages were responsible for 64% of all Foreign Interference related customer outage minutes due to animal contacts (2) and motor vehicle accidents (2).

Tree Contacts number of outages remained the same compared to 2021 however outage minutes decreased substantially and accounted for only 8% of all outage minutes. A single outage in Stratford affecting the entire 8051M1 feeder was responsible for 76% of those outage minutes.

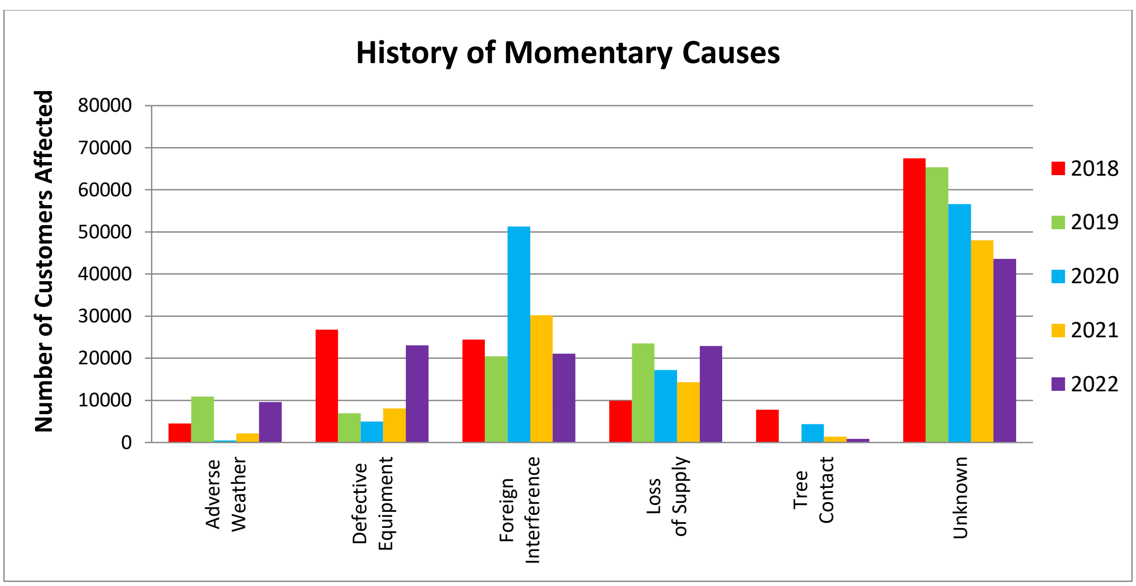
Defective Equipment number of outages in 2022 were slightly less than in 2021 however outage minutes were 80% higher yet still below the 5-year average, contributing to 14% of all outage minutes. The 4 of 38 longest outages in this category accounted for 49% of all outage minutes due to defective equipment and 93% of outage minutes occurred in Stratford. The largest amount of customer outage minutes this year was attributed to defective connections.

Outages due to Unknown causes accounted for approximately 2% of all outage minutes in 2022, well below the 5-year average with all 3 outages occurring in St. Mary's.

Human Element outage minutes did not have a significant impact on the overall system.

MOMENTARY OUTAGES:

The MAIFI (Momentary Average Interruption Frequency Index) measures the number of outages less than 1 minute, as seen by the average customer. The graph below shows the causes of the outages for the past five years based on number of customers affected.



DETAILED ANALYSIS – Cont'd

Overall, the number of customers affected by momentary outages increased by about 16% in comparison to 2021, which is also approximately 4% below the 5-year average. Unknown cause was responsible for 36% of affected customers with Defective Equipment, Loss of Supply and Foreign Interference responsible for 19%, 19% and 17% respectively.

Approximately 49% of the total number of customers affected in 2022 were on the 68M4, 68M5 and 8051M1 feeders. There was a significant improvement to the number of affected customers on the 68M3 while the 68M4 saw an increase, mainly resulting from Foreign Interference.

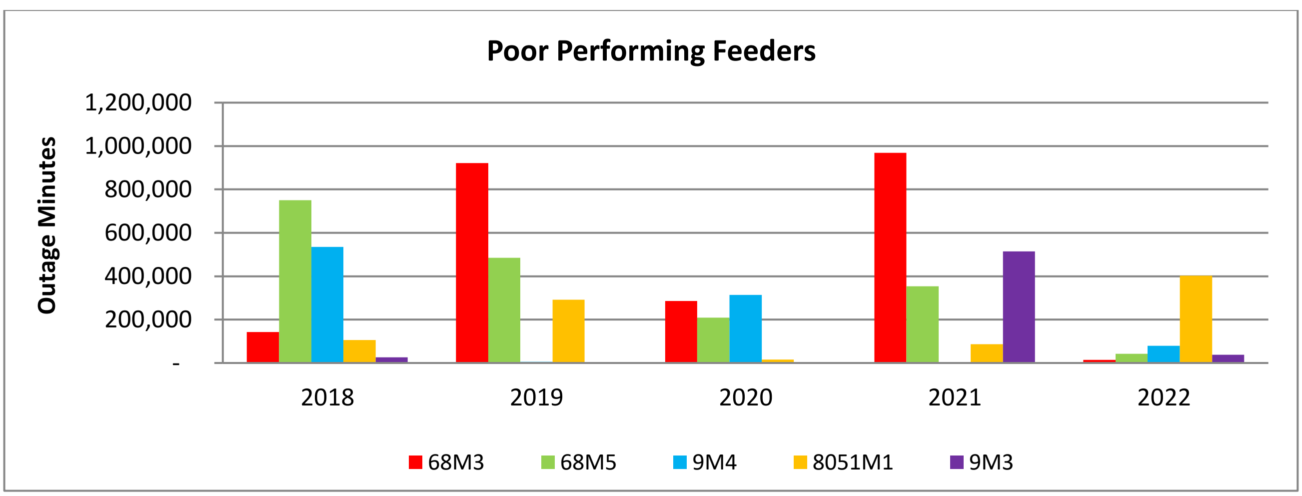
POOR PERFORMING FEEDERS:

Using the historical records, the worst performing feeders have been identified using customer minutes of outage as the primary criteria (excluding scheduled and loss of supply outages).

The decision to rank the feeders based on customer outage minutes assumes that the objective is to improve the overall system reliability by identifying those areas that contribute the most to the overall indices of SAIDI and SAIFI. This will have the effect of decreasing the duration and frequency of outages to the average customer. The feeders with the most customers respectfully become the targets for potential improvements.

The chart below ranks the Stratford and St. Mary's feeders with over 500,000 cumulative customer outage minutes over the past 5 years from worst to best.

Feeder	% of Customer Base in 2022	2018	2019	2020	2021	2022	Total	% of Outage Minutes
68M3	20.4%	143,001	922,089	285,557	969,396	14,763	2,334,806	30.78%
68M5	19.7%	749,759	485,094	208,967	353,715	42,575	1,840,110	24.26%
9M4	3.8%	535,066	6,042	314,234	581	74,827	930,750	11.15%
8051M1	15.4%	105,158	291,569	16,467	86,288	402,454	901,936	11.89%
9M3	6.1%	26,220	35	150	514,724	37,962	579,091	7.63%



DETAILED ANALYSIS – Cont'd

1. <u>68M3 Feeder in Stratford</u>
   This feeder supplies primarily residential customers in the south-central area of Stratford and is almost exclusively overhead distribution in older residential areas. The proximity to mature trees also makes this feeder susceptible to animal and tree contacts. This feeder had outage minutes substantially below its 5-year average in 2022 and was responsible for only 1% of outage minutes system wide (excluding Loss of Supply and Scheduled). The average customer on this feeder experienced almost no outages (0.07) in 2022 with Loss of Supply excluded. 99% of all outage minutes on this feeder were attributed to either Loss of Supply or Scheduled outages. Of its 14 outages, one Loss of Supply issue at the Stratford TS was responsible for 94% of the outage minutes.

2. <u>68M5 Feeder in Stratford</u>
   This feeder supplies mostly residential customers in the north-west part of Stratford. It is one of the longest feeders with a lot of exposure to weather, animals and tree contacts. This feeder's outage minutes were 88% lower than its 5-year average in 2022. 50% of outage minutes on this feeder were the result of one defective switch. The average customer on this feeder experienced 0.14 outages in 2022 with Loss of Supply excluded.

3. <u>9M4 Feeder in St. Mary's</u>
   This is the second full year with the 9M4 feeder reconfigured. Prior to April 2020, this feeder supplied power to over half of the customers in St. Mary's, mostly in the west part of town and a portion of the downtown core. After April 2020, the 9M3 and 9M4 feeders in St. Mary's were reconfigured to reduce the number of customers on the 9M4, as well as to help reduce outage durations during sustained outages using smart switches. The 9M4 now supplies power to a quarter of the customers in St. Mary's, mostly throughout the center of Town. While still high on the list due to outage minutes from 2018 to 2020, in 2022 this feeder performed 57% below its 5-year average and was responsible for 10 outages contributing to 8% of system wide outage minutes (excluding Loss of Supply and Scheduled). A single Foreign Interference outage was responsible for 77% of the outage minutes on this feeder with the average customer experiencing nearly 2 outages in 2022 with Loss of Supply excluded.

4. <u>8051M1 Feeder in Stratford</u>
   This feeder supplies mostly residential customers in the west part of Stratford. This feeder had outage minutes substantially (123%) above its 5-year average and was the worst performing feeder in 2022 with 44% of outage minutes system wide (excluding Loss of Supply and Scheduled). The two largest outages on this feeder caused over 52% of its outage minutes; Tree Contacts and Foreign Interference (vehicular) with 29% caused from another Foreign Interference (vehicle) outage. Customers on this feeder experienced an average of just over 2 outages in 2022.

5. <u>9M3 Feeder in St. Mary's</u>
   This is the second year with the 9M3 feeder reconfigured. In April 2020 the 9M3 and 9M4 feeders in St. Mary's were reconfigured to better balance the load and customer count between them, adding more customers and exposure primarily on the west side of Town to this feeder compared to previous years. This feeder's outage minutes were 67% less than the 5-year average and accounted for only 4% of outage minutes system wide (excluding Loss of Supply and Scheduled). This feeder remains on the list due to an uncharacteristically high number of outage minutes from 2021 caused in large part by a tree that has since been removed.

6. <u>2022 Poor Performers</u>
   This year many of the historically poor performing feeders operated quite well, with only the 8051M1 being above its 5-year average for outage minutes. As a result, it's worth briefly noting the remaining top 3 worst performing feeders. The 9M2 in St. Mary's was the second worst feeder and it experienced 3.4 times more outage minutes in 2022 than its 5-year average however, 90% of these minutes are from a single Foreign Interference event. The 68M2 in Stratford was the third worst feeder in 2022 and it had outage minutes 4.3 times above its 5-year average for 11% system wide (excluding Loss of Supply and Scheduled). Two outage events on this feeder were responsible for 96% of its outage minutes, all caused by Defective Equipment.

6. RECOMMENDATIONS

CAPITAL BUDGET ITEMS

There are several projects in the 2023 budget that are focused solely on reducing momentary and prolonged outages, including the following:

- Continue live front padmount switchgear replacement and removal in Stratford and St. Mary's with elimination of all Live front units by 2025.
- Animal guarding equipment will be installed around poles difficult to re-insulate in an attempt to further reduce momentary outages in St. Mary's.
- Smart Fault Indicators which relay information back to our SCADA system are being deployed to give insight into pinpointing outage locations.
- Deployment of a new team of smart switches in St. Mary's that will work to automatically restore and reroute power during outage situations, minimizing length of time customers will be out of power.
- The Utilismart Outage Management System will give Festival Hydro new insights into outage locations and times. By leveraging existing information Festival Hydro has from its smart meters and distribution system, the location and potential causes of outages will be identified in near real time, allowing for a quicker and more focused response.

OPERATING BUDGET ITEMS

Asset Condition Assessment and Distribution System Plan to update and prioritize our biggest risk assets to ensure we are optimizing the spending of our budget dollars.

The Operations Manager will continue to meet with the City of Stratford and Town of St Mary's representatives on a regular basis to review tree trimming requirements and performance.

Festival Hydro will continue with transformer painting as an economical approach to extending the useful life of existing transformers that have started to show signs of rust and otherwise would continue to deteriorate, eventually requiring replacement or causing an outage. This preventative measure aims to reduce Defective Equipment outages specifically related to transformer replacement and pre-mature aging of the asset.

Festival Hydro will continue with infrared inspections, pole inspections, manhole inspections and the use of the maintenance matrix to ensure all systems are being inspected at regular intervals. We will also be continuing maintenance on load interrupter switches.

This information has been prepared by Jordan Murray, Distribution Engineer. Any questions should be directed to the author.

Festival Hydro Inc.
187 Erie Street
PO Box 397
Stratford, ON N5A 6T5

Attention: Jordan Murray, Distribution Engineer
Phone: 519-271-4703 x 312
Fax: 519-271-7204
Email: jmurray@festivalhydro.com

Appendix J

Kinectrics 2023 Asset Condition Assessment

FESTIVAL HYDRO INC.
2023 ASSET CONDITION ASSESSMENT

Kinectrics Report: K-814374-RA-0001-R01

December 19, 2023

Kinectrics Inc.
800 Kipling Avenue
Toronto, ON
M8Z 6C4 Canada
www.kinectrics.com

DISCLAIMER

FESTIVAL HYDRO INC.
2023 ASSET CONDITION ASSESSMENT

Kinectrics Report: K-814374-RA-0001-R01

December 19, 2023

Prepared by:

Digitally signed by WANG Fan
Date: 2023.12.19 10:13:10 -05'00'

Fan Wang Ph. D. P. Eng.
Senior Engineer

Reviewed by:

Digitally signed by LOTHO Katrina
Date: 2023.12.19 11:42:53 -05'00'

Katrina Lotho BE Sc, BSc, P. Eng.
Senior Engineer

Approved by:

Digitally signed by COELHO Garreth
Date: 2023.12.19 12:19:45 -05'00'

Garreth Coelho P. Eng.
Business Area Director – Distribution and Asset Management

Dated: ________________________

To: Festival Hydro Inc
187 Erie Street, P. O. Box 397
Stratford, Ontario
N5A 6T5

Revision History

Revision Number	Date	Comments	Approved
R00	2023-06-09	Draft	
R01	2023-12-19	Final	

EXECUTIVE SUMMARY

In 2023 Festival Hydro Inc. (FHI) determined a need to perform a condition assessment of its key distribution assets. FHI selected and engaged Kinectrics Inc. (Kinectrics) to assist with this work. This report presents the results of 2023 Asset Condition Assessment (ACA) study, based on the available condition data as of the end of June 2023.

Asset Categories Considered

The 11 asset categories (19 sub-categories in total) included in the 2023 ACA are as follows:

- Power Transformers
- MS Switchgear
- Distribution Transformers (Pad, Pole)
- Poles (Wood, Concrete)
- OH Primary Conductors
- UG Primary Cables (XLPE, TRXLPE)
- OH Gang Switches
- Pad Mounted Switchgear (Solid Dielectric, Air)
- Structures (Vault, Manhole)
- Fleet Vehicles (Pickup, Bucket)
- Meters (Residential, Industrial/Commercial, Primary Metering Unit)

For each asset category, available data are assessed, Health Index distribution is determined, and condition-based Flagged-for-action plan is developed.

For asset categories inside substations, specifically Power transformers and MS switchgear, assets are typically replaced *proactively*, i.e., before they fail, while for the rest of the asset categories assets (except for poles) are typically run to failure and replaced *reactively*. For the asset categories with assets replaced *proactively,* a risk-based prioritized list that identifies specific units and required time of action is developed. For assets replaced *reactively*, quantities of units expected to be replaced each year is estimated without identifying specific units.

Overall Health Index Distribution

In general, 9 of the 19 sub-categories have more than 70% of their units classified as “good” or “very good” and with an average Health Index score of greater than 70%.

With respect to the asset categories of concern, Poles (Wood), Pad Mounted Switchgear (Air), Structures (all types), Fleet Vehicles (all types), and Meters (all types) have more than 25% of units classified as “poor” or “very poor” condition.

Flagged-for-action Plans

Flagged-for-action plan refers to a 10-year plan identifying how many units within each asset category require some action. In most cases the required action is replacement, however, for the asset categories replaced proactively other options are available, e.g., refurbishment, enhanced maintenance, operating solution, real time monitoring, or even “do nothing”. For that reason, the numbers presented in the Flagged-for-action plan are not necessarily equal to the number of assets to be replaced, as units to be replaced represent a subset of the Flagged-for-action units.

It is worth noting that nearly the entire populations of Pad Mounted Switchgear (Air Insulated), Fleet Vehicles (all types), and Meters (Residential, Industrial/Commercial) have been flagged for action in the next 10 years.

Additionally, over one quarter of Poles (Wood), UG Primary Cables (XLPE), OH Gang Switches, and Structures (Manhole) are expected to require some action to be taken to address their condition.

Data Availability

All the asset categories have basic information to develop health index scores.

Power Transformers and MS Switchgear have relatively complete data sets, with both test and inspection data available in addition to age.

Poles (wood) have relatively complete data sets with both test and inspection data, but only available for roughly half of the population.

Poles (concrete), Structures (all types) and Fleet Vehicles (all types) have inspection data available for the majority of the population.

Distribution Transformers (all types) and Pad Mounted Switchgear have either very limited inspection data available, or inspection data for small portion of the asset population.

The remaining asset categories have age information only.

Distribution Transformers (pole mounted), Pad Mounted Switchgear and Meters have historic removal data available for developing FHI specific degradation curves.

Recommendations

The following are recommended:

1. It is recommended that FHI use the HI and FFA results of this ACA study as an input into its Asset Management process. The results of the HI and FFA provides insight to the condition of FHI’s key distribution assets and the quantities of assets that need to be addressed in the coming years. This information can be used to facilitate decisions related to the key aspects

of the asset management process, including inspection and maintenance practices, as well as investment or capital planning decisions.

2. Conduct an ACA study on a regular basis. This will show how the condition of FHI's key assets change over time. It will provide insight to the impact of FHI's operation and maintenance as well as capital investments.

3. To improve the data collection process and the quality and quantity of data of subsequent ACA studies, the following are recommended:

   - Standardize inspection forms to ensure consistency of inspections records collected in the field.

   - Standardize the collection of by-exception routine inspection records for assets. This is important even for the newer units to establish long-term degradation trends.

   - Start tracking of OH Conductors and UG Cables failures by location in the outage database, as well as cable testing data. Once sufficient data are available, they could be incorporated in ACA.

   - Start collecting loading data for the distribution transformers using the new SmartMAP software at FHI on a go-forward basis.

   - Create a single file (instead of separate files) for storing inspection and test data for all the individual units collected for an asset category.

   - Continue to collect removal and failure records for all asset groups to enable development of FHI specific asset degradation curves.

Findings and recommendations of this study are based on asset condition only as determined from available data and information. Note that there are numerous other considerations that may influence FHI's planning process, such as obsolescence, system growth, corporate priorities, technological advancements, etc.

It is also important to note that the Flagged-for-action plans are based solely on asset condition using a probabilistic, non-deterministic, approach and, as such, can only show expected failures or probable number of units that are expected to be candidates for replacement or other action. While this condition-based Flagged-for-action plan can be used as a guide for Renewal Investment category within Distribution System Plan, it is not expected that it be followed directly or as the final deciding factor in making investment decisions. There are numerous other factors and considerations that will influence FHI's Asset Management decisions, such as obsolescence, system expansion, regulatory requirements, municipal projects, customer preferences, etc.

DEFINITIONS

Terminology	Acronym	Definition
Age Limiting	AL	The final HI assigned to an individual asset may also be limited by the asset's age. The AL is generally equal to the cumulative survival probability at a given age of an asset category. If the calculated HI is less than or equal to the AL, the final HI assigned is the calculated HI. Otherwise, the final HI assigned is equal to the AL.
Asset Condition Assessment	ACA	Process of using asset information to determine the condition of assets. Condition data can include nameplate information, test results, asset inspection records, corrective maintenance records, operational experience, etc.
Condition Parameter Score	CPS	Score of an asset for a particular condition parameter. In this study, the scoring system used ranges from 0 through 4 (0 = worst; 4 = best).
Condition Parameters	CP	Asset characteristics or properties that are used to derive the HI.
Criticality		Metric used to quantify consequence of failure in this methodology.
Criticality Index	CI	Index used to determine asset Criticality. CI ranges from 0% to 100%, with 100% representing the unit with the highest possible consequence of failure.
Cumulative Distribution Function	CDF	Cumulative distribution function. Assumed in this methodology as the Weibull function representing the cumulative likelihood of removals.

Terminology	Acronym	Definition
Data Availability Indicator	DAI	A measure of the amount of condition parameter data that an asset has, as measured against the full data sets that are practically available and included in the HI formula. It is determined by the weighted ratio of the condition parameters availability of an individual unit, over the maximum condition parameters availability of an asset category.
Data Gap		A data gap is the case where none of the units in an asset category has data for a particular item as requested by "ideal" data sets. A data gap means the data is either unavailable or not in a useable format.
De-rating Multiplier	DR	Multipliers used to adjust a condition or sub-condition parameter score or calculated Health Index to reflect certain conditions.
Flagged-for-action plan	FFA Plan	Number of units that are expected to require attention annually.
Flagged-for-action Year	FFA Year	The year that a particular unit is flagged for action.
Health Index	HI	Health Indexing quantifies equipment condition-based on numerous condition parameters that are related to the factors that cumulatively lead to an asset's end of life. HI is given in terms of a percentage range of 0%-100%, with 100% representing as new condition.
Probability Density Function	PDF	Probability density function. Assumed in this methodology as the Weibull function representing the likelihood that an asset will be removed from service when its age is within a particular range.
Removal Rate		Weibull hazard function. Assumed in this methodology as the rate of removal (removals per year for given age, including failures, proactively replaced, removal for non-condition reasons).
Risk		Product of likelihood of removal and consequence of failure.
Sample Size		Subset of an asset population with enough data (i.e., age or condition data) to calculate the HI.

Terminology	Acronym	Definition
Sub-Condition Parameter Score	SCPS	Score of an asset for a particular sub-condition parameter. In this study, the scoring system used ranges from 0 through 4 (0 = worst; 4 = best).
Sub-Condition Parameters	CP	Asset characteristics or properties that are used to derive the HI. Each condition parameter can be comprised of multiple sub-condition parameters.
Weibull Distribution		Continuous function used, in this methodology to model, the removal rates of assets.
Weight of Condition Parameter	WCP	In the HI formula, condition parameters are assigned a weight that is based on the degree of contribution or relevance to asset degradation.
Weight of Sub-Condition Parameter	WSCP	In the HI formula, condition parameters are assigned a weight that is based on the degree of contribution or relevance to asset degradation.

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I INTRODUCTION

Festival Hydro Inc. (FHI) engaged Kinectrics Inc (Kinectrics) in 2023 to perform an Asset Condition Assessment (ACA) on selected distribution assets. ACA produces a quantifiable evaluation of asset condition and aids in prioritizing and allocating sustainment investments. This undertaking, if done continuously over time, would allow FHI to monitor trends in the condition of its assets and to continuously improve its ACA process and asset management practices. This ACA covers FHI's asset population as of December 2022. This report presents results based on the available data. Year 0 shown in all figures is for 2023, year 1 for 2024, year 2 for 2025 etc.

I.1 Objective and Scope of Work

The categories and sub-categories of assets considered in this study are as follows:

- Power Transformers
- MS Switchgear
- Distribution Transformers (Pad, Pole)
- Poles (Wood, Concrete)
- OH Primary Conductors
- UG Primary Cables (XLPE, TRXLPE)
- OH Gang Switches
- Pad Mounted Switchgear (Solid Dielectric, Air)
- Structures (Vault, Manhole)
- Fleet Vehicles (Pickup, Bucket)
- Meters (Residential, Industrial/Commercial, Primary Metering Unit)

I.2 Deliverables

The deliverable in this study is a Report that includes the following information:

- Description of the Asset Condition Assessment methodology
- For each asset category the following are included:
    - Health Index formulation
    - Age distribution
    - Health Index distribution
    - Condition-based Flagged-for-action plan
    - Assessment of data availability and a Data Gap analysis

- Additionally, prioritized risk-based lists are provided for Power transformers and MS Switchgear, as these assets are typically replaced before they fail.

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II ASSET CONDITION ASSESSMENT METHODOLOGY

The Asset Condition Assessment (ACA) Methodology involves the process of determining asset Health Index, as well as developing a condition-based Flagged-for-action plan for each asset category. The methods used are described in the subsequent sections.

II.1 Health Index

Health Indexing quantifies equipment condition-based on numerous condition parameters that are related to the degradation factors leading to an asset's end of service life. The Health Index is an indicator of the asset's overall health and is typically given in terms of percentage, with 100% representing an asset in brand new condition and 0 asset at the end of its life. Health Indexing provides a measure of long-term degradation and thus differs from defect management, whose objective is finding defects and deficiencies that need correction or remediation to keep an asset operating prior to reaching its end of life.

Condition parameters are the asset characteristics or properties that are used to derive the Health Index. A condition parameter may be comprised of several sub-condition parameters. For example, a parameter called "Oil Quality" may be a composite of parameters such as "Moisture", "Acid", "Interfacial Tension", "Dielectric Strength" and "Color".

In formulating a Health Index, condition parameters are ranked, through the assignment of *weights*, based on their contribution to asset degradation. The *condition parameter score* for a particular parameter is a numeric evaluation of an asset with respect to that parameter.

Health Index (HI), which is a function of scores and weightings, is therefore given by:

$$HI = \frac{\sum_{m=1}^{\forall m} \alpha_m (CPS_m \times WCP_m)}{\sum_{m=1}^{\forall m} \alpha_m (CPS_{m.\max} \times WCP_m)} \times DR$$

Equation 1

where

$$CPS = \frac{\sum_{n=1}^{\forall n} \beta_n (CPF_n \times WSCP_n)}{\sum_{n=1}^{\forall n} \beta_n (WSCP_n)}$$

Equation 2

CPS	Condition Parameter Score
WCP	Weight of Condition Parameter
α_m	Data availability coefficient (1 if available; 0 if not available)
CPF	Sub-Condition Parameter Score
WSCP	Weight of Sub-Condition Parameter
β_n	Data availability coefficient for sub-condition parameter (1 if available; 0 if not available)
DR	De-Rating Multiplier

The scale that is used to determine an asset's score for a particular parameter is called the *condition criteria*. For this project, a condition criterion scoring system of 0 through 4 is used. A score of 0 represents the worst score while 4 represents the best score, i.e., $CPF_{max} = 4$.

De-Rating multipliers are applied to the calculated HI. These may be used to represent the impact of non-condition issues such as design or operating environment.

Age is used as a limiting factor to reflect the degradation of asset over time.

The calculated overall HI result (after considering all the possible de-rating multipliers) is then compared with an age limiting factor.

$$Final\ overall\ HI = \begin{cases} HI_{calculated} & if\ HI_{calculated} <= Age\_Limiter \\ Age\_limiter & if\ HI_{calculated} > Age\_Limiter \end{cases}$$

II.1.1 Health Index Results

As stated previously, an asset's Health Index is given as a percentage, with 100% representing "as new" condition. The Health Index is calculated only if there is sufficient condition data. The subset of the population with sufficient data is called the *sample size*. Results are generally presented in terms of number of units and as a percentage of the sample size. If the sample size is sufficiently large and the units within the sample size are sufficiently random, the results may be extrapolated for the entire population.

The Health Index distribution given for each asset category illustrates the overall condition of the asset category. Further, the results are aggregated into five categories and the categorized distribution for each asset category is given. The Health Index categories are as follows:

Very Poor	Health Index < 25%
Poor	25 ≤ Health Index < 50%
Fair	50 ≤ Health Index <70%
Good	70 ≤ Health Index <85%
Very Good	Health Index ≥ 85%

Note that for critical asset categories, such as Power Transformers, the Health Index of each individual unit is given.

II.2 **Condition-Based Flagged-for-action plan**

The condition-based Flagged-for-action plan outlines the number of units that are expected to require attention in the next 10 years. The numbers of units are estimated using either a *proactive* or *reactive* approach. In the proactive approach, units are considered for action prior to failure, whereas the reactive approach is based on expected failures per year.

Both approaches consider asset removal rate and probability of failure. The removal rate is estimated using the method described in the subsequent section.

II.2.1 Removal Rate and Probability of Removal

Based on Kinectrics' experience in removal rate studies of multiple power system asset categories, Weibull equation is used to model the removal curves. The Weibull function has no specific characteristic shape and, as such, can model the exponentially increasing removal rate using empirically derived parameters.

The Weibull removal density function is defined as:

$$f(t) = \frac{\beta t^{\beta-1}}{\alpha^{\beta}} e^{-(\frac{t}{\alpha})^{\beta}}$$

Equation 3

f	= removal rate per unit time
t	= time
α, β	= constant that control the scale and shape of the curve

The corresponding cumulative removal distribution also sometimes referred to as Probability of Failure is:

$$Q(t) = 1 - R(t) = 1 - e^{-(\frac{t}{\alpha})^{\beta}}$$

Equation 4

Q(t)	= cumulative failure distribution
R(t)	= survival function

Finally, the removal rate function also known as hazard function) is:

$$\lambda(t) = \frac{f(t)}{1 - Q(t)} = \frac{\beta t^{\beta-1}}{\alpha^{\beta}}$$

Equation 5

$\lambda(t)$	= hazard function (removals per year)

Different asset categories have different removal rates corresponding to different removal distributions. The parameters α and β are determine the shapes of these curves. For each asset category, the values of these constant parameters are selected to reflect typical useful lives for assets in this asset category.

Consider, for example, an asset class where at the ages of 40 and 75 the asset has cumulative probabilities of removal of 20% and 95% respectively. It follows that when using Equation 5, α and β are calculated as 57.503 and 4.132 respectively. The removal rate and probability of removal graphs for these parameters are as follows:

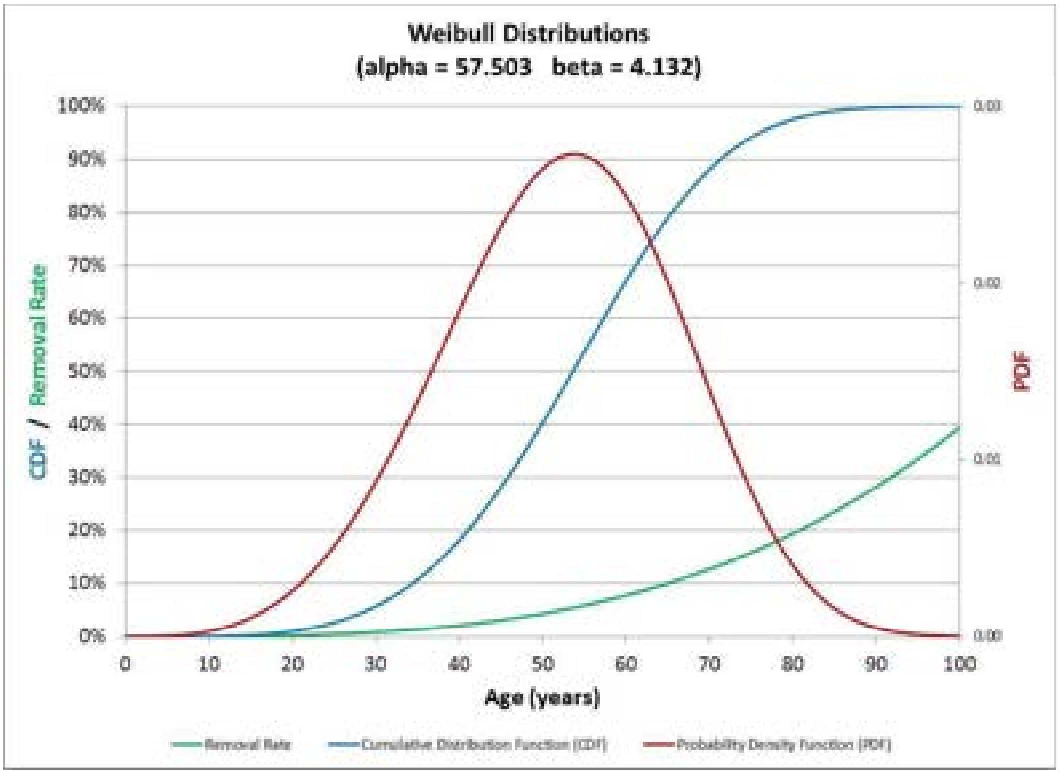

Figure 1 Removal rate vs. Age

II.2.2 Projected Flagged-for-action plan Using a Reactive Approach

For assets that have low consequences of failure that are run to failure and are replaced *reactively*, a probabilistic approach is taken to estimate the number of units that are expected to fail/get removed and flagged-for-action in each year.

For these asset categories, the number of units expected to be replaced in a given year is determined based on the asset's failure/removal rates. The number of failures per year is given by Equation 5.

An example of such a Flagged-for-action plan is as follows: Consider an asset distribution of 100 - 5-year-old units, 20 – 10-year-old units, and 50 - 20-year-old units. Assume that the removal rates for 5-, 10-, and 20-year-old units for this asset class are $\lambda_5 = 0.02$, $\lambda_{10} = 0.05$, $\lambda_{20} = 0.1$ failures / year respectively. In the current year, the total number of replacements is 100(.02) + 20(0.05) + 50(0.1) = 2 + 1 + 5 = 8.

In the following year, the expected asset distribution is, as a result, as follows: 8 – 1 year old units, 98 – 6-year-old units, 19 – 11-year-old units, and 45 - 21-year-old units. The number of replacements in year 2 is therefore 8(λ_1) + 19(λ_6) + 45(λ_{11})+ 45(λ_{21}).

Note that in this study the "age" used is in fact "effective age", or condition-based age if available, as opposed to the chronological age of the asset.

For all the asset categories below, the probabilistic approach is used to estimate the FFA Plan. It is also important to note that the FFA gives the estimated number of assets per year that need to be addressed; the year that a specific unit needs to be addressed is not calculated.

- OH Conductors
- OH Gang Switches
- Poles (wood, concrete)
- Distribution transformers (pole mounted, pad mounted)
- Pad mounted switchgear
- UG Cables
- Structures
- Fleet Vehicles
- Meters

II.2.3 Projected Flagged-for-action plan Using a Proactive Approach

For some asset categories costs of replacement and/or consequences of failure are more substantial, and they are typically replaced *proactively*, i.e., before they fail. For such assets planning for replacement requires a risk-based approach when developing the FFA Plan. This risk-based methodology considers both the asset likelihood of removal (as related to HI) and its consequence of failure (criticality). The product of likelihood or removal and consequence of failure determines asset risk.

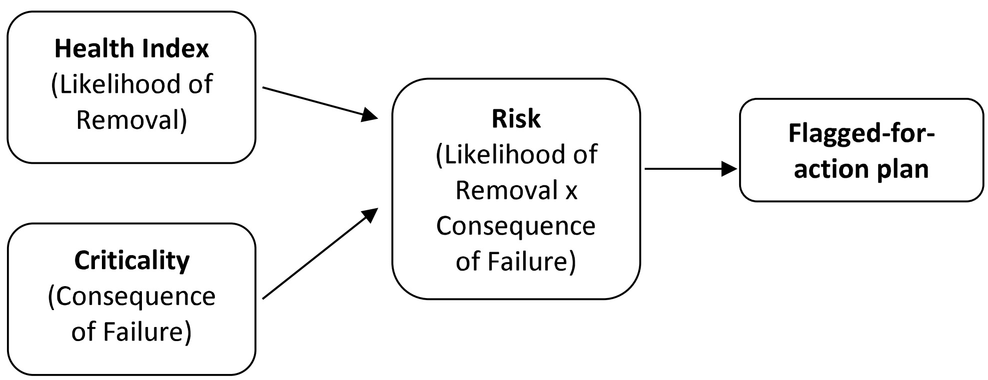

Figure 2 Risk Assessment Procedure

For all the asset categories below, the risk-based approach is used to estimate the FFA Plan:

- Power Transformers
- MS Switchgear

Relating Health Index and Probability of Removal

Typically, a stress asset is exposed is not constant and has normal frequency distribution. This is illustrated by the probability density curve of the stress below. The vertical lines in the figure represent condition or strength (Health Index) of an asset and bell-shaped curved stress distribution.

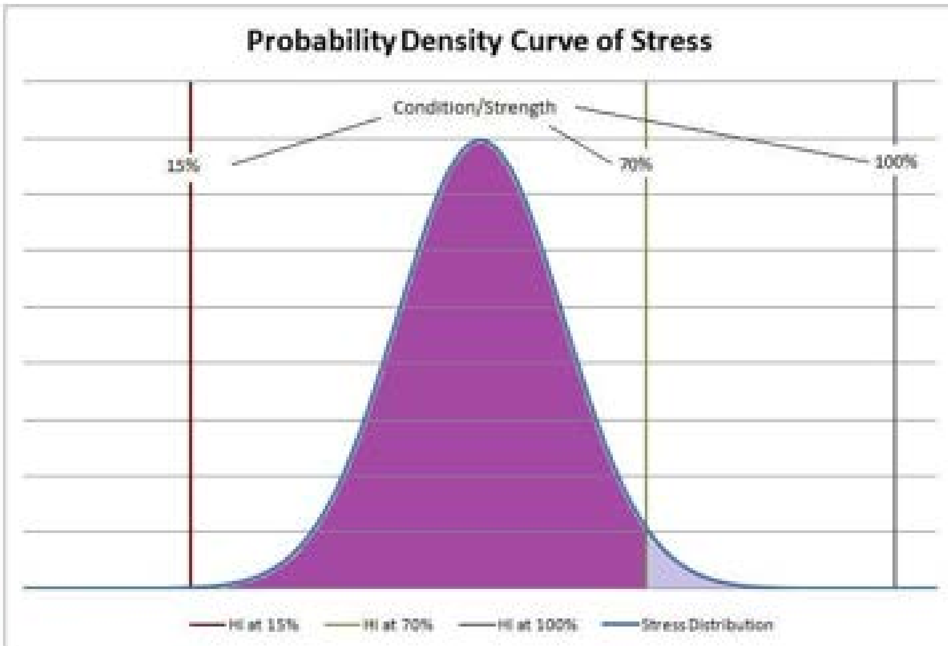

Figure 3 Stress Curve

An asset is in as-new condition (100% strength) should be able to withstand all levels of stress. As the condition of the asset deteriorates, it may be less able to withstand higher levels of stress. Consider, for example, the green vertical line that represents 70% condition/strength. The asset should be able to withstand magnitudes of stress to left of the green line. If, however, the stress is of a magnitude to the right of the green line, the asset will fail.

To create a relationship between the Health Index and likelihood of removal, assume two “points” on the stress curve that correspond to two different Health Index values. In this example, assume that an asset that has a condition/strength (Health Index) of 100% can withstand all magnitudes of stress to the left of the purple line. It then follows that probability that an asset in 100% condition will fail is the probability that the magnitude of stress is at levels to the right of the purple line. This corresponds to the area under the stress density curve to the right of the purple line. Similarly, if it assumed that an asset with a condition of 15% will fail if subjected to stress at magnitudes to the right of the red line, the probability of failure at 15% condition is the area under the stress density curve to the right of the red line.

The likelihood of removal at a particular Health Index is found from plotting the Health Index on X-axis and the area under the probability density curve to the right of the Health Index line on Y-axis, as shown on the graph of the figure below.

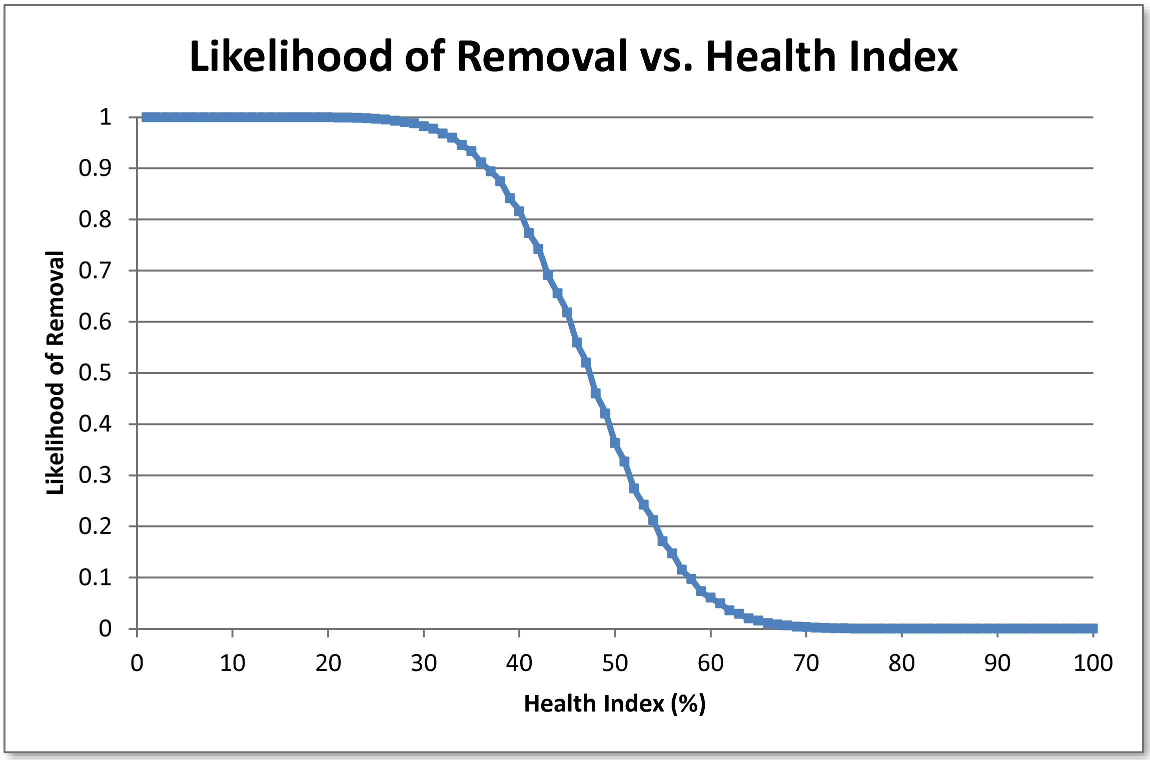

Figure 4 Likelihood of Removal vs. Health Index

Criticality

The metric used to measure consequence of failure is referred to as *Criticality*. Criticality may be determined in numerous ways, with monetary consequence or degree of risk to corporate business values being examples. The higher the criticality value assigned to a unit, the higher it's consequence of failure. According to FHI, all Power Transformers and all MS Switchgear are of equal criticality.

Risk-Based Flagged-for-action plan

As previously mentioned, risk is the product of a unit's likelihood of removal and its consequence of failure. To develop a Flagged-for-action plan, the risk of removal of each unit must be quantified. An asset is flagged for action when the calculated risk value exceeds a pre-set threshold. With this approach, the FFA Year (i.e., the years that a particular unit is flagged for action) is determined for each asset.

II.3 **Data Assessment**

The condition data used in this study include the following:

- Test Results (e.g., Oil Quality, DGA)
- Inspection Records
- Loading
- Make, Model, and Type

- Age

The Health Index formulae developed and used in this study are based only on FHI's available data. There are additional parameters or tests that FHI may not collect at the present time but that are important indicators in determining the extent of assets degradation. While these will not be included in the HI formula, they are referred to as data gaps. A data gap is the case where none of the units in an asset category has data for a particular item as requested by "ideal" data sets.

As part of this study, the data gaps of each asset category are identified. In addition, the data items are ranked in terms of importance. There are three priority levels, the highest being most indicative of asset degradation.

Priority	Description	Symbol
High	Impactive data; most useful as an indicator of asset degradation	☆☆☆
Medium	Important data; can indicate the need for corrective maintenance or increased monitoring	☆☆
Low	Helpful data; least indicative of asset deterioration	☆

When closing data gaps, it is generally recommended that data collection be initiated for the items marked with higher priority because when more impactive and important data are included in the Health Index formula the higher is confidence in the calculated Health Index score.

If an asset category has significant data gaps and lacks good quality condition, there is less confidence that the Health Index score of a particular unit accurately reflects its condition, regardless of the value of its DAI.

To facilitate the incorporation of data gap items into improved Health Index formulas for future assessments, the data gaps are shown at sub-condition parameters level. For each of them, the parent condition parameter is identified. Also given are the object or component addressed by the parameter, a description of what to assess for each component or object, and the possible source of data.

The following is an example for "Tank Corrosion" on a Pad-Mounted Transformer:

Data Gap (Sub-Condition Parameter)	**Condition Parameter Group**	**Priority**	**Object or Component Addressed**	**Description**	**Source of Data**
Tank Corrosion	Physical Condition	☆☆	Oil Tank	Tank surface rust or deterioration due to environmental factors	Visual Inspection

III RESULTS

This section summarizes the findings of this study.

III.1 Health Index Results

A summary of the Health Index results is shown in Table 1. For each asset category the population, sample size (number of assets with sufficient data for Health Indexing), average age, age availability and average DAI are given. The average Health Index and distribution are also shown. A summary of the Health Index distribution for all asset categories are also graphically shown in Figure 5. Note that the Health Index distribution percentages are based on the asset category's sample size.

It can be observed that out of the 19 sub-categories, 9 of them have over 70% of their units classified as "good" or "very good". Additionally, the 9 categories have average Health Index scores greater than 70%.

The asset categories that have all the units in "very good" condition are OH Primary Conductors and UG Primary Cables (TR-XLPE).

The results show that Meters (residential) have a high percentage of assets, i.e. 85% of the sample size, classified as "poor" or "very poor". The other two categories, Meters (industrial/commercial) and Meters (primary metering unit) respectively have 66% and 44% of their assets in "poor" and "very poor" categories.

Pad Mounted Switchgear (air) also have over 80% of the entire population in "poor" or "very poor". However, given that there are only 12 assets in entire fleet, this represented only 10 assets.

Approximately 70% and 36% of Fleet Vehicles (bucket trucks) and Fleet Vehicles (pick up) respectively were classified in the "poor" and "very poor" categories.

In the case of Poles (wood), 42% were categorized as "poor" or "very poor".

The assessment of Structures (both types), which were based on inspections and repair records, showed close to 30% of asset in "poor" or "very poor" condition.

Power Transformers have 25% of asset in "poor" condition. This however refers to only 1 individual asset that has low HI score due to its physical age.

Table 1 Health Index Results Summary

Asset Category	Population	Sample Size	Average Health Index	Health Index Distribution					Average Age
				Very Poor (< 25%)	Poor (25 - <50%)	Fair (50 - <70%)	Good (70 - <85%)	Very Good (>= 85%)	
Power Transformers	4	4	84%	0	1	0	0	3	29
MS Switchgear	2	2	68%	0	0	2	0	0	39
Distribution Transformers - Pad Mounted	1017	985	88%	1	33	96	154	701	19
Distribution Transformers - Pole Mounted	989	921	90%	21	36	8	65	791	21
Poles - Wood	2133	2093	60%	162	718	324	380	509	36
Poles - Concrete	3924	3774	88%	8	121	280	463	2902	20
OH Primary Conductors	393.5	125.5	100%	0.0	0.0	0.0	0.0	125.5	13
UG Primary Cables - XLPE	101.6	101.6	76%	4.9	13.2	10.4	19.8	53.4	24
UG Primary Cables - TR_XLPE	51.9	51.9	100%	0.0	0.0	0.0	0.0	51.9	6
OH Gang Switches	122	116	66%	15	12	19	36	34	22
Pad Mounted Switchgear - Solid Dielectric	25	25	97%	0	0	1	0	24	6
Pad Mounted Switchgear - Air Insulated	12	12	21%	8	2	2	0	0	33
Structures - Vault	7	7	75%	0	2	0	0	5	58
Structures - Manhole	38	38	71%	5	5	4	3	21	51
Fleet Vehicles - Pickup	11	11	56%	1	3	4	2	1	8
Fleet Vehicles - Bucket	10	10	41%	2	5	2	0	1	17
Meters - Residential	19348	19320	33%	15817	530	278	0	2695	12
Meters - Industrial/Commercial	3117	3097	47%	2005	46	61	17	968	10
Meters - Primary Metering Unit	25	25	61%	8	3	1	0	13	9

0% 100%

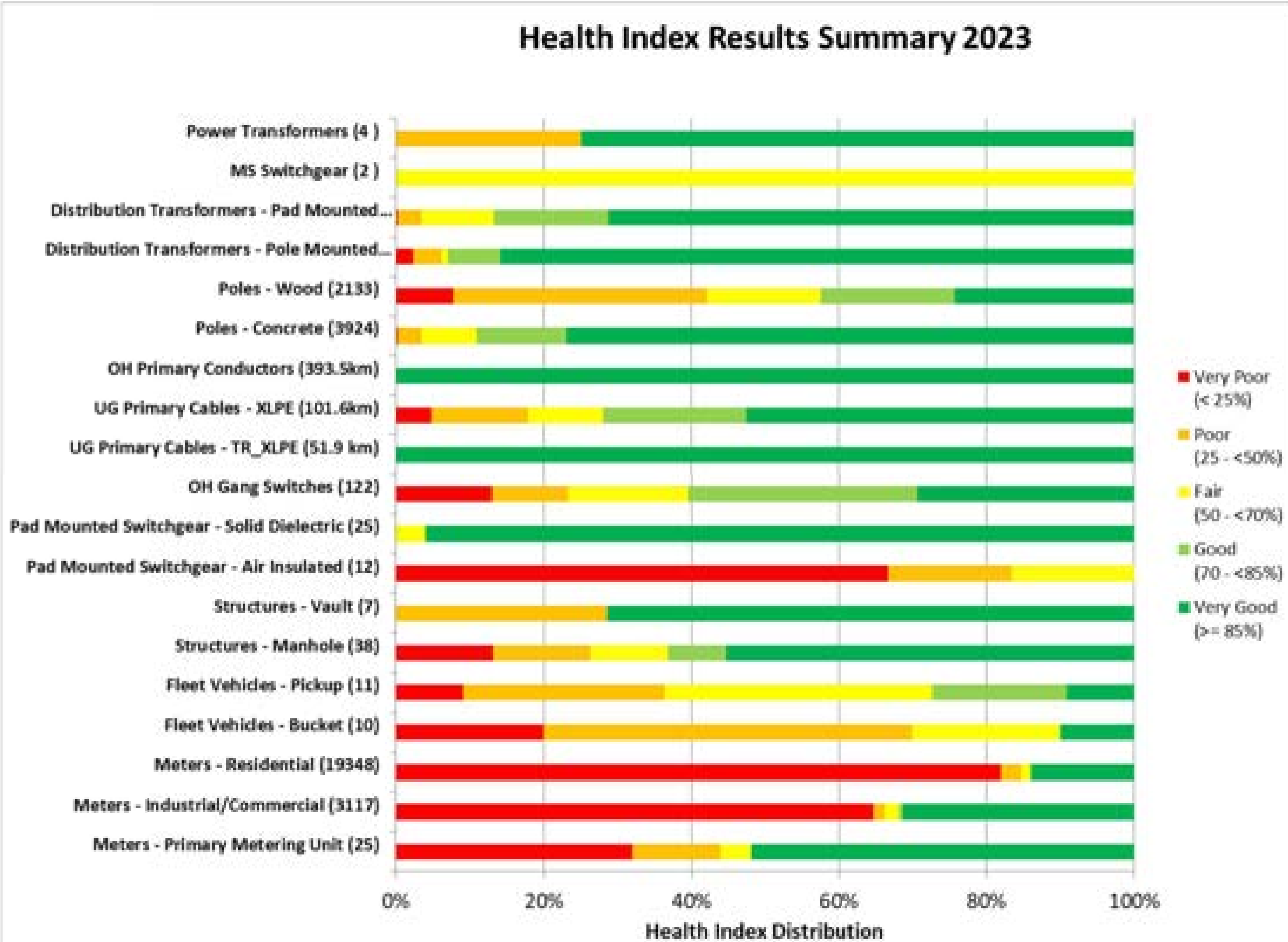

Figure 5 Health Index Results Summary

III.2 Condition-Based Flagged-for-action plan

The Flagged-for-action plan estimates the number of units expected to require attention in a given year, with the attention being replacement or other actions described earlier in this document.

It is important to note that the Flagged-for-action plan is based solely on asset condition. It uses a probabilistic, non-deterministic, approach and, as such, can only show expected failures or probable number of units that are expected to be candidates for replacement or other action. While this condition-based Flagged-for-action plan can be used as a guide for Renewal Investment category within Distribution System Plan, it is not expected that it be followed directly or as the final deciding factor in making investment decisions. There are numerous other factors and considerations that will influence FHI's Asset Management decisions, such as obsolescence, system expansion, regulatory requirements, municipal demand, customer preferences, etc.

Table 2 shows the Year 0 (year 2023) and 10 Year cumulative Flagged-for-action plan. Table 3 shows annual 10 Year Flagged-for-action plan.

Table 2 Summary of Flagged-for-action

Asset Category	1st Year Action		10 Year Action in Total	
	Quantity #	Percentage	Quantity #	Percentage
Power Transformers	0	0.0%	0	0.0%
MS Switchgear	0	0.0%	0	0.0%
Distribution Transformers - Pad Mounted	20	2.0%	211	20.7%
Distribution Transformers - Pole Mounted	16	1.6%	164	16.6%
Poles - Wood	66	3.1%	556	26.1%
Poles - Concrete	49	1.2%	481	12.3%
OH Primary Conductors	0*	0.0%	2.5*	0.6%
UG Primary Cables - XLPE	6.7*	6.6%	59.9*	58.9%
UG Primary Cables - TR_XLPE	0*	0.0%	0*	0.0%
OH Gang Switches	7	5.7%	57	46.7%
Pad Mounted Switchgear - Solid Dielectric	0	0.0%	3	12.0%
Pad Mounted Switchgear - Air Insulated	4	33.3%	11	91.7%
Structures - Vault	0	0.0%	0.0	0.0%
Structures - Manhole	1	2.6%	10	26.3%
Fleet Vehicles - Pickup	2	18.2%	11	100.0%
Fleet Vehicles - Bucket	4	40.0%	9	90.0%
Meters - Residential	3491	18.0%	23044	119.1%
Meters - Industrial/Commercial	458	14.7%	3317	106.4%
Meters - Primary Metering Unit	3	12.0%	24	96.0%

* in km

High Low

The above FFA summary reflects the percentagewise severity in terms of near future or long term action. A percentage over 100% suggests that the entire fleet will get replaced within the 10 year period. Due to low population sizes in some asset groups (e.g. pad mounted switchgear in the above table), a high percentage does not always present a concern in practice. Therefore a utility needs to take into account the asset population size when interpreting this stable.

Table 3 Ten Year Flagged-for-action Plan

Asset Category	Flagged for Action Plan by Year									
	0	1	2	3	4	5	6	7	8	9
Power Transformers	0	0	0	0	0	0	0	0	0	0
MS Switchgear	0	0	0	0	0	0	0	0	0	0
Distribution Transformers - Pad Mounted	20	18	19	19	21	22	22	23	23	24
Distribution Transformers - Pole Mounted	16	14	15	15	15	17	17	18	18	19
Poles - Wood	66	55	56	55	54	54	54	54	54	54
Poles - Concrete	49	42	44	46	47	48	49	51	52	53
OH Primary Conductors	0	0	0	0	0.3	0.3	0.3	0.4	0.6	0.6
UG Primary Cables - XLPE	6.7	6.6	6.2	6.4	5.9	5.8	5.8	5.6	5.5	5.4
UG Primary Cables - TR_XLPE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OH Gang Switches	7	6	6	6	6	6	5	5	5	5
Pad Mounted Switchgear - Solid Dielectric	0	0	0	1	0	0	0	1	0	1
Pad Mounted Switchgear - Air Insulated	4	3	2	1	0	1	0	0	0	0
Structures - Vault	0	0	0	0	0	0	0	0	0	0
Structures - Manhole	1	1	1	1	1	1	1	1	1	1
Fleet Vehicles - Pickup	2	2	1	1	1	1	1	1	1	0
Fleet Vehicles - Bucket	4	2	1	1	1	0	0	0	0	0
Meters - Residential	3491	3491	3491	3491	3491	416	625	981	1492	2075
Meters - Industrial/Commercial	458	458	458	458	458	153	170	192	232	280
Meters - Primary Metering Unit	3	3	3	3	2	2	2	2	2	2

* Year 0 = 2023, year 1 = 2024, year 2 = 2025 … etc.

km for OH Primary Conductors and UG Primary Cables

III.3 **Data Assessment Results**

Data assessment determines the data availability of each asset category and identifies data gaps for each asset category. Data gaps are data that are not collected or available for any asset in an asset category. The higher the DAI and the fewer the data gaps, the higher the confidence in the Health Index results.

Data for Power Transformers include age, loading, test results on oil and bushings, inspection records on windings and insulations. Data gaps are inspection records for oil storage and cooling system.

Data for MS Switchgear include age, test results and inspection records. There are no data gaps for this asset category.

Data for Distribution Transformers include age and limited inspection (Infrared)/maintenance (painting) records (by exceptions). Data gaps include routine inspection records and maintenance work order counts.

Data for Poles include age and test/inspection results. There are no data gaps for this asset category.

Data for OH Conductors and UG Cables include age only. Data gaps include routine inspection records, cable testing results and failure rate records at segment level.

Data for OH Switches include age only. Data gaps include routine inspection records.

Data for Pad Mounted Switchgear include age and limited inspection (Infrared) records (by exceptions). Data gaps include routine inspection records and maintenance work order counts.

Data for Structures include installation decades and inspection results. Data gaps include more accurate age estimates.

Data for Fleet Vehicles include age, mileage and maintenance costs. There are no data gaps for this asset category.

Data for Meters include age only. As Meters are assessed based on age only, there are no data gaps for this asset category.

IV CONCLUSIONS

An Asset Condition Assessment is conducted for 11 distribution asset categories of FHI (19 sub-categories in total). For each asset category, the Health Index distribution is determined, and a condition-based Flagged-for-action plan is developed.

Risk-based prioritized lists are developed for Power Transformers. These lists indicate the projected flagged-for-action year for each individual unit.

Flagged-for-action plan presented in this study is based solely on available asset condition data and there are other considerations that may influence FHI's Asset Management Plan, such as obsolescence, system growth, regulatory requirements, municipal initiatives, etc.

The following conclusions are drawn based on the ACA findings of this study.

1) In general, FHI's assets are in good condition, with 9 out of 19 sub-categories having an average Health Index score of greater than 70%.

2) Among all the asset categories, OH Primary Conductors are in the best condition, having all the units classified as "very good".

3) Meters in general have higher percentage of its assets in "poor" or "very poor" condition than other asset groups. This is mainly due to its aged units and relatively shorter life expectancy. For 10-year long term flagged-for-action plans, Meters (residential and industrial/commercial) have the most assets to be addressed, both percentagewise and by number of assets. Nearly all Meters have been flagged for action in the next 10 years.

4) Pad Mounted Switchgear (Air) have 83% of its assets in "poor" or "very poor" condition. Given the that there are in total 12 Pad Mounted Switchgear (air), this represents only 10 assets. However, the flagged-for-action analysis shows that 11 of the 12 switchgear need to be addressed in the next 10 years.

5) A large percentage of Fleet vehicles were classified as "poor" or "very poor". Nearly all vehicles were flagged for action in the next 10 years.

6) Approximately 42% of Poles (wood) were classified as "poor" or "very poor". It was found that over 25% will need to be addressed in the next 10 years.

7) Nearly 30% of Structures were found to be in "poor" or "very poor" condition. The flagged-for-action plan shows that more than 25% of Structures (manholes) should be addressed in the next 10 years.

8) It is also worth noting that 23% of OH Gang switches and 18% of UG Primary Cables (XLPE) were classified "poor" or "very poor". About half these populations were flagged for action in the next 10 years

9) The assessment of data used as input to the ACA showed the following:

   a) All the asset categories have basic information to develop health index scores.

   b) Power Transformers and MS Switchgear have relatively complete data sets, with both test and inspection data available in addition to age. However, inspection information was not available for Power Transformers.

   c) Poles (wood) have relatively complete data sets with both test and inspection data, but only available for roughly half of the population. Poles (concrete) have inspection data available for most of the population. No data gaps were identified for Poles.

   d) Structures (all types) have inspection data available for the majority of the population, but accurate age information was not available.

   e) Fleet Vehicles (all types) have inspection data available for the majority of the population. No data gaps were identified.

   f) Distribution Transformers (all types) and Pad Mounted Switchgear have either very limited inspection data available, or inspection data for small portion of the asset population. Data gaps include routine inspection records and maintenance work order counts.

   g) OH Conductors and UG Cables have age information only. Data gaps include routine inspection records, testing results and failure rate records at segment level. Similarly, only age was available for OH Switches; data gaps include routine inspection records.

   h) Meters only have age information. However, because Meters are generally assessed based on age, there are no data gaps.

   i) Distribution Transformers (pole mounted), Poles, Pad Mounted Switchgear and Meters have historic removal data available for developing FHI specific degradation curves.

V RECOMMENDATIONS

The following recommendations are made based on the study results:

1. Use the HI and FFA results of this ACA study as an input into FHI's Asset Management process. The results of the HI and FFA provides insight to the condition of FHI's key distribution assets and the quantities of assets that need to be addressed in the coming years. This information can be used to facilitate decisions related to the key aspects of the asset management process, including inspection and maintenance practices, as well as investment or capital planning decisions.

2. Conduct ACA study on a regular basis. This will show how the condition of FHI's assets change over time and provide insight on the impact of operation and maintenance and capital investments.

3. To improve the data collection process and the quality and quantity of data of subsequent ACA studies, the following are recommended:

    a) Standardize inspection forms to ensure consistency of inspections records collected in the field.

    b) Standardize the collection of by-exception routine inspection records for Power Transformers, Distribution Transformers, OH Gang Switches, OH Conductors, UG Cables and Pad Mounted Switchgear.

    c) Start tracking failure records at segment level for OH Conductors and UG Cables in the outage database, as well as cable testing data. to improve the input granularity for better assessment of component condition status.

    d) Start standardizing the collection of loading data by the newly available SmartMAP software, for both pole mounted and pad mounted distribution transformers. . Although these transformers are usually sized with some margin to meet forecasted load, the expected proliferation of EVs will results in reduced margins and different loading patterns.

    e) For Power transformers and MS switchgear collect Inspection and test data for the individual units in extractable electronic format (e.g., Excel) for each asset category.

    f) Continue collecting asset failure and removal records for all the asset categories, to improve the accuracy of asset degradation curves.

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VI Appendix A: Results for Each Asset Category

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1 POWER TRANSFORMERS

1.1 Health Index Formula

1.1.1 Condition and Sub-Condition Parameters

For substation transformers without a separate tap changer tank, the overall calculated health index is simply HI_{TX}. For transformers with tap changers, a composite health index, HI_{COM}, is calculated. HI_{COM} is a weighted composite of the transformer main tank and tap changer component. The formula is as follows, where HI_{TX} refers to the Health Index of the main tank:

Table 1-1 Power Transformers Composite Health Index Formula

If (***Transformer has LTC***)	If (***HI_{TX} < 50%***) then **HI_{COM} = HI_{TX}**
	ElseIf (***HI_{LTC} < 50%***) then **HI_{COM} = HI_{LTC}**
	Else **HI_{COM} = 60%HI_{TX} + 40%HI_{LTC}**
Else	**HI_{COM} = HI_{TX}**

Main Tank (LTC and Non-LTC)

Table 1-2 Main Tank Condition Parameter and Weights – Power Transformers

m	Condition Parameter	WCP_m	Sub-Condition Parameters
1	Internal Components	5	Table 1-3
2	Insulation Oil	4	Table 1-4
3	Winding	3	Table 1-5
4	Paper	4	Table 1-6
5	Bushing	4	Table 1-7
6	Service Record	5	Table 1-8
	Age Limiting	Overall Limiter	Figure 1-1

Table 1-3 Internals Sub-Condition Parameters and Weights (m=1) – Power Transformers

n	Sub-Condition Parameter	$WCPF_n$	Condition Criteria Table
1	H2	5	Table 1-10
2	CH4	3	Table 1-10
3	C2H6	3	Table 1-10
4	C2H4	3	Table 1-10
5	C2H2	5	Table 1-10

Table 1-4 Insulation Oil Sub-Condition Parameters and Weights (m=2) – Power Transformers

n	Sub-Condition Parameter	$WCPF_n$	Condition Criteria Table
1	Dissipation Factor	2	Table 1-12

2	Moisture	4	Table 1-12
3	IFT	3	Table 1-12
4	Acid Number	2	Table 1-12

Table 1-5 Winding Sub-Condition Parameters and Weights (m=2) – Power Transformers

n	Sub-Condition Parameter	$WCPF_n$	Condition Criteria Table
1	TTR	1	Equation 1-1
2	Excitation Resistance	1	Equation 1-1
3	Winding Resistance	1	Equation 1-1

Table 1-6 Paper Sub-Condition Parameters and Weights (m=3) – Power Transformers

n	Sub-Condition Parameter	$WCPF_n$	Condition Criteria Table
1	Dissipation Factor	5	Equation 1-1
2	Insulation Resistance	1	Equation 1-1
3	CO	2	Table 1-10
4	CO2	1	Table 1-10
5	Degree of polymerization	3	Table 1-13

Table 1-7 Bushing Sub-Condition Parameters and Weights (m=3) – Power Transformers

n	Sub-Condition Parameter	$WCPF_n$	Condition Criteria Table
1	Bushing PF	1	Equation 1-1

Table 1-8 Service Record Sub-Condition Parameters and Weights (m=4) – Power Transformers

n	Sub-Condition Parameter	$WCPF_n$	Condition Criteria Table
1	Loading	1	Table 1-16

LTC

Table 1-9 Condition Parameters and Weights – LTC

n	Condition Parameter	WCP_m	Condition Criteria Table
1	Oil Quality	3	Table 1-12
2	Oil DGA	4	Table 1-11
	Age Limiting	Overall Multiplier	Figure 1-1

1.1.2 Condition Criteria

<u>Oil DGA – Transformer Oil</u>

--- Main Tank

Table 1-10 DGA Criteria – Transformers

	Dissolved Gas	Scores					
		4	**3.2**	**2.4**	**1.6**	**0.8**	**0**
Mineral Oil 2.5 MVA to 10 MVA	**H2 (Hydrogen)**	X ≤ 70	70 < X ≤ 100	100 < X ≤ 200	200 < X ≤ 400	400 < X ≤ 1000	X >1000
	CH4 (Methane)	X ≤ 70	70 < X ≤ 120	120 < X ≤ 200	200 < X ≤ 400	400 < X ≤ 600	X > 600
	C2H6 (Ethane)	X ≤ 75	75 < X ≤ 100	100 < X ≤ 150	150 < X ≤ 250	250 < X ≤ 500	X > 500
	C2H4 (Ethylene)	X ≤ 60	60 < X ≤ 100	100 < X ≤ 150	150 < X ≤ 250	250 < X ≤ 500	X > 500
	C2H2 (Acetylene)	X ≤ 3	3 < X ≤ 7	7 < X ≤ 35	35 < X ≤ 50	50 < X ≤ 100	X > 100
	CO (Carbon Monoxide)	X ≤ 750	750 < X ≤ 1000	1000 < X ≤ 1300	1300 < X ≤ 1500	1500 < X ≤ 1700	X > 1700
	CO2 (Carbon Dioxide)	X ≤ 7500	7500 < X ≤ 8500	8500 < X ≤ 9000	9000 < X ≤ 12000	12000 < X ≤ 15000	X > 15000
Mineral Oil > 10 MVA	**H2 (Hydrogen)**	X ≤40	40 < X ≤ 100	100 < X ≤ 300	300 < X ≤ 500	500 < X ≤ 1000	X >1000
	CH4 (Methane)	X ≤ 80	80 < X ≤ 150	150 < X ≤ 200	200 < X ≤ 500	500 < X ≤ 700	X > 700
	C2H6 (Ethane)	X ≤ 70	70 < X ≤ 100	100 < X ≤ 150	150 < X ≤ 250	250 < X ≤ 500	X > 500
	C2H4 (Ethylene)	X ≤ 60	60 < X ≤ 100	100 < X ≤ 150	150 < X ≤ 250	250 < X ≤ 500	X > 500
	C2H2 (Acetylene)	X ≤ 3	3 < X ≤ 7	7 < X ≤ 35	35 < X ≤ 50	50 < X ≤ 80	X > 80
	CO (Carbon Monoxide)	X ≤ 350	350 < X ≤ 500	500 < X ≤ 600	600 < X ≤ 1000	1000 < X ≤ 1500	X > 1500
	CO2 (Carbon Dioxide)	X ≤ 3000	3000 < X ≤ 4500	4500 < X ≤ 5700	5700 < X ≤ 7500	7500 < X ≤ 12000	X > 12000

--- LTC

Table 1-11 DGA Criteria – LTC

Dissolved Gas (X)	Scores					Weight
	1	2	3	4	5	
X = C2H4/C2H2	X < 0.33	0.33 ≤ X < 0.67	0.67 ≤ X < 1	1 ≤ X < 1.33	X ≥ 1.33	3
X = C2H6/CH4	X < 0.20	0.2 ≤ X < 0.4	0.4 ≤ X < 0.6	0.6 ≤ X < 0.8	X ≥ 0.80	2
H2	X < 70	70 ≤ X < 500	500 ≤ X < 1000	1000 ≤ X < 1500	X ≥ 1500	1

Note: Overall Factor =1.2 when ALL the following conditions meet

- H2 (hydrogen)< 1500 ppm
- C2H4 (Ethylene) < 1000 ppm
- C2H2 (Acetylene) < 1000 ppm

A test must have been conducted within the past 5 years to be considered.

General Oil Quality

Table 1-12 Oil Quality Test Criteria

Oil Quality Test		Voltage Class [kV]	Score				
			4	3	2	1	0
Mineral Oil							
Water Content (D1533) [ppm]		V ≤ 69	< 30	[30, 33.3)	[33.3, 36.6)	[36.6, 40)	> =40
		69 < V < 230	< 20	[20, 25)	[25, 30)	[30, 35)	>= 35
		V ≥ 230	< 15	[15, 18.3)	[18.3, 21.6)	[20, 25)	> = 25
Dielectric Strength (D1816 – 1mm gap) [kV]		V ≤ 69	> 20	(20, 17.5]	(12.5, 17.5]	(10, 12.5]	< =10
		69 < V < 230	> 25	(21, 25]	(17, 21]	(13,17]	< =13
		V ≥ 230	> 27	(23, 27]	(20, 23]	(17, 20]	< 17
IFT (D971) [dynes/cm]		V ≤ 69	> 25	(21.6, 25]	(18.3, 21.6]	(15, 18.3]	< = 15
		69 < V < 230	> 30	(26, 30]	(22, 26]	(18, 22]	< = 18
		V ≥ 230	> 32	(28, 32]	(24, 28]	(20, 24]	< = 20
Acid Number (D974) [mg KOH/g]		V ≤ 69	< 0.05	[0.05, 0.1)	[0.1, 0.15)	[0.15, 0.2)	> = 0.2
		69 < V < 230	< 0.04	[0.04,.077)	[0.077,0.113)	[0.113,0.15)	> = 0.15
		V ≥ 230	< 0.03	[0.03,0.053)	[0.053,0.076)	[0.076,0.1)	> = 0.1

Degree of polymerization

Table 1-13 Furan Criteria

Score	Description
4	2FAL < 100
3	100 <= 2FAL < 200
2	200 <= 2FAL < 600
1	600 <= 2FAL < 1000
0	2FAL >= 1000

Multiple years of test records

Whenever there are multiple years of test records for a parameter, the score of the parameter is calculated as the weighted average scores of multiple years, with more recent years being assigned of higher year weights as follows:

$$Test\ Score = \frac{\sum_i (S_i W_i)}{\sum_i W_i}$$

Equation 1-1

Where *i* refers to the year the inspection was conducted
W refers to the assigned year weight as follows

Year	Weight
2023	1
2022	0.9
2021	0.8
2020	0.7
2019	0.6
2018	0.5
2017	0.4
2016	0.3
2015	0.2
2014	0.1
2013	0

S refers to the score in a specific year, as per criteria as follows

- **Insulation Resistance**

Table 1-14 Insulation Resistance Criteria

Score	Description
4	Insulation Resistance > =1.58 G Ohm
0	Insulation Resistance < 1.58 G Ohm

- **Transformer Turns Ratio (TTR)**

The "turns ratio" parameter compares the TTR variation between phases in all tap positions.

If Maximum TTR variation between three phases across any tap position is greater than 0.5% *Then* **Score** = 0

Else **Score** = 4

- **Excitation Current**

There will be two high readings ($Reading_{High1}$ and $Reading_{High2}$) and one low reading ($Reading_{low}$). Evaluation is done by comparing the two similar high readings.

Score = Max($Score_i$, $Score_2$, …, $Score_t$)

Where
$Score_t$ are scores for different tap positions and

And
If $Reading_{High1}$ or $Reading_{High2}$ > 50 mA
If Variation between $Reading_{High1}$ and $Reading_{High2}$ > 10%
$Score_{tap}$ = 0
Else **$Score_{tap}$** = 4

Else
If Variation between $Reading_{High1}$ and $Reading_{High2}$ > 5%
$Score_{tap}$ = 0
Else **$Score_{tap}$** = 4
End if

- **Power Factor Test**

Table 1-15 Power Factor Test Criteria

Score	Description
4	PF < 0.05%
3	0.05% < PF < 0.5%
2	0.5% < PF < 1%
1	1% < PF < 2%
0	PF >2%

- **Winding Resistance**

  The “winding resistance” parameter compares the winding resistance variation between phases in all tap positions.

  If Maximum winding resistance variation between three phases across any tap position (LV or HV) is greater than 5% *Then* **Score** = 0

  Else **Score** = 4

Loading History

Table 1-16 Loading History - Power Transformers

Data: S1, S2, S3, …, Si recorded data (average daily loading)
SB= rated MVA NA=Number of Si/SB which is lower than 0.6 NB= Number of Si/SB which is between 0.6 and 0.8 NC= Number of Si/SB which is between 0.8 and 1.0 ND= Number of Si/SB which is between 1 and 1.2 NE= Number of Si/SB which is greater than 1.2 Score = $\frac{NA \times 4 + NB \times 3 + NC \times 2 + ND \times 1}{N}$

Age Limiting Factor

The age derating is the Weibull survival function (1 – cumulative distribution function).

$$Age\_Derating = S_f = e^{-(\frac{x}{\alpha})^{\beta}}$$

Equation 1-2

S_f	= survivor function
x	= age in years
α	*= constant that controls scale of function*
β	*= constant that controls shape of function*

The parameters of Power Transformers age limiting curve are shown in the following table and are based on industry information.

Table 1-17 Age Limiting Curve Parameters - Power Transformers

Asset Type	α	β
Power Transformers	**58.1804**	**9.8989**

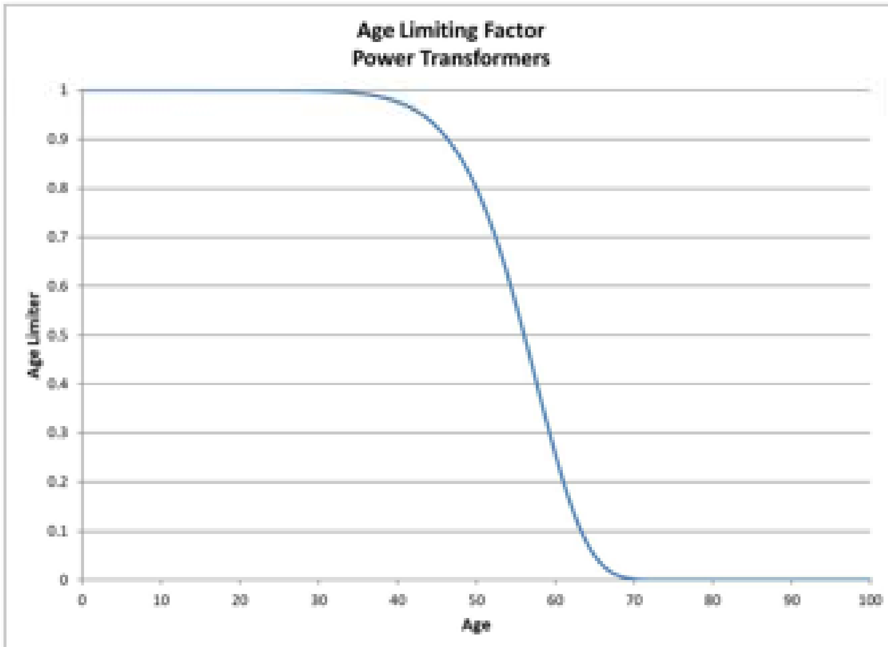

Figure 1-1 Age Limiting Factor Criteria - - Power Transformers

De-Rating Multiplier

The de-rating is based on the following equation and DR is described in the subsequent table.

$$DR = \min(DR_1, DR_2)$$

Equation 1-3

Where DR_1 and DR_2 are as follows:

Table 1-18 De-Rating Multiplier Based on Oil Quality Score

$DR_1 = \min(DR\_Score_{Moisture}, DR\_Score_{Dielectric\ Strength})$	
DR_Score	**$Score_{Oil\ Quality\ Test}$** $Score_{Oil\ Quality}$ is defined in Table 1-12
0.25	$0 \leq Score_{Oil\ Quality\ Test} < 1$
0.5	$1 \leq Score_{Oil\ Quality\ Test} < 2$
1	$Score_{Oil\ Quality\ Test} \geq 2$

<u>DR$_2$: Dissolved Gas Trend</u>

DR$_2$ is based on total dissolved combustible gas (TDCG) concentration daily rate increase.

Table 1-19 De-Rating Multiplier Based on TDCG Trend

Daily Increase (ppm/day)	**IEEE C57.104 Condition Codes for TDCG**			
	Condition 1	Condition 2	Condition 3	Condition 4
	$0 \leq TDCG \leq 720$	$720 \leq TDCG < 1920$	$1920 \leq TDCG < 4630$	$TDCG > 4630$
	DR_Score			
$0 \leq X < 0.33$	1	1	1	1
$0.33 \leq X < 1$	0.9	0.9	0.85	0.75
$1 \leq X < 1.43$	0.9	0.9	0.75	0.75
$1.43 \leq X < 4.29$	0.9	0.9	0.75	0.5
$X \geq 4.29$	0.9	0.9	0.5	0.25

1.2 Age Distribution

The average age is 29 for Power Transformers. The age distribution is as follows.

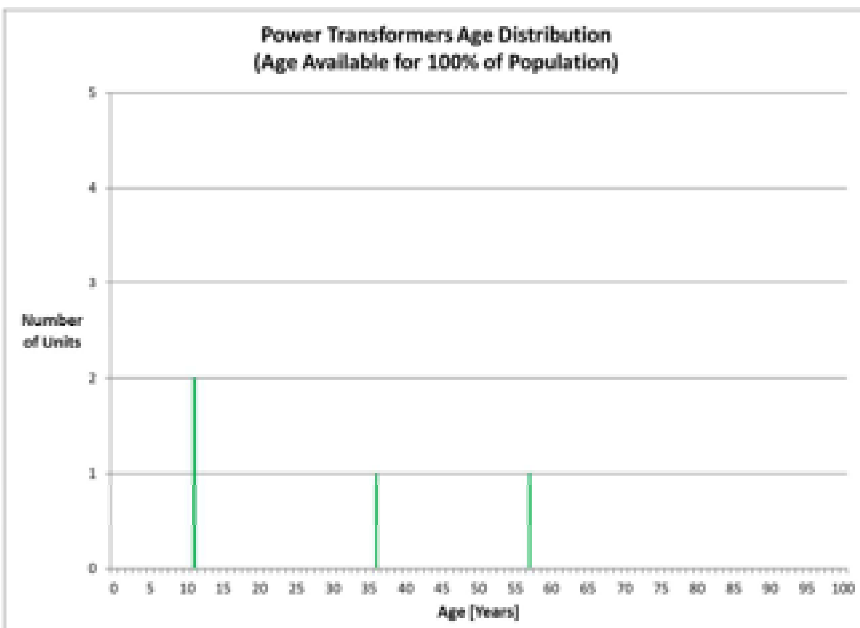

Figure 1-2 Age Distribution –Power Transformers

1.3 Health Index Results

There are 4 units of Power Transformers, with 2 of them equipped with LTC. The average Health Index is 84%.

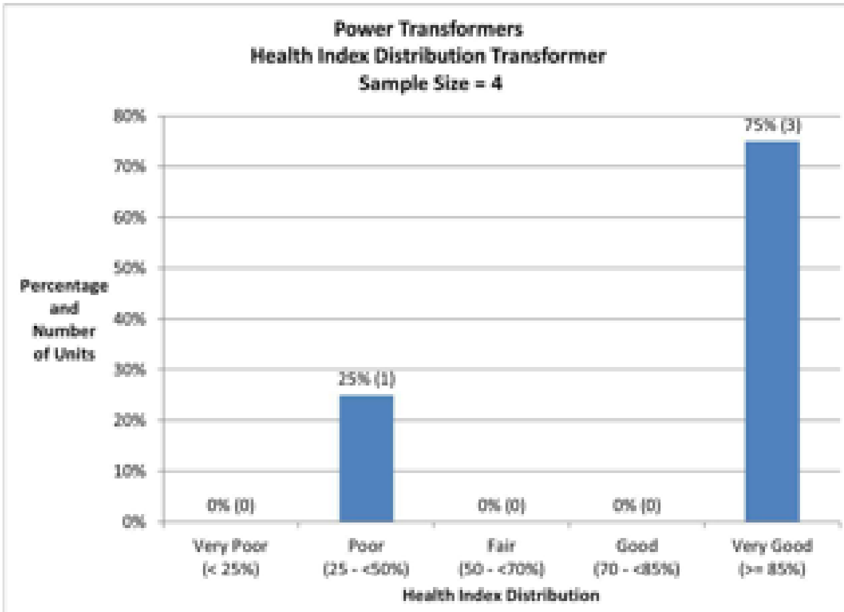

Figure 1-3 Health Index Distribution –Power Transformers

In the above diagram, the only unit categorized in poor condition is due to its physical age, while its test results do not show anything abnormal. It is recommended that FHI keep on monitoring the condition status of this individual asset.

1.4 Flagged-for-Action Plan

Power Transformers are proactively replaced and the risk assessment and methodology described in Section II.2.3 is used to develop flagged-for-action plan.

In this study, the same criticality value is assigned to each of Power Transformers asset.

The following is the flagged-for-action plan in the next 10 years. In the diagram, the only one that is flagged for action is the individual unit that is categorized in poor condition due to physical age.

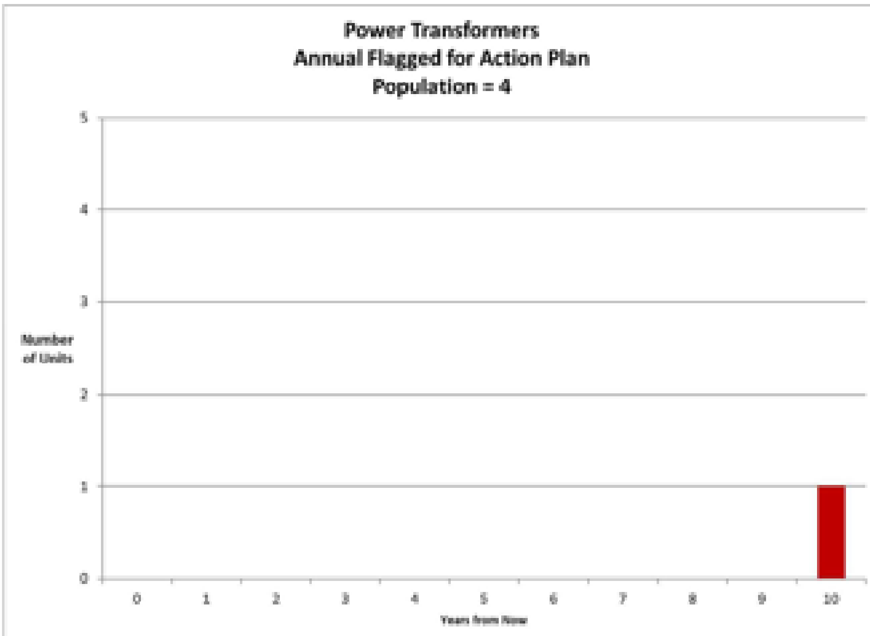

Figure 1-4 Flagged-for-action plan – Power Transformers

1.5 Risk-Based Prioritized List

The following table shows the risk-based prioritization list if units.

Table 1-20 Risk-Based Prioritization List - Power Transformers

Rank	ID	Substation	Position	MVA	Age	HI	Risk Index 100% = Most Risk 0% = Least Risk	FFA Year
1	Welsh-T1	Welsh	1	5	57	44%	67.3%	10
2	Chalk-T1	Chalk	1	5	36	96%	0.0%	>20
3	MTS-T2	MTS	2	25	11	95%	0.0%	>20
4	MTS-T1	MTS	1	25	11	98%	0.0%	>20

1.6 Data Gaps

Available data for Power Transformers include age, loading, oil, DGA and other transformer test results. The following table shows the data gaps.

Table 1-21 Data Gap for Power Transformers

Data Gap (Sub-Condition Parameter)	**Condition Parameter Group**	**Priority**	**Description**	**Source of Data**
Oil Level, Conservator, Tank Breather	Oil Storage	✫	Defect due to ageing, installation or lack of maintenance	Maintenance and/or Inspection records
Radiators, Coolers Fans	Cooling System	✫	Defect due to ageing, installation or lack of maintenance	Maintenance and/or Inspection records

2 MS SWITCHGEAR

2.1 Health Index Formula

2.1.1 Condition and Sub-Condition Parameters

Table 2-1 Condition Parameter and Weights - MS Switchgear

m	Condition parameter	WCP_m	Sub-Condition Parameters
1	Bus and Cable	2	Table 2-2
2	Fuse Compartment	1	Table 2-3
3	Switch	4	Table 2-4
4	Service Record	2	Table 2-5
	Age Limiting		Figure 2-1

Table 2-2 Physical Condition Sub-Condition Parameters and Weights (m=1) - MS Switchgear

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Cable Termination	2	Table 2-6
2	Insulator	3	Table 2-6
3	Barrier	3	Table 2-6
4	Grounding	1	Table 2-6
5	Lightning Arrester	1	Table 2-6

Table 2-3 Fuse Compartment Sub-Condition Parameters and Weights (m=2) - MS Switchgear

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Fuse Contact R	1	Table 2-7

Table 2-4 Switch Sub-Condition Parameters and Weights (m=3) - MS Switchgear

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Operating Mechanism	5	Table 2-6
2	Switch Contact R	4	Table 2-7

Table 2-5 Service Record Sub-Condition Parameters and Weights (m=4) - MS Switchgear

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Overall	1	Table 2-6

2.1.2 Condition Criteria

Multiple years of test records

Whenever there are multiple years of test records for a parameter, the score of the parameter is calculated as the weighted average scores of multiple years, with more recent years being assigned of higher year weights as follows:

$$Test\ Score = \frac{\sum_i (S_i W_i)}{\sum_i W_i}$$

Equation 2-1

Where *i* refers to the year the inspection was conducted
W refers to the assigned year weight as follows

Year	Weight
2023	1
2022	0.9
2021	0.8
2020	0.7
2019	0.6
2018	0.5
2017	0.4
2016	0.3
2015	0.2
2014	0.1
2013	0

S refers to the score in a specific year, as per criteria as follows

- **Inspection**

Table 2-6 Inspection Criteria

Score	Description
4	OK
2	Fair
1	Poor

- **Contact Resistance**

Table 2-7 Contact Resistance Criteria

Score	Description (R in μΩ)	
	Air Switch	Fuse
4	[0, 120)	[0, 5920)
3	[120, 150)	[5920, 7400)
1	[150, 180)	[7400, 8880)
0	[180, ∞)	[8880, ∞)

Age Limiting Factor

The parameters of MS Switchgear age limiting curve are shown in the following table and are based on other utility's historical removal data.

Table 2-8 Age Limiting Curve Parameters - MS Switchgear

Asset Type	α	β
MS Switchgear	**37.1098**	**2.2246**

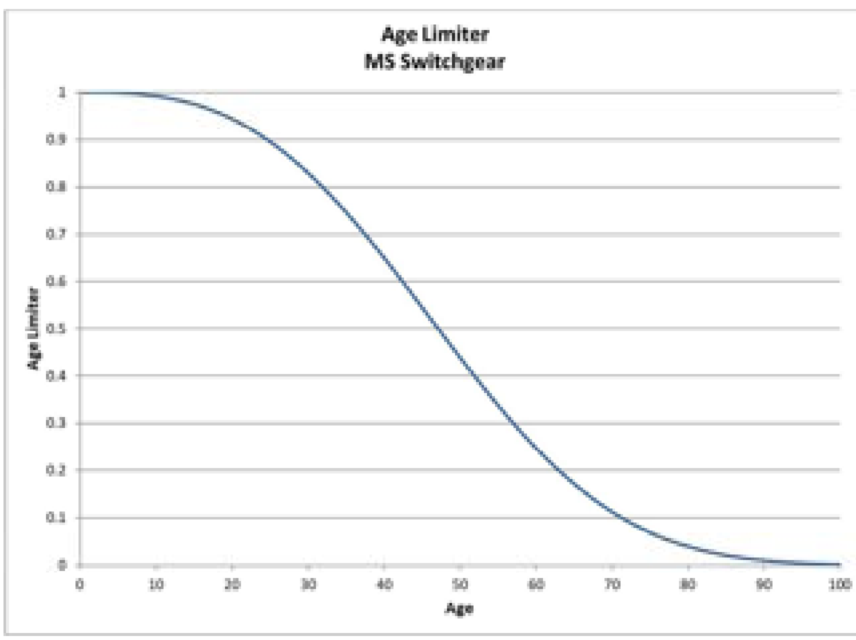

Figure 2-1 Age Limiting Factor Criteria - - MS Switchgear

2.2 Age Distribution

In total there are 2 MS switchgear. Both have age information. The average age is 39. The age distribution is as follows.

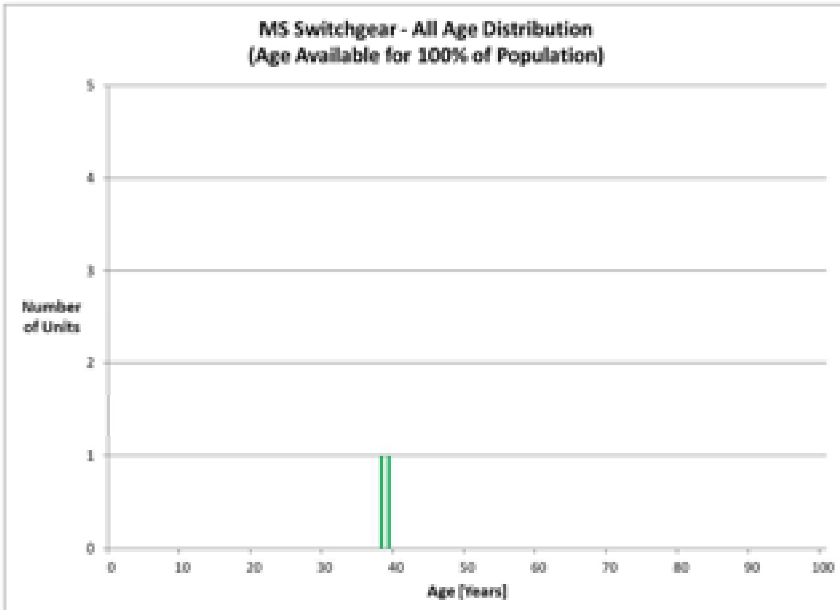

Figure 2-2 Age Distribution –MS Switchgear

2.3 Health Index Results

The average Health Index of MS Switchgear is 68%.

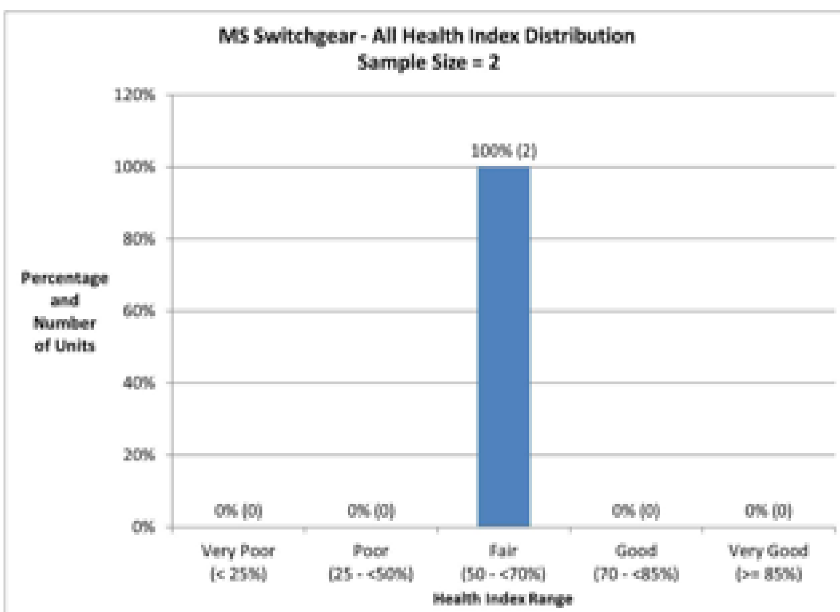

Figure 2-3 Health Index Distribution –MS Switchgear

2.4 Flagged-for-Action Plan

MS Switchgear are proactively replaced and the risk assessment and methodology described in Section II.2.3 is used to develop flagged-for-action plan.

Minimum criticality value is assigned for each of MS Switchgear asset so that a unit becomes a candidate for action when its cumulative probability of failure is greater than or equal to 80%.

According to analysis, no asset is flagged for action in the next 10 years.

2.5 Risk-Based Prioritized List

The following table shows the risk-based prioritization list if units.

Table 2-9 Risk-Based Prioritization List - MS Switchgear

Rank	ID	Busbar	Manufacturer	Type	Age	HI (Final)	Risk Index 100%=Most Risk 0% = Least Risk	FFA Year
1	SWGR-Welsh	Welsh	S&C Electric	Air	39	67.0	11.4%	>20
2	SWGR-Chalk	Chalk	S&C Electric	Air	38	69.0	9.7%	>20

2.6 Data Gaps

Available data for MS Switchgear include age, inspection, and test results. There are no data gaps for this asset category.

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3 DISTRIBUTION TRANSFORMERS

3.1 Health Index Formula

3.1.1 Condition and Sub-Condition Parameters

Table 3-1 Condition Parameter and Weights – Distribution Transformers

m	Condition Parameter	WCP_m		Sub-Condition Parameters
		Pole	Pad	
1	Corrosion	3		Table 3-2
2	Termination	5		Table 3-3
	Age Limiting			Figure 3-1

3.1.2 Condition Criteria

Painting

Table 3-2 Painting Criteria

Score	Description (in the past 5 years)
4	Painted

Infrared Inspection

Table 3-3 Infrared Inspection Criteria

Score	Description (total count of IR issues in the past 5 years)
4	0
3	1
2	2
1	3
0	>=4

Age Limiting Factor

The parameters for Distribution Transformers age limiting curve are shown in the following table and are based on industry curve for pad mounted type, and FHI's historical removal data for pole mounted type.

Table 3-4 Age Limiting Curve Parameters - Distribution Transformers

Asset Type	α	β
Pad Mounted	**42.01**	**3.51**
Pole Mounted	**46.26**	**3.86**

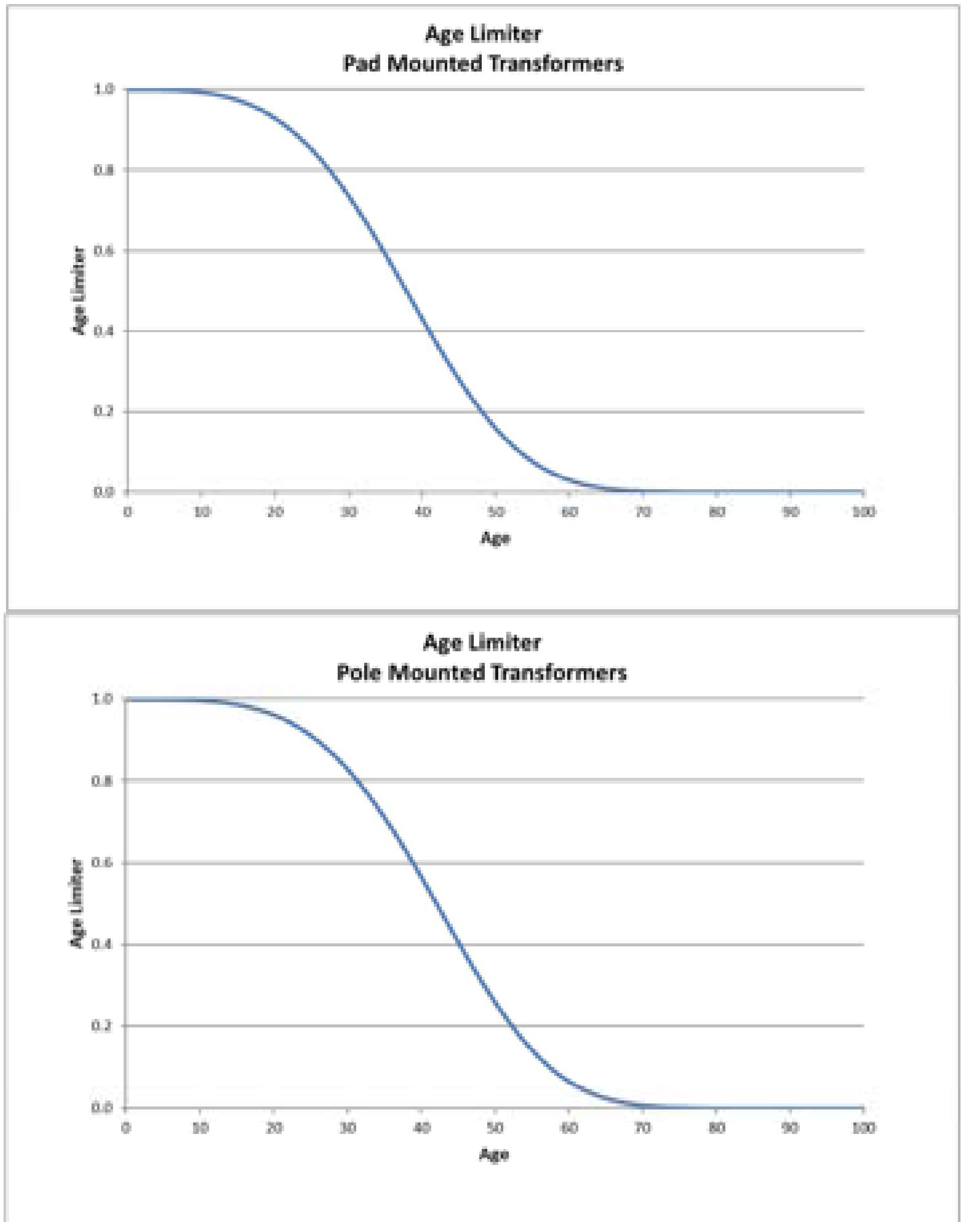
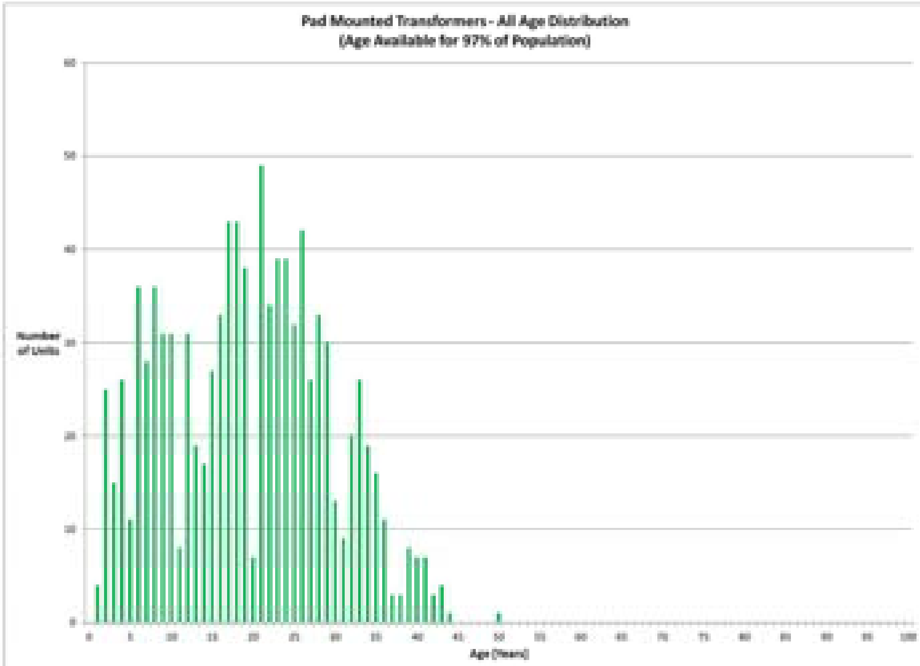


Figure 3-1 Age Limiting Factor Criteria - - Distribution Transformers

3.2 Age Distribution

The average ages of all in service units are 19 and 21, for Pad Mounted and Pole Mounted Distribution Transformers respectively. The age distributions are as follows.



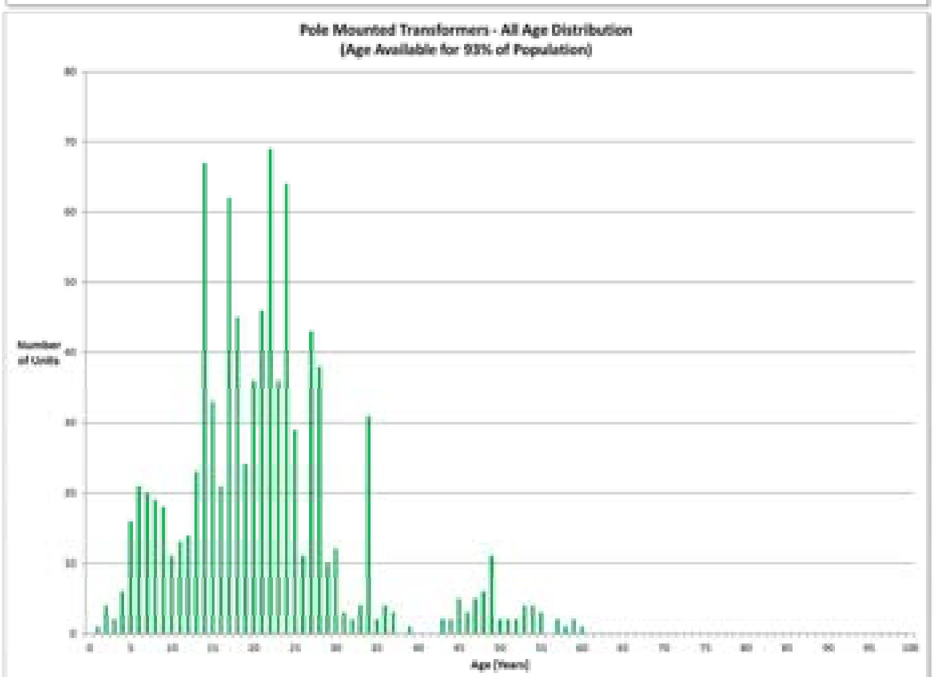


Figure 3-2 Age Distribution - Distribution Transformers

3.3 Health Index Results

There are 1017 Pad Mounted Distribution Transformers. Among them, 985 units have age or other data for calculating a Health Indexing score.

There are 989 Pole Mounted Distribution Transformers. Among them, 921 units have age or other data for calculating a Health Indexing score.

The average Health Index are 88% and 90%, for Pad Mounted and Pole Mounted Distribution Transformers respectively.

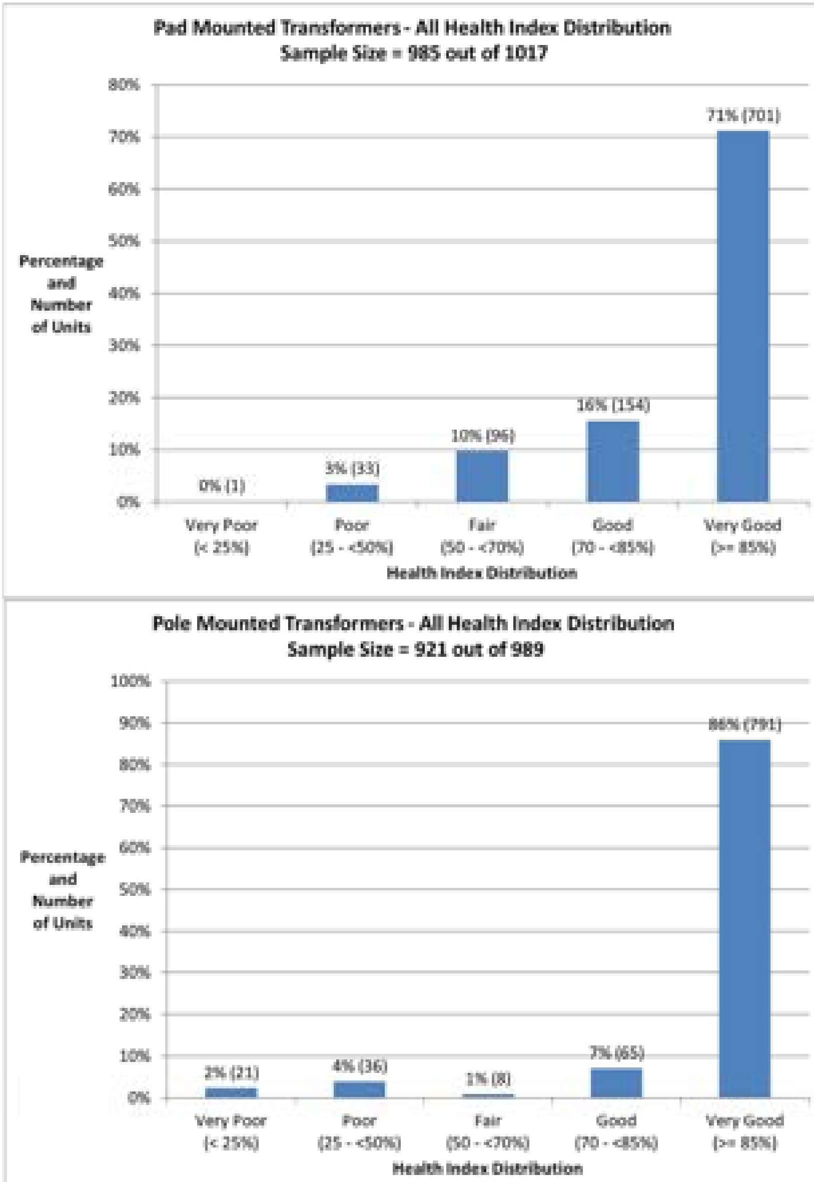


Figure 3-3 Health Index Distribution - Distribution Transformers

3.4 Flagged-for-action Plan

The flagged-for-action plan for Distribution Transformers is based on the asset removal rate and age distribution.

The flagged-for-action plan for Distribution Transformers is as follows:

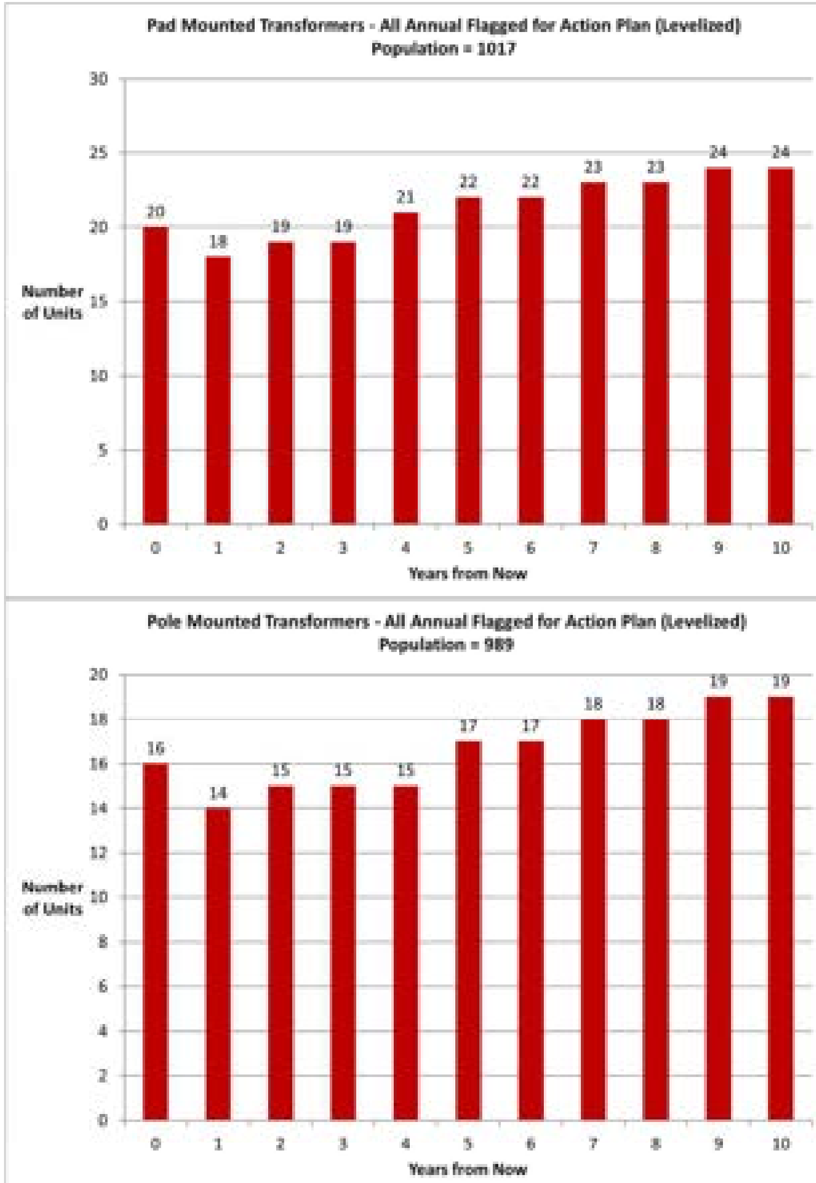


Figure 3-4 Flagged-for-action plan – Distribution Transformers

3.5 Data Gaps

The data for in service Distribution Transformers include age, tank corrosion and connection infrared inspection information.

The data gaps for this asset category are as follows:

Table 3-5 Data Gap for Distribution Transformers

Data Gap (Sub-Condition Parameter)	**Condition Parameter Group**	**Priority**	**Description**	**Source of Data**
Access *	Physical Condition	☆	Physically locked	On-site visual inspection
Base *		☆	Physically worn-out	On-site visual inspection
Oil Leak	Connection and Insulation Condition	☆☆☆	Leakage	On-site visual inspection
Grounding		☆	Loose connection	On-site visual inspection
Insulator		☆☆	Insulation Defect	Test
Loading	Service Record	☆	Monthly 15 min peak load throughout years	Operation Record

* Pad Mounted Transformers only

4 POLES

4.1 Health Index Formula

Assume a parameter scoring system of 0 through 4, where 0 and 4 represent the “worst” and “best” scores respectively. Thus, the maximum score for any condition or sub-condition parameter (maximum CPS and CPF) is “4”.

4.1.1 Condition and Sub-Condition Parameters

Table 4-1 Condition Parameter and Weights - Poles

m	Condition parameter	WCP_m		Sub-Condition Parameters
		Wood	Concrete	
1	Pole Strength	7		Table 4-2
2	Pole Condition	5	5	Table 4-3
3	Pole Accessories	3		Table 4-4
4	Service Record	6	6	Table 4-5
	Age Limiting			Figure 4-1

Table 4-2 Pole Strength Sub-Condition Parameters and Weights (m=1) - Poles

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Pole Strength	1	Table 4-6

Table 4-3 Pole Condition Sub-Condition Parameters and Weights (m=2) - Poles

n	Sub-Condition Parameter	$WSCP_n$		Condition Criteria Table
		Wood	Concrete	
1	Crack	2	2	Table 4-6
2	Rot/Rust Rebar	2	2	Table 4-6
3	Decay/Spalling	3	3	Table 4-6
4	Woodpeckers	2		Table 4-6
5	Damage	1	1	Table 4-6

Table 4-4 Pole Accessories Sub-Condition Parameters and Weights (m=3) - Poles

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Crossarm	3	Table 4-6
2	Leaning	4	Table 4-6

Table 4-5 Service Record Sub-Condition Parameters and Weights (m=4) - Poles

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Overall	1	Table 4-6

4.1.2 Condition Criteria

Individual Inspection

The score based on individual inspection in the past years is calculated as:

$$Average\ Score = \frac{\sum W_i Score_i}{\sum W_i}$$

Equation 4-1

Where *i* represents the year of inspection

Table 4-6 Individual Inspection Criteria - Poles

Score	Inspection Defect	Pole Strength Test %
4	0, False	$Score = \frac{S_t}{S_d} \times 4$ Where S_t – test strength in psi S_d – design strength in psi **
3	1, Good	
2	2, Fair	
1	3, Fair-Poor	
0	4, Poor, True	

And the weights for different inspection years are as follows

Year (i)	Weight (W_i)
2023	1
2022	0.9
2021	0.8
2020	0.7
2019	0.6
2018	0.5
2017	0.4
2016	0.3
2015	0.2
2014	0.1
2013	0

** Where the design strength limits are summarized in the following table

Wood Pole Species	Design Strength (psi) *
Douglas Fir	6800
Lodgepole Pine	6600
Red Pine	6000
Southern Yellow Pine	7800
Western Red Cedar	5600
Jack Pine	6400
Default	6000

* CSA standard O15

<u>Age Limiting Factor</u>

Age is used as a limiting factor to reflect the degradation of asset over time. Methodology for applying the degradation survival curve is described in Equation 1-2 of Section 1.1.2.

The parameters of Poles age limiting curve are shown in the following table and based on other utility's historical removal data.

Table 4-7 Age Limiting Curve Parameters - Poles

Asset Type	α	β
Wood Poles	**52.9706**	**2.4198**
Concrete Poles	**57.1481**	**2.2686**

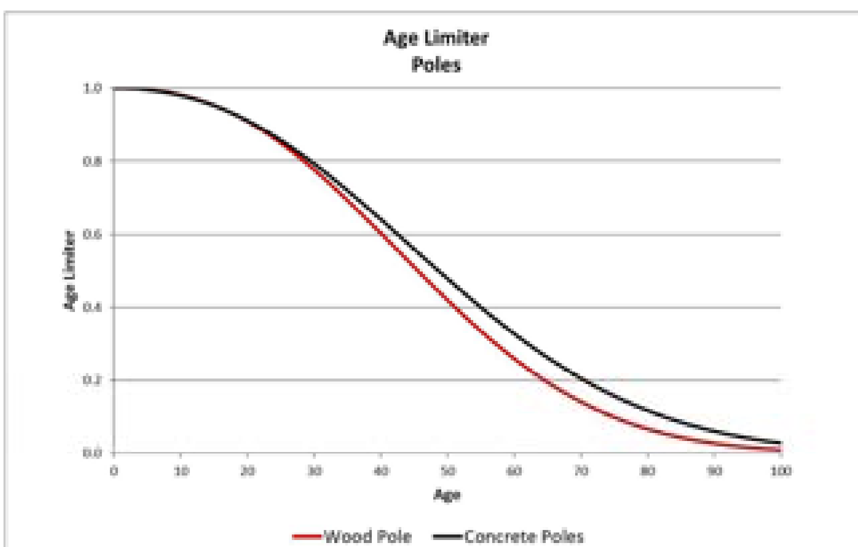


Figure 4-1 Age Limiting Factor Criteria - Poles

4.2 Age Distribution

The average ages of all units are 36 years and 20 years, for Wood Poles and Concrete Poles respectively.

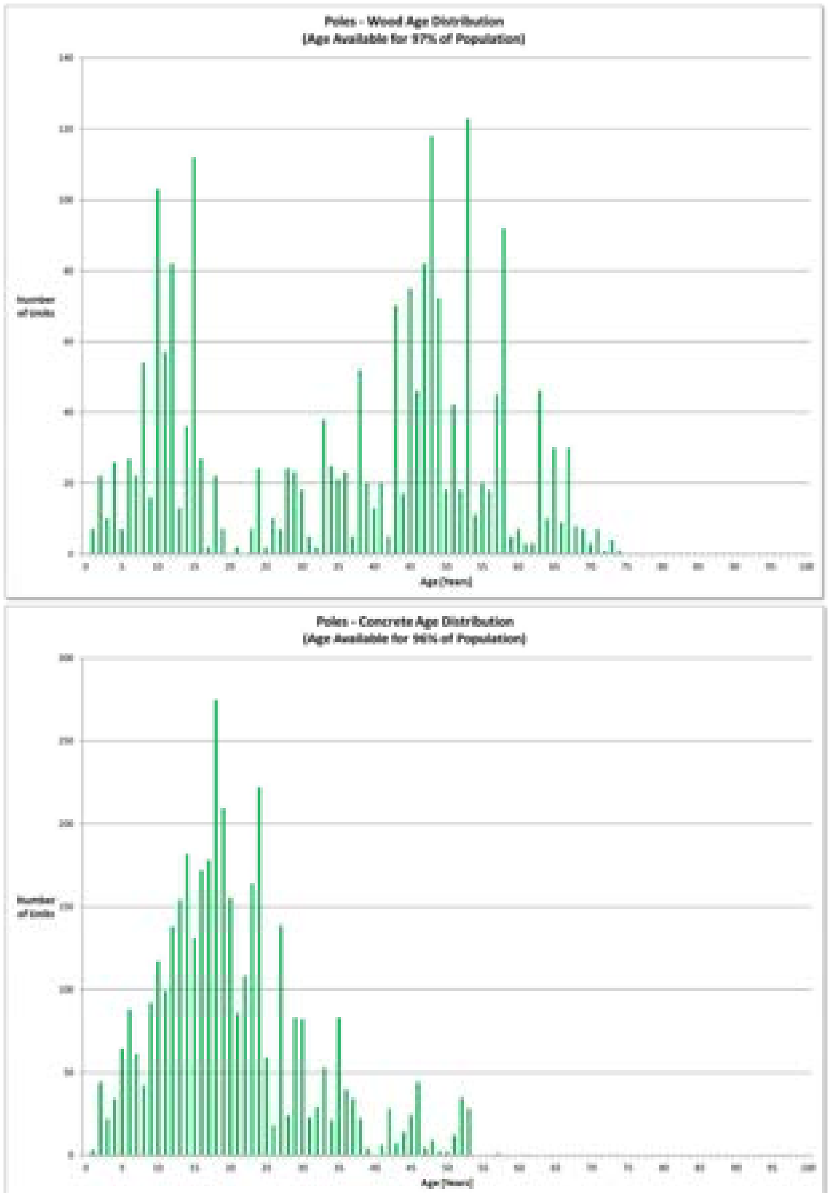


Figure 4-2 Age Distribution – Poles

4.3 Health Index Results

There are 2133 units of Wood Poles. Among them, 2093 units have sufficient data for obtaining Health Indexing results.

There are 3924 units of Concrete Poles. Among them, 3774 units have sufficient data for obtaining Health Indexing results.

The average Health Index scores are 60% and 88%, for Wood Poles and Concrete Poles respectively.

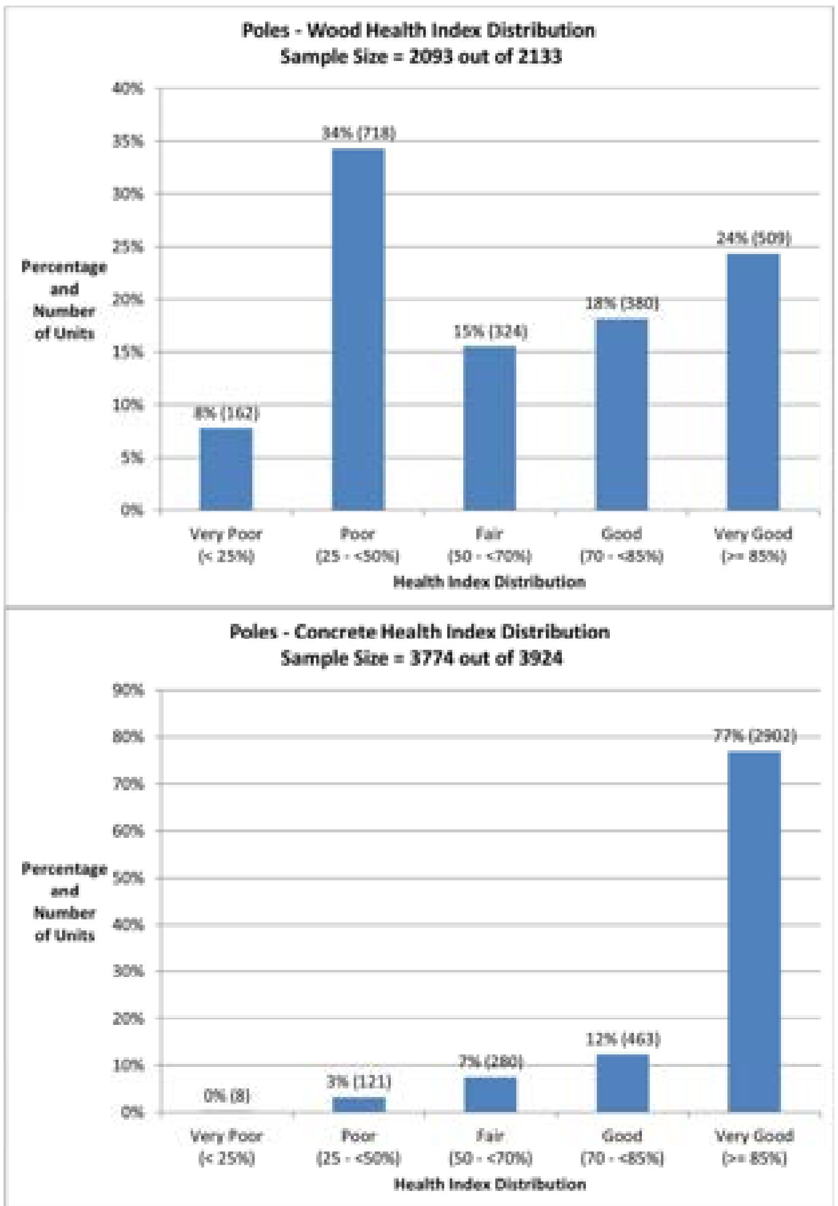


Figure 4-3 Health Index Distribution - Poles

4.4 Flagged-for-Action Plan

The flagged-for-action plan of Poles is based on the asset removal rate and age distribution.

The following diagram shows the flagged-for-action plan:

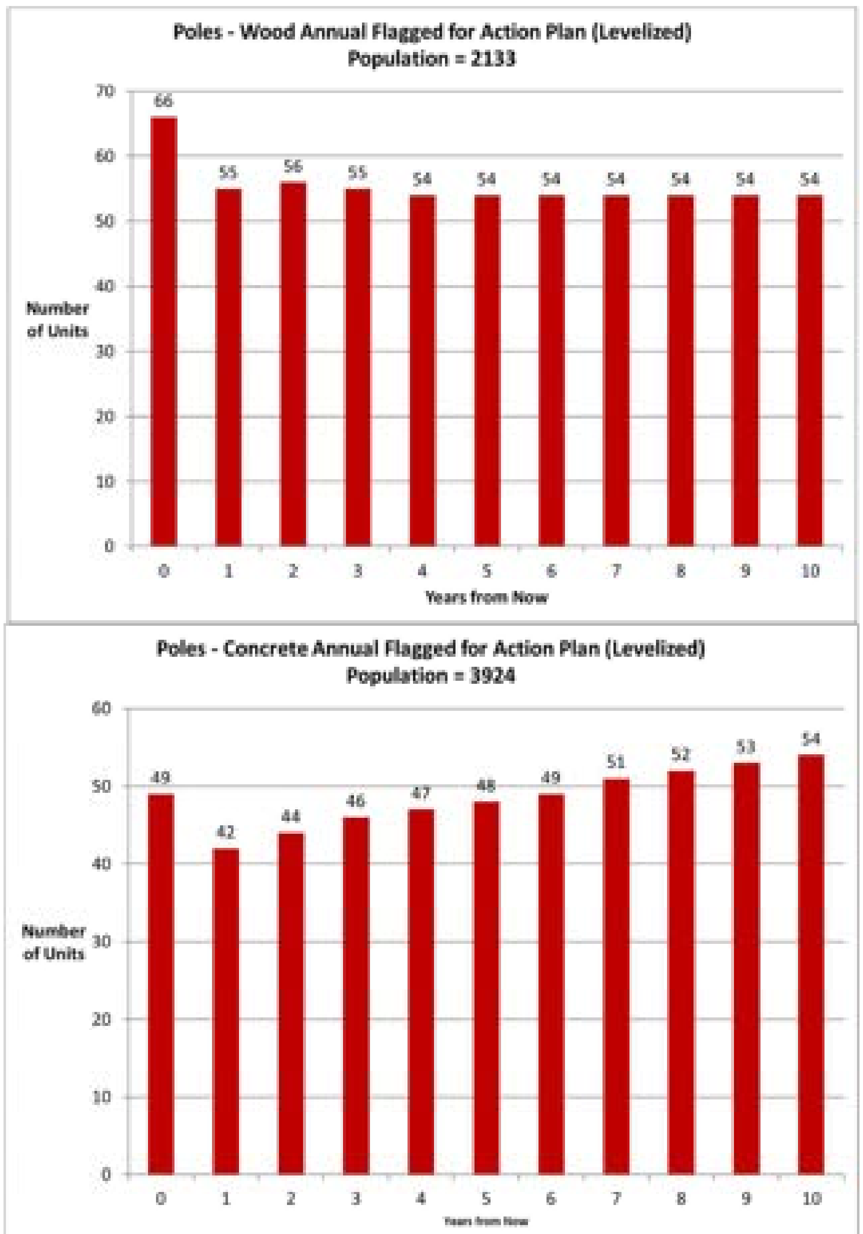


Figure 4-4 Flagged-for-action plan - Poles

4.5 Data Gaps

The data used for assessing condition of Poles assessment include age, test and inspection results. There are no data gaps for this asset category.

5 OH PRIMARY CONDUCTORS

5.1 Health Index Formula

The HI assessment for this asset category is based on age and the cumulative likelihood of survival at a given age.

Age is used as a limiting factor to reflect the degradation over time as described in section 1.1.2.

5.1.1 Condition and Sub-Condition Parameters

Table 5-1 Condition Parameter and Weights – OH Primary Conductors

m	Condition Parameter	WCP_m	Sub-Condition Parameters
	Age Limiting		Figure 5-1

5.1.2 Condition Criteria

Age Limiting Factor

The parameters of OH Primary Conductors age limiting curve are shown in the following table and are based on industry information.

Table 5-2 Age Limiting Curve Parameters - OH Primary Conductors

Asset Type	α	β
OH Primary Conductors	**59.2788**	**4.364**

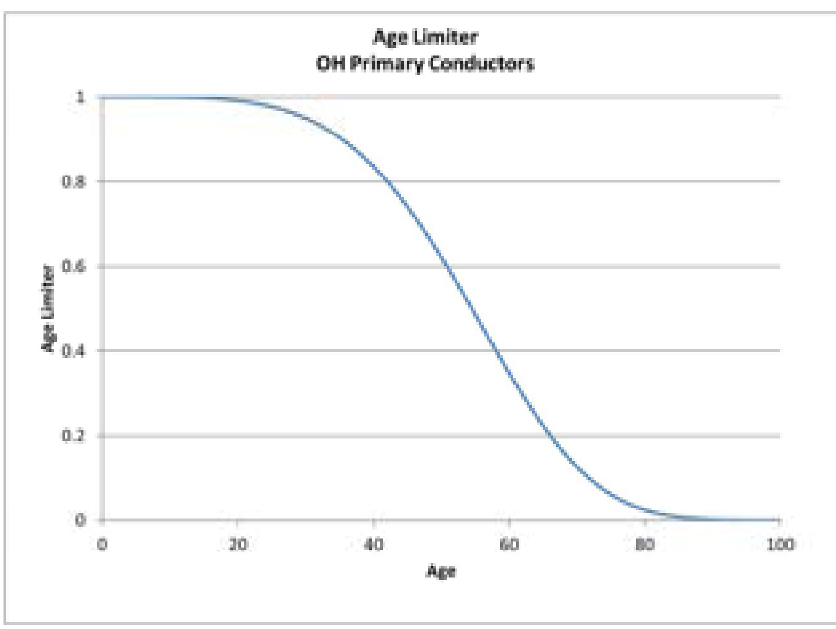


Figure 5-1 Age Limiting Factor Criteria - - OH Primary Conductors

5.2 Age Distribution

The average age of OH Primary Conductors segments is 13 years. The age distributions for OH Primary Conductors are as follows:

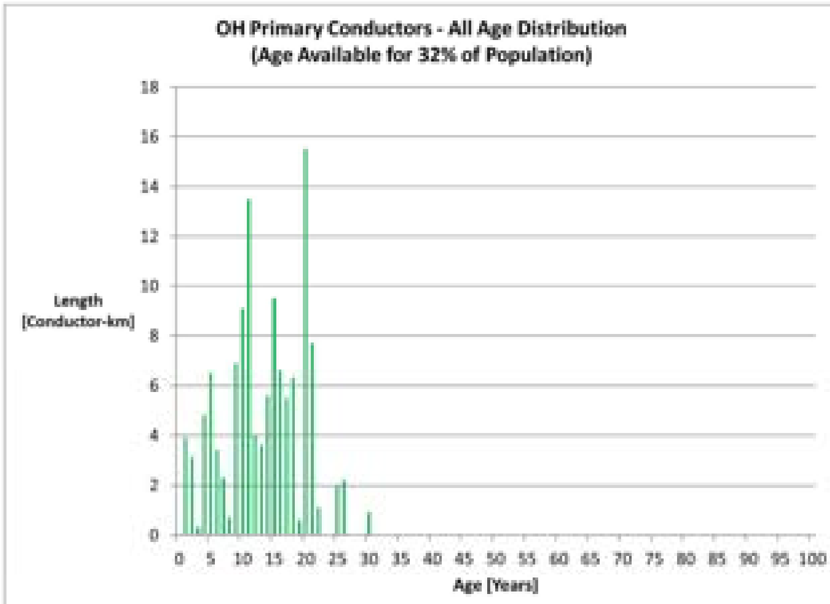


Figure 5-2 Age Distribution - OH Primary Conductors

5.3 Health Index Results

There are 393.5 km OH Primary Conductors. Among them, 125.5 km have age data used for Health Indexing and the average Health Index for this asset category is close to 100%.

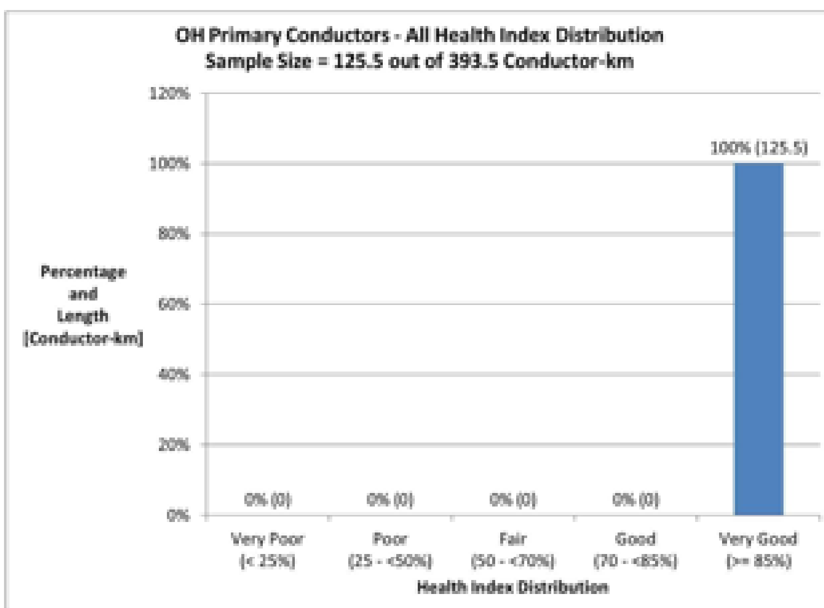


Figure 5-3 Health Index Distribution - OH Primary Conductors

5.4 Flagged-for-action Plan

The flagged-for-action plan for OH Primary Conductors is based on asset removal rate and age distribution and is extrapolated to the entire population.

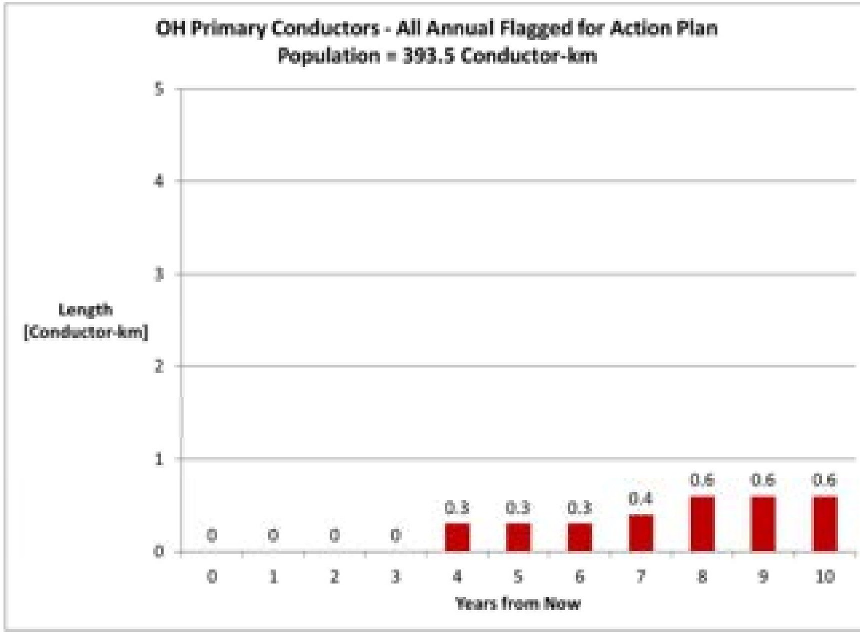


Figure 5-4 Flagged-for-action plan – OH Primary Conductors

5.5 Data Gaps

The data used for assessing condition of OH Primary Conductors assessment include age only.

The data gaps are as follows:

Table 5-3 Data Gap for OH Primary Conductors

Data Gap (Sub-Condition Parameter)	**Condition Parameter Group**	**Priority**	**Description**	**Source of Data**
Splices & Termination	Physical Condition	☆ ☆	Connection defect	Inspection & Maintenance Records
Clamp & Insulator		☆	Loose installation & crack	
Fault rate at Segment Level	Service Record	☆ ☆	Failure records	Historic records

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6 UG PRIMARY CABLES

6.1 Health Index Formula

As there is insufficient condition data available and HI assessment for this asset category is based simply on age and the cumulative likelihood of survival at a given age.

6.1.1 Condition and Sub-Condition Parameters

Table 6-1 Condition Parameter and Weights – UG Primary Cables

m	Condition Parameter	WCP_m	Sub-Condition Parameters
	Age Limiting		Figure 6-1

6.1.2 Condition Criteria

<u>Age Limiting Factor</u>

The parameters of UG Primary Cables age limiting curve are shown in the following table and are based on industry information.

Table 6-2 Age Limiting Curve Parameters - UG Primary Cables

Asset Type	α	β
TR XLPE cables	**53.13**	**9.03**
XLPE cables	**32.80**	**5.53**

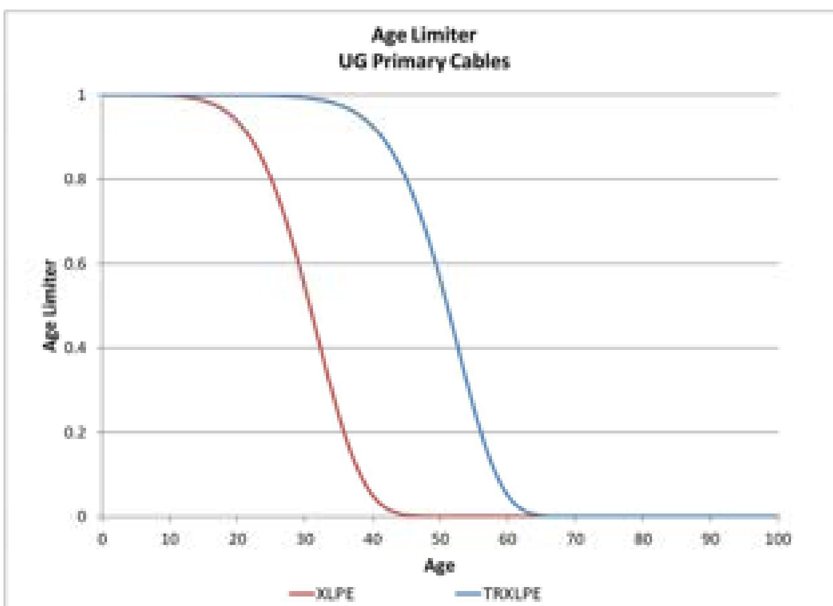

Figure 6-1 Age Limiting Factor Criteria - - UG Primary Cables

6.2 Age Distribution

The average age of Primary XLPE UG Primary Cables segments is 24 years.

The average age of Primary TRXLPE UG Primary Cables segments is 6 years.

The age distributions for UG Primary Cables is as follows:

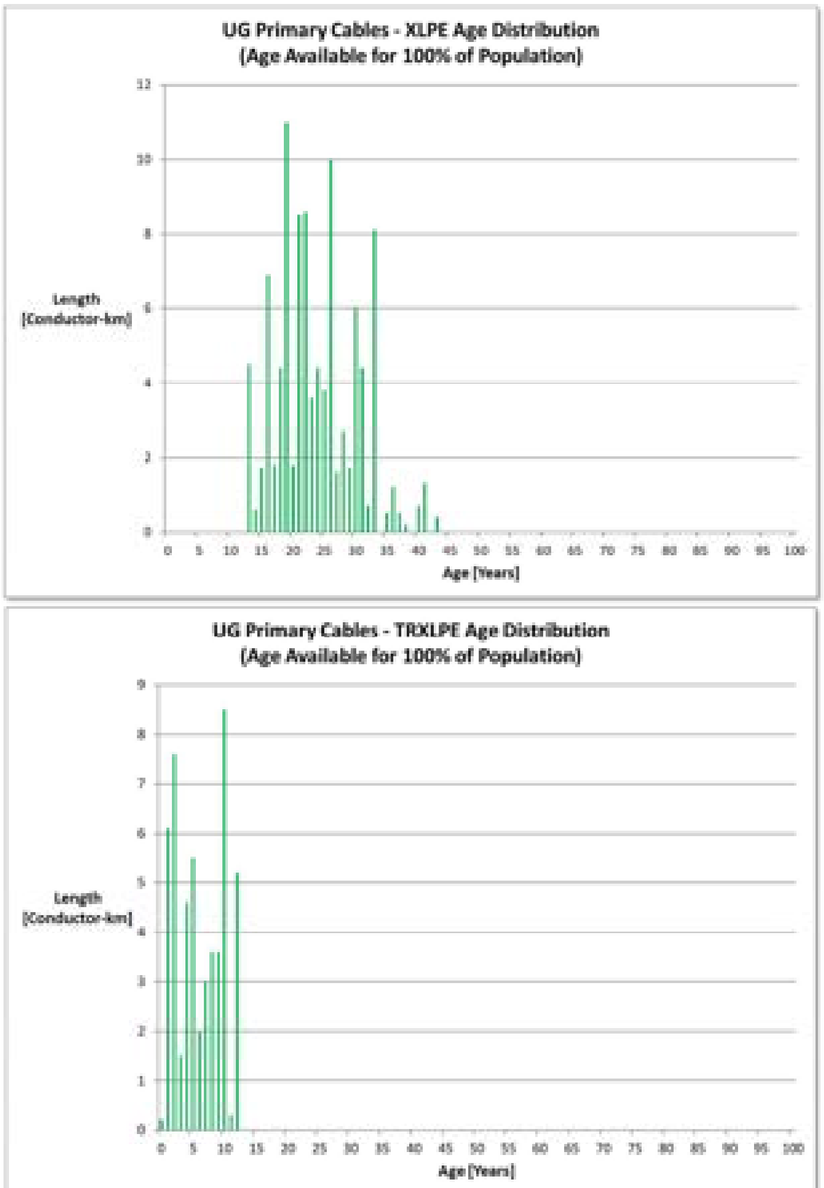

Figure 6-2 Age Distribution - UG Primary Cables

6.3 Health Index Results

There are 101.6 km XLPE UG Primary Cables. All of them have age data used for Health Indexing. The average Health Index for this asset category is 76%.

There are 51.9 km TRXLPE UG Primary Cables. All of them have age data used for Health Indexing. The average Health Index for this asset category is close to 100%.

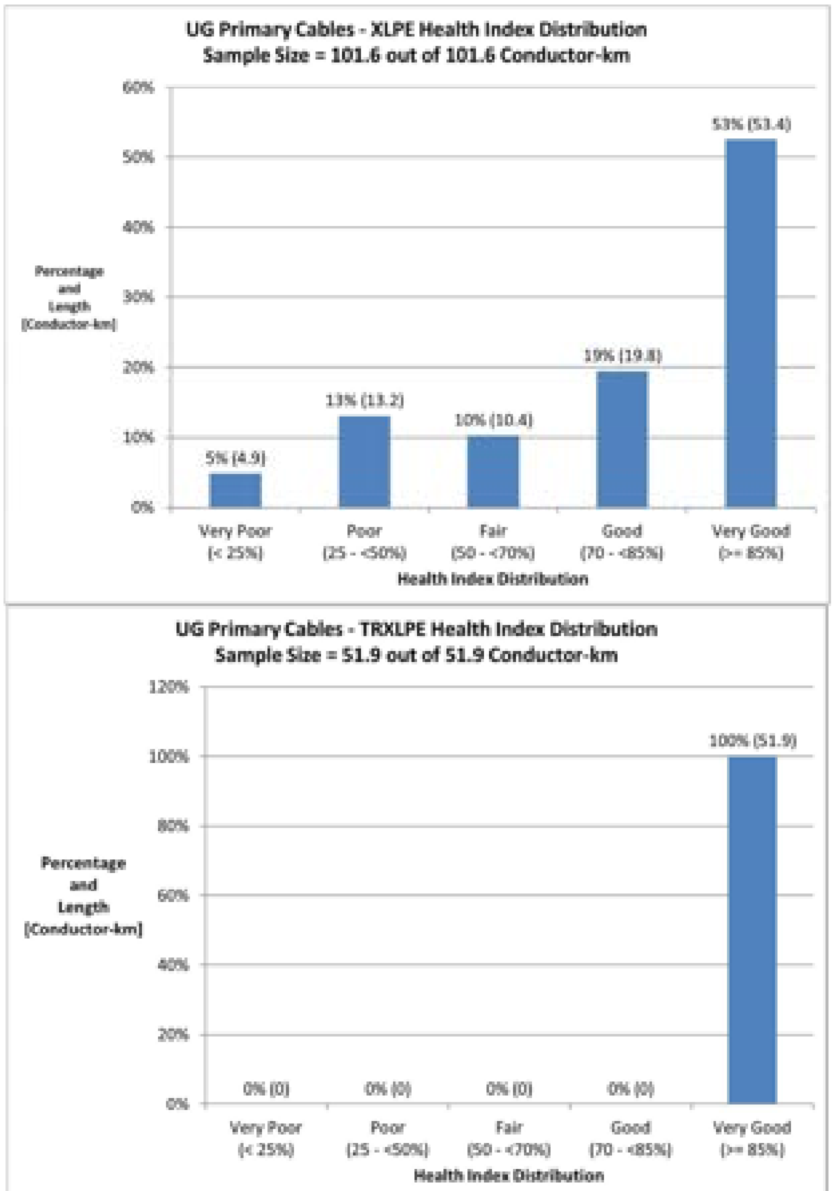

Figure 6-3 Health Index Distribution - UG Primary Cables

6.4 Flagged-for-action Plan

The flagged-for-action plan for UG Primary Cables is based on asset removal rate and age distribution and is extrapolated to the entire population.

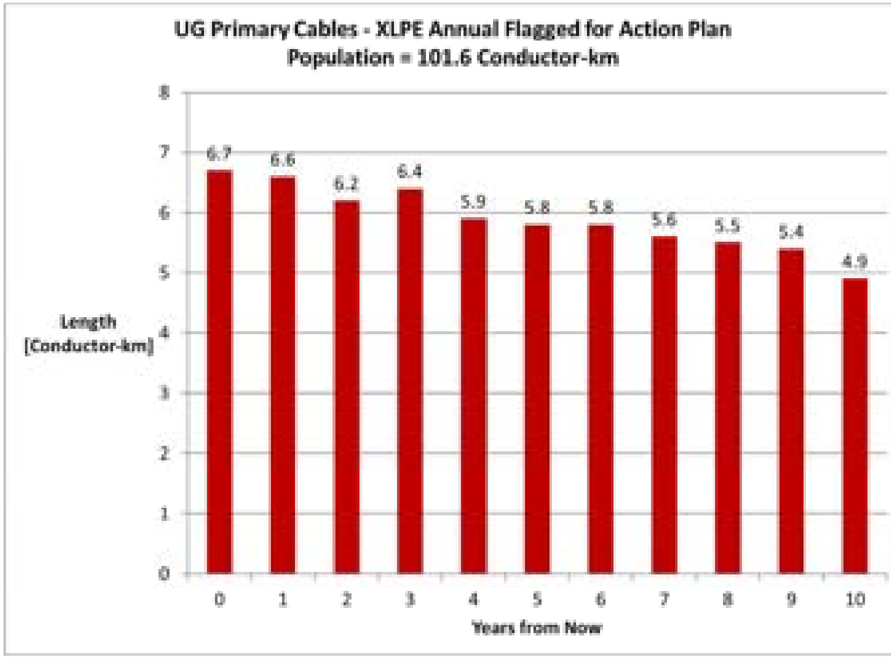

Figure 6-4 Flagged-for-action plan – UG Primary Cables (XLPE Type)

According to analysis, no asset is flagged for action for TRXLPE UG Primary Cables in the next 10 years.

6.5 Data Gaps

The data used for assessing condition of UG Primary Cables assessment include age only.

The data gaps are as follows:

Table 6-3 Data Gap for UG Primary Cables

Data Gap (Sub-Condition Parameter)	**Condition Parameter Group**	**Priority**	**Description**	**Source of Data**
Conductor Condition	Conductor	✮✮	Conductor resistance, damage	Off-line test
Splices & Terminations	Accessories	✮✮	Connection defect	Test, IR scan, visual inspection
Fault rate at Segment Level	Service Record	✮✮	Failure records	Historic records

Since 2022, FHI has started the following UG cable tests:

- Very-low frequency (VLF) tan-delta (TD) to assess the overall (global) aging of the cable insulation

- Offline Partial Discharge (PD) measurement to assess the condition of the cable insulation

- Time Domain Reflectometry (TDR) to verify the cable reel length and the condition of the concentric neutral and identify

Such test results will be collected and incorporated in future ACA study.

7 OH GANG SWITCHES

7.1 Health Index Formula

As there is insufficient condition data available and HI assessment for this asset category is based simply on age and the cumulative likelihood of survival at a given age.

Age is used as a limiting factor to reflect the degradation of asset over time, refer to section 1.1.2 for the description.

7.1.1 Condition and Sub-Condition Parameters

Table 7-1 Condition Parameter and Weights – OH Gang Switches

m	Condition Parameter	WCP_m	Sub-Condition Parameters
	Age Limiting		Figure 7-1

7.1.2 Condition Criteria

Age Limiting Factor

The parameters of OH Gang Switches age limiting curve are shown in the following table and are based on other utility's historical removal data.

Table 7-2 Age Limiting Curve Parameters - OH Gang Switches

Asset Type	α	β
OH Gang Switches	**31.35**	**2.647**

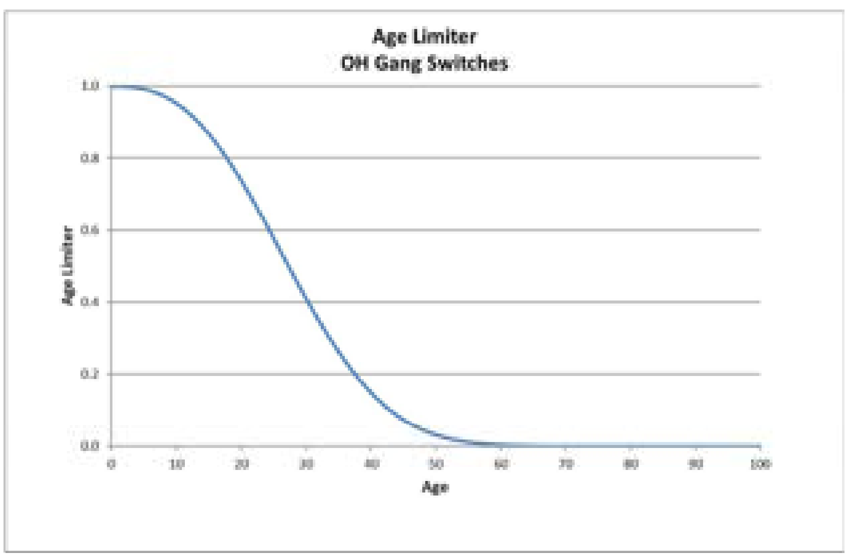

Figure 7-1 Age Limiting Factor Criteria - - OH Gang Switches

7.2 Age Distribution

The average age of all units is 22 years for OH Gang Switches.

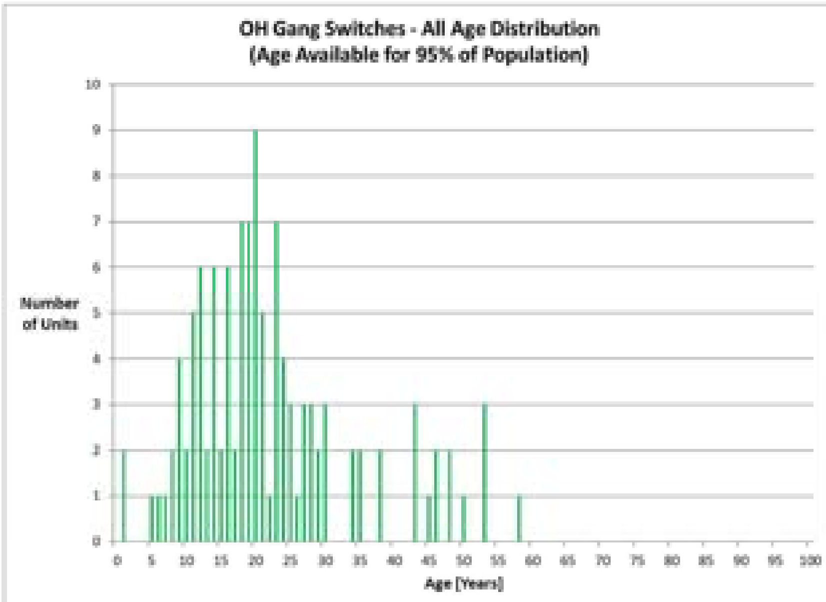

Figure 7-2 Age Distribution – OH Gang Switches

7.3 Health Index Results

There are 122 OH Gang Switches. Among them, 116 units have age data for a Health Indexing.

The average Health Index is 66% for OH Gang Switches.

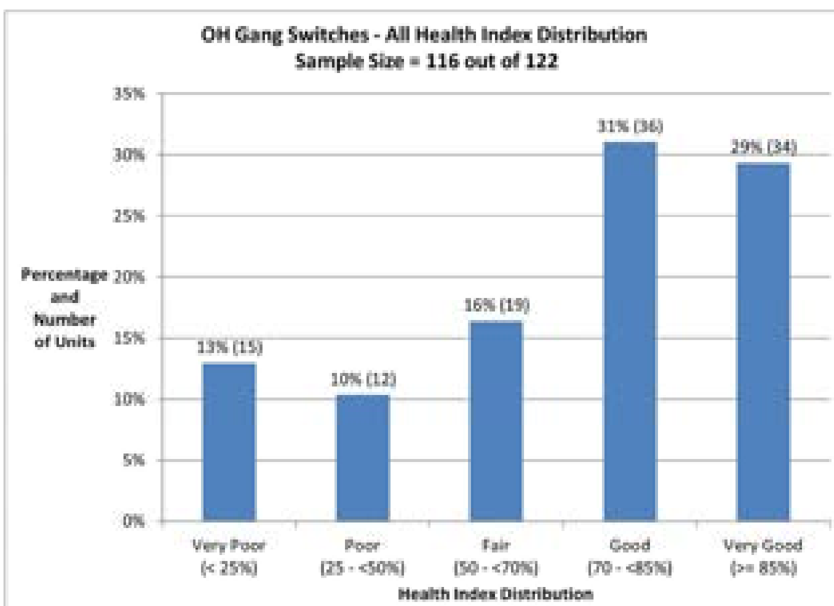

Figure 7-3 Health Index Distribution - OH Gang Switches

7.4 Flagged-for-action Plan

The flagged-for-action plan of OH Gang Switches is based on the asset removal rate and age distribution.

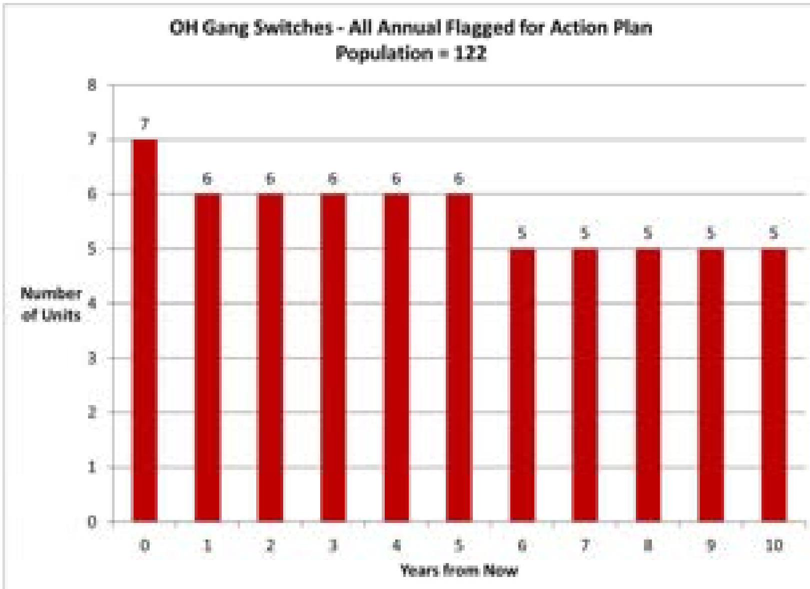

Figure 7-4 Flagged-for-action plan – OH Gang Switches

7.5 Data Gaps

The data used for OH Gang Switches assessment include age only. The data gaps are as follows.

Table 7-3 Data Gap for OH Gang Switches

Data Gap (Sub-Condition Parameter)	Parent Condition Parameter	Priority	Description	Source of Data
Load Break handle	Operation Mechanism	✮ ✮	Mechanical part and linkage issue	Inspection/ Maintenance Records
Switch Mounting		✮	Loose installation	
Arc Horn	Arc Extinction		Arc horn surface worn-out	
Insulator	**Insulation**	✮	Crack	

8 PAD MOUNTED SWITCHGEAR

8.1 Health Index Formula

As there is insufficient condition data available and HI assessment for this asset category is based simply on age and the cumulative likelihood of survival at a given age.

Age is used as a limiting factor to reflect the degradation of asset over time, refer to section 1.1.2 for the description.

8.1.1 Condition and Sub-Condition Parameters

Table 8-1 Condition Parameter and Weights – Pad Mounted Switchgear

m	Condition Parameter	WCP_m		Sub-Condition Parameters
		Solid	Air	
1	Termination	1		Table 8-2
	Age Limiting			Figure 8-1

8.1.2 Condition Criteria

Infrared Inspection

Table 8-2 Infrared Inspection Criteria

Score	Description (total count of IR issues in the past 5 years)
4	0
3	1
2	2
1	3
0	>=4

Age Limiting Factor

The parameters of Pad Mounted Switchgear age limiting curve are shown in the following table and are based on FHI's historical removal data.

Table 8-3 Age Limiting Curve Parameters - Pad Mounted Switchgear

Asset Type	α	β
Pad Mounted Switchgear	**30.5**	**3.64**

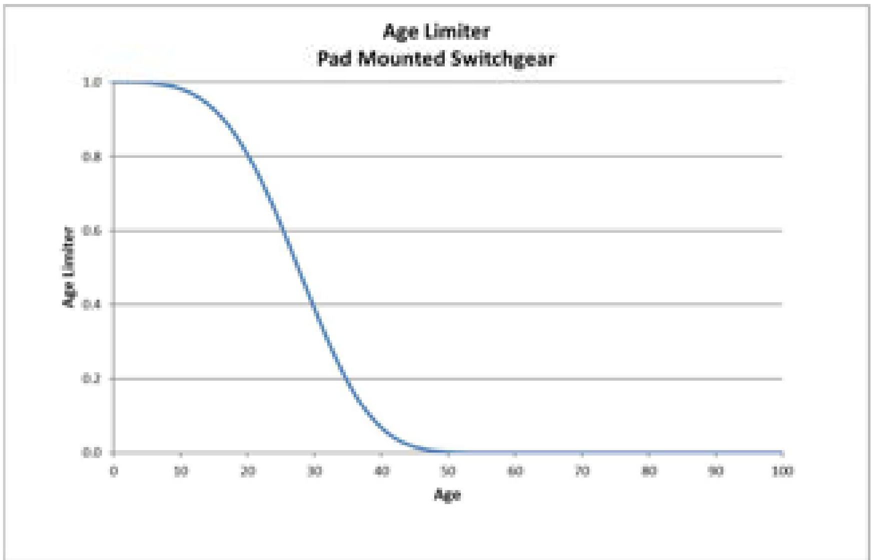

Figure 8-1 Age Limiting Factor Criteria - - Pad Mounted Switchgear

8.2 Age Distribution

The average ages of the units are 6 years and 33 years, for Solid Dielectric and Air Insulated Pad Mounted Switchgear respectively.

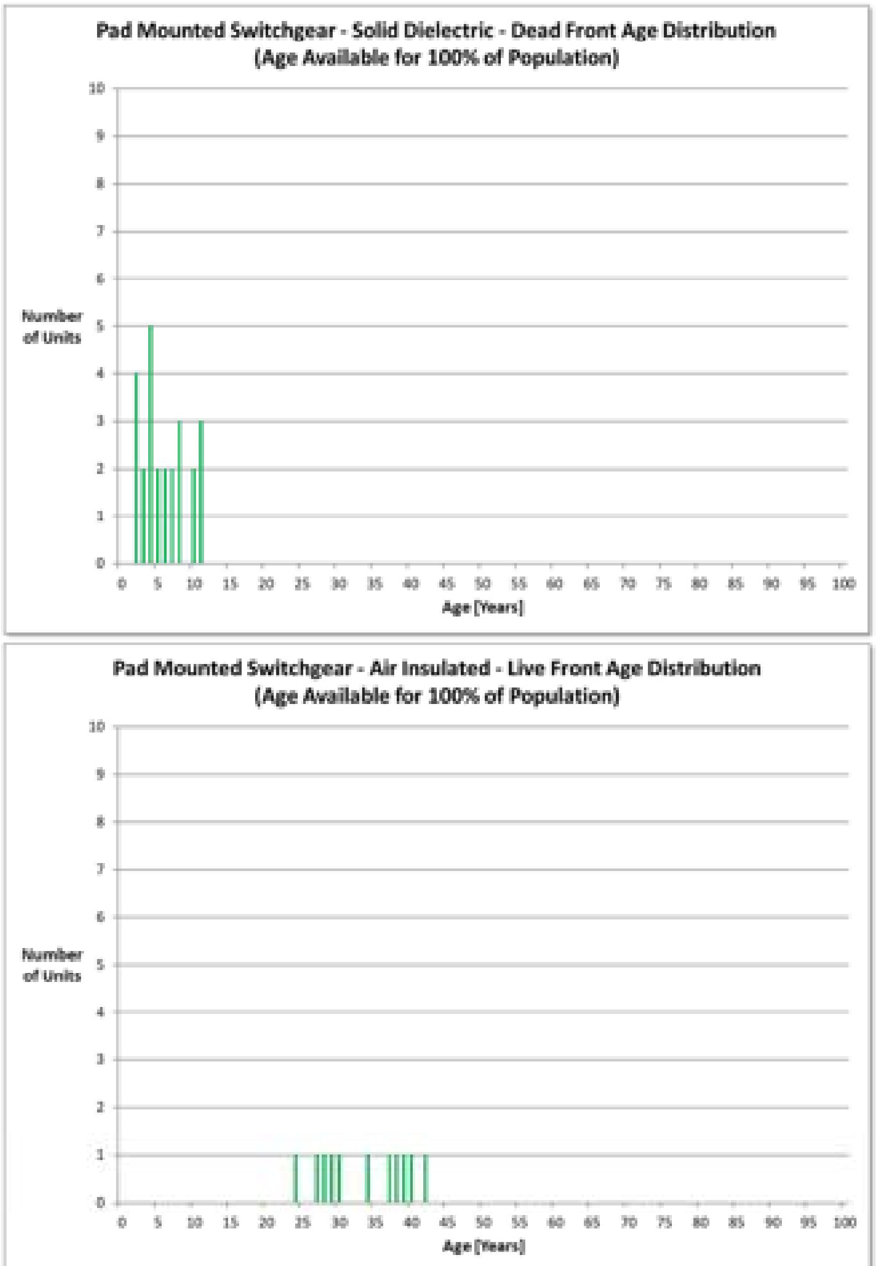

Figure 8-2 Age Distribution - Pad Mounted Switchgear

8.3 Health Index Results

There are a total of 25 units of Solid Dielectric Pad Mounted Switchgear. All the units have age and/or inspection data for deriving Health Indexing results.

There are a total of 12 units of Air Insulated Pad Mounted Switchgear. All the units have age and/or inspection data for deriving Health Indexing results.

The average Health Index scores are 97% and 21%, for Solid Dielectric and Air Insulated Pad Mounted Switchgear respectively.

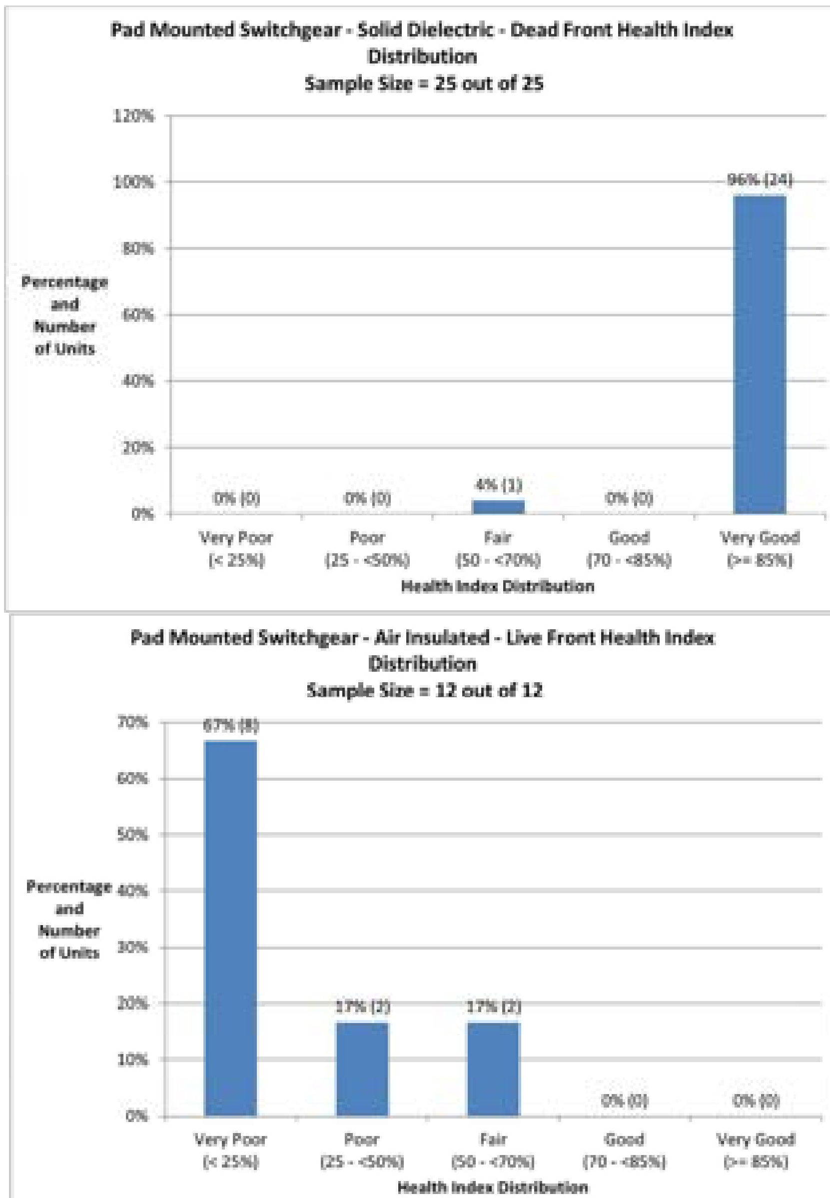

Figure 8-3 Health Index Distribution - Pad Mounted Switchgear

8.4 Flagged-for-action Plan

The flagged-for-action plan of Pad Mounted Switchgear is based on the asset removal rate and age distribution.

The following diagram shows the flagged-for-action plan:

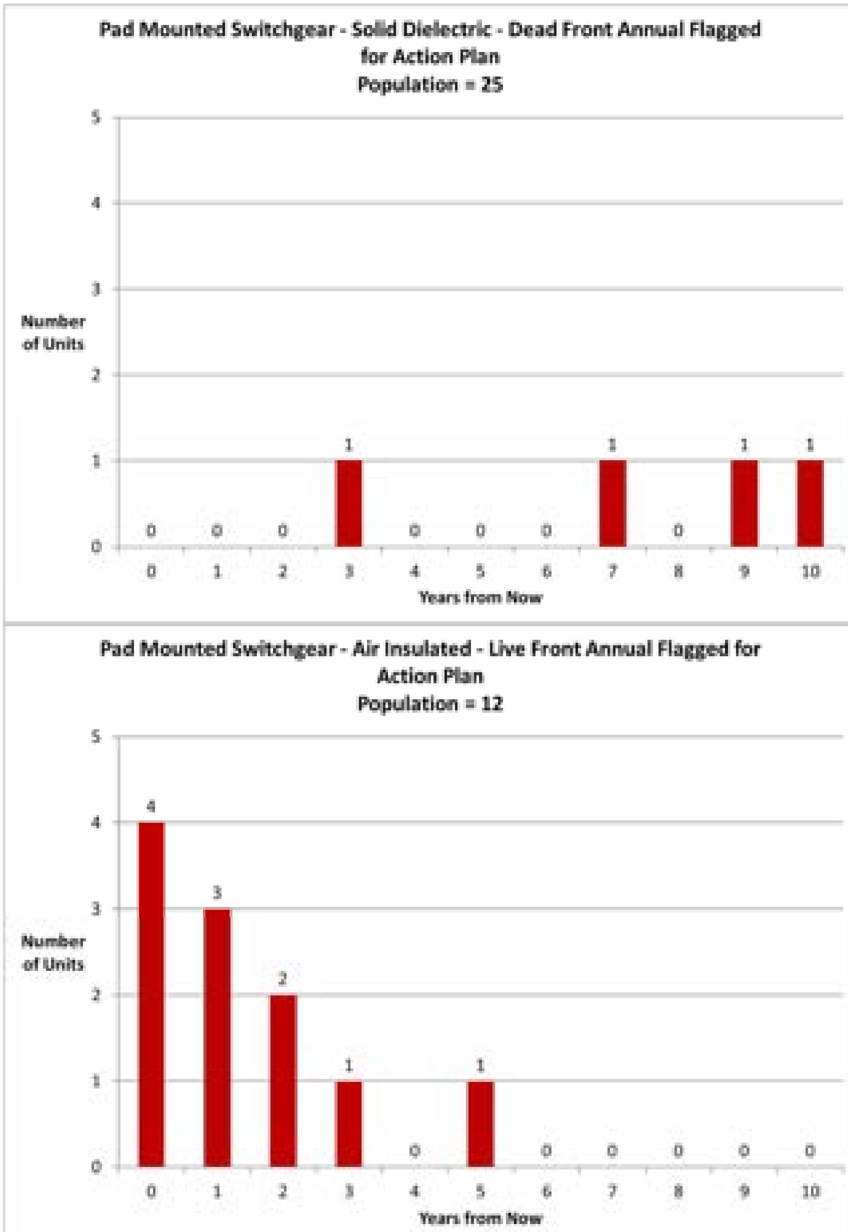

Figure 8-4 Flagged-for-action plan - Pad Mounted Switchgear

8.5 Data Gaps

The data used for Pad Mounted Switchgear assessment include age only.

The data gaps are as follows.

Table 8-4 Data Gap for Pad Mounted Switchgear

Data Gap (Sub-Condition Parameter)	**Parent Condition Parameter**	**Priority**	**Object or Component Addressed**	**Description**	**Source of Data**
Concrete Pad	Physical Condition	✯	Foundation	Physically worn-out	On-site visual inspection
Corrosion		✯ ✯	External status	Physically worn-out	On-site visual inspection
Excess Moisture		✯	Environment	Humid operating condition	On-site visual inspection

FHI is phasing out all the Air Insulated Pad Mounted Switchgear and replace them with Solid Dielectric Switchgear. The above table represents the data gaps for solid dielectric switchgear.

9 STRUCTURES

9.1 Health Index Formula

Assume a parameter scoring system of 0 through 4, where 0 and 4 represent the “worst” and “best” scores respectively. Thus, the maximum score for any condition or sub-condition parameter (maximum CPS and CPF) is “4”.

9.1.1 Condition and Sub-Condition Parameters

Table 9-1 Condition Parameter and Weights - Structures

m	Condition parameter	WCP_m	Sub-Condition Parameters
1	Structure	3	Table 9-2
2	Access	1	Table 9-3
3	Service Record	2	Table 9-4
	Age Limiting Factor		Figure 9-1
	De-rating Factor		Table 9-7

Table 9-2 Structure Sub-Condition Parameters and Weights (m=1) - Structures

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Roof	3	Table 9-5
2	Wall	3	Table 9-5
3	Floor	1	Table 9-5

Table 9-3 Access Sub-Condition Parameters and Weights (m=2) - Structures

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Lid	1	Table 9-5

Table 9-4 Service Record Sub-Condition Parameters and Weights (m=3) - Structures

n	Sub-Condition Parameter	$WSCP_n$	Condition Criteria Table
1	Overall	1	Table 9-5

9.1.2 Condition Criteria

<u>**Multiple years of test records**</u>

Whenever there are multiple years of test records for a parameter, the score of the parameter is calculated as the weighted average scores of multiple years, with more recent years being assigned of higher year weights as follows:

$$Test\ Score = \frac{\sum_i (S_i W_i)}{\sum_i W_i}$$

Equation 9-1

Where *i* refers to the year the inspection was conducted
W refers to the assigned year weight as follows

Year	Weight
2023	1
2022	0.9
2021	0.8
2020	0.7
2019	0.6
2018	0.5
2017	0.4
2016	0.3
2015	0.2
2014	0.1
2013	0

S refers to the score in a specific year, as per criteria as follows

- **Inspection**

Table 9-5 Inspection Criteria

Score	Description (inspection entry)
4	1
3	2
2	3
1	4
0	5

Age Limiting Factor

Age was used as a limiting factor to reflect the degradation of asset unit as time passed by. Refer to section 1.1.2 for principle.

In this project, the parameters of Structures age limiting curve are shown in the following table, based on industry practice.

Table 9-6 Age Limiting Curve Parameters - Structures

Asset Type	α	β
Structures	**56.4249**	**2.005**

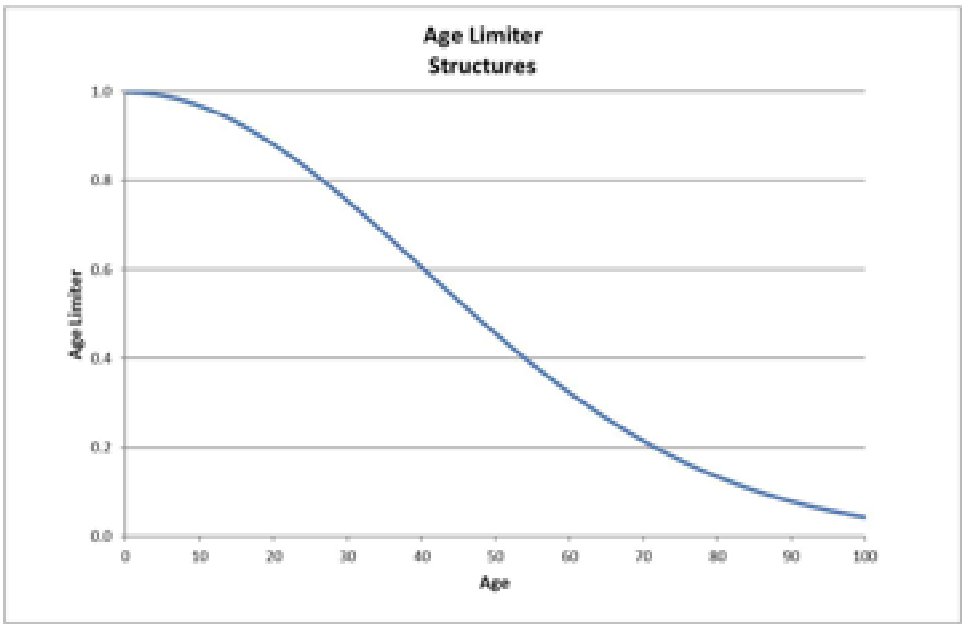

Figure 9-1 Age Limiting Factor Criteria - - Structures

De-rating Factor

De-rating factor is applied when the following conditions meet:

Table 9-7 De-rating Criteria

De-rating Factor	Description
0.5	Min (Score_roof, Score_wall) <=1

9.2 Age Distribution

The average ages are 58 and 51, for Vault and Manhole Structures respectively. The age distributions are as follows.

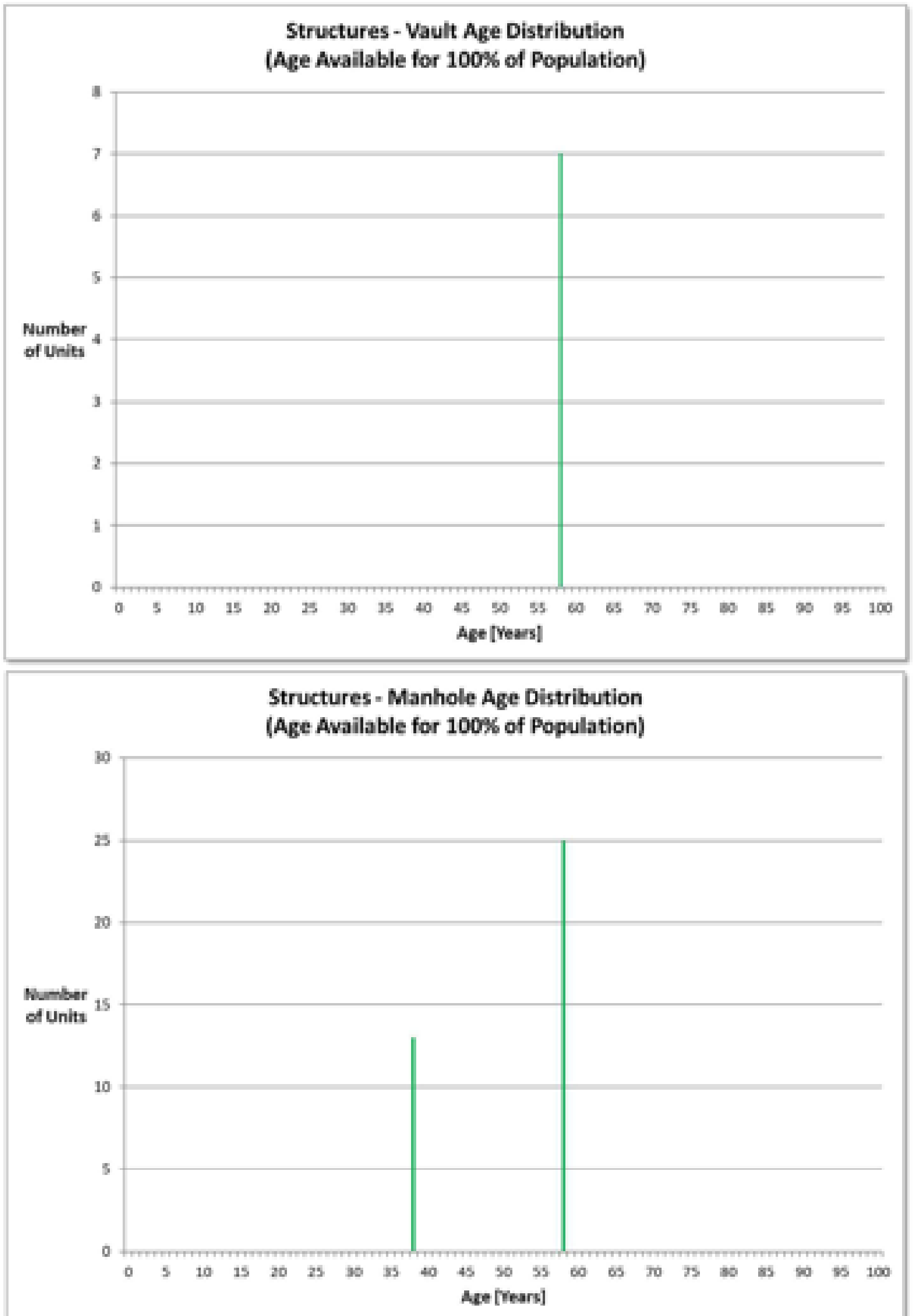

Figure 9-2 Age Distribution –Structures

9.3 Health Index Results

There are 7 units of Vault Structures. All of them have sufficient data for a Health Indexing.

There are 38 units of Manhole Structures. All of them have sufficient data for a Health Indexing.

The average Health Index scores are 75% and 71%, for Vault and Manhole Structures respectively.

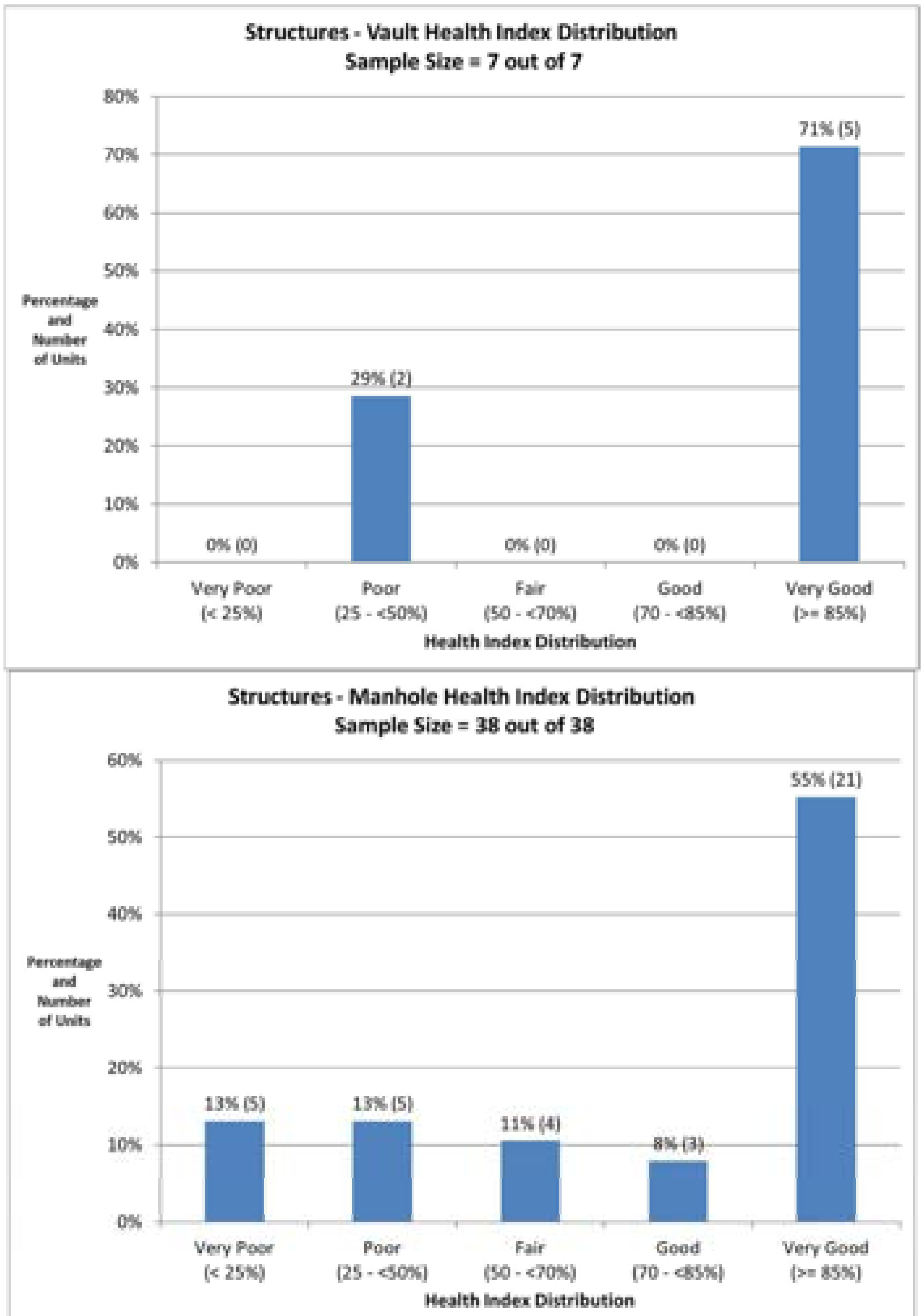

Figure 9-3 Health Index Distribution –Structures

9.4 Flagged for Action Plan

The flagged for action plan of Structures was based on the asset removal rate.

The flagged for action plans for Structures were based on the data from sample size and extrapolated to the entire population. The following diagram shows the flagged for action plans:

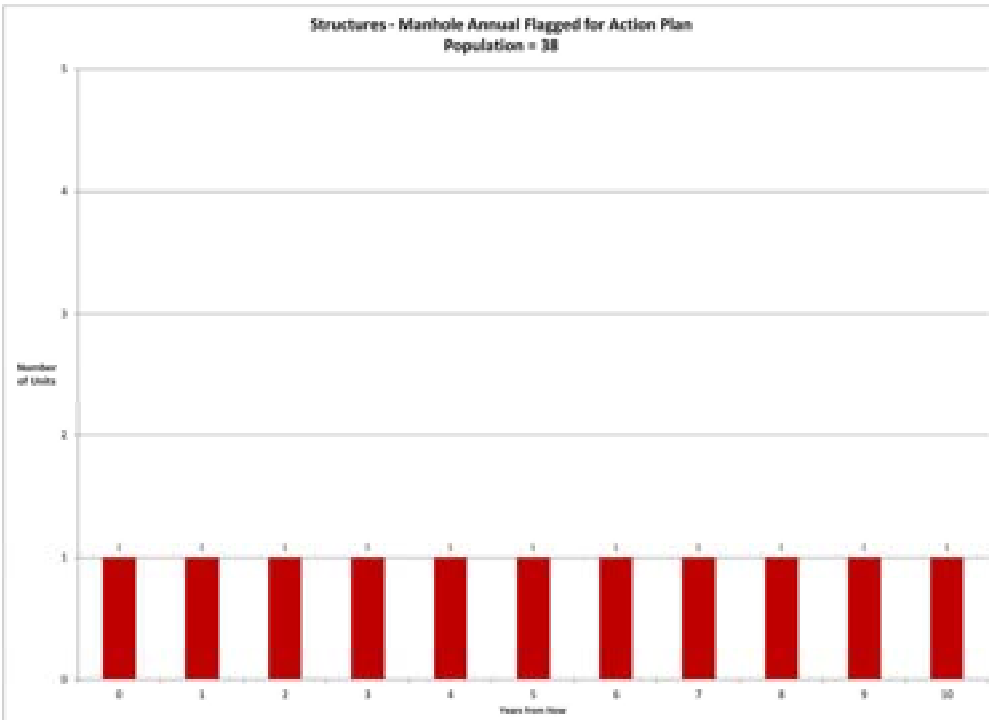

Figure 9-4 Flagged for Action Plan – Structures (Manhole)

According to analysis, no asset is flagged for action for Vault Structures in the next 10 years.

9.5 Data Gaps

The data used for assessing condition of Structures assessment include age (estimated by decade) and inspection results. There are no data gaps for this asset category. However, more accurate age information remains to be obtained.

10 FLEET VEHICLES

10.1 Health Index Formula

Assume a parameter scoring system of 0 through 4, where 0 and 4 represent the "worst" and "best" scores respectively. Thus, the maximum score for any condition or sub-condition parameter (maximum CPS and CPF) is "4".

10.1.1 Condition and Sub-Condition Parameters

Table 10-1 Condition Parameter and Weights – Fleet Vehicles

m	Condition Parameter	WCP_m		Sub-Condition Parameters
		Pickup	Bucket	
1	Depreciation	1		Equation 10-1
2	Mileage	2		Table 10-2
	Age Limiting			Figure 10-2

10.1.2 Condition Criteria

<u>Depreciation</u>

$$Depreciation\ Score = MAX\ (D_{by\ age}, D_{by\ cost})*4$$

Equation 10-1

Where $D_{by\ age}$ Depreciation by age as per Figure 10-1

$D_{by\ cost}$ Remaining value after up-to-date maintenance cost,

i.e., $\frac{Original\ Purchase\ Value - Total\ Maintenance\ Cost}{Original\ Purchase\ Value}$

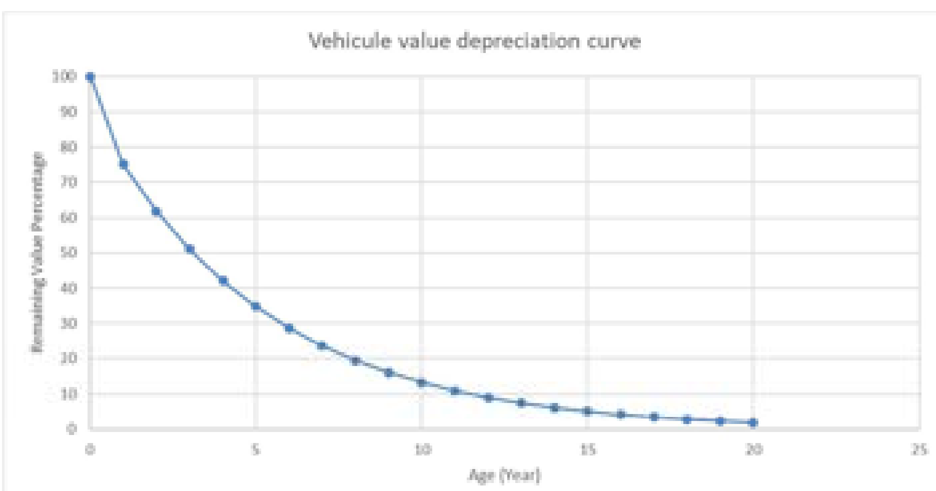

Figure 10-1 Fleet Yearly Depreciation Criteria - - Fleet Vehicles

<u>Mileage</u>

$$Mileage\ Score = \left(1 - \frac{Actual\ Mileage}{Design\ Mileage}\right) * 4$$

where

Table 10-2 Default Design Mileage

Vehicle Type	Design Mileage
Pickup	200 k miles
Bucket	750 k miles

<u>Age Limiting Factor</u>

The parameters of Fleet Vehicles age limiting curve are shown in the following table and are based on industry practice.

Table 10-3 Age Limiting Curve Parameters - Fleet Vehicles

Asset Type	α	β
Pickup	**14.923**	**3.7469**
Bucket	**17.0299**	**4.2847**

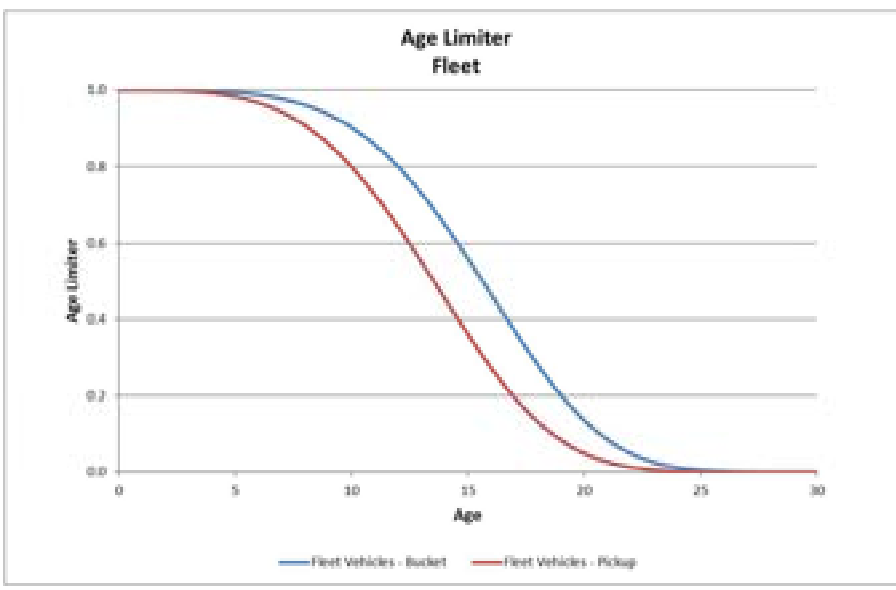

Figure 10-2 Age Limiting Factor Criteria - - Fleet Vehicles

10.2 Age Distribution

The average ages of the asset units are 8 years and 17 years, for Pickup and Bucket Fleet Vehicles respectively.

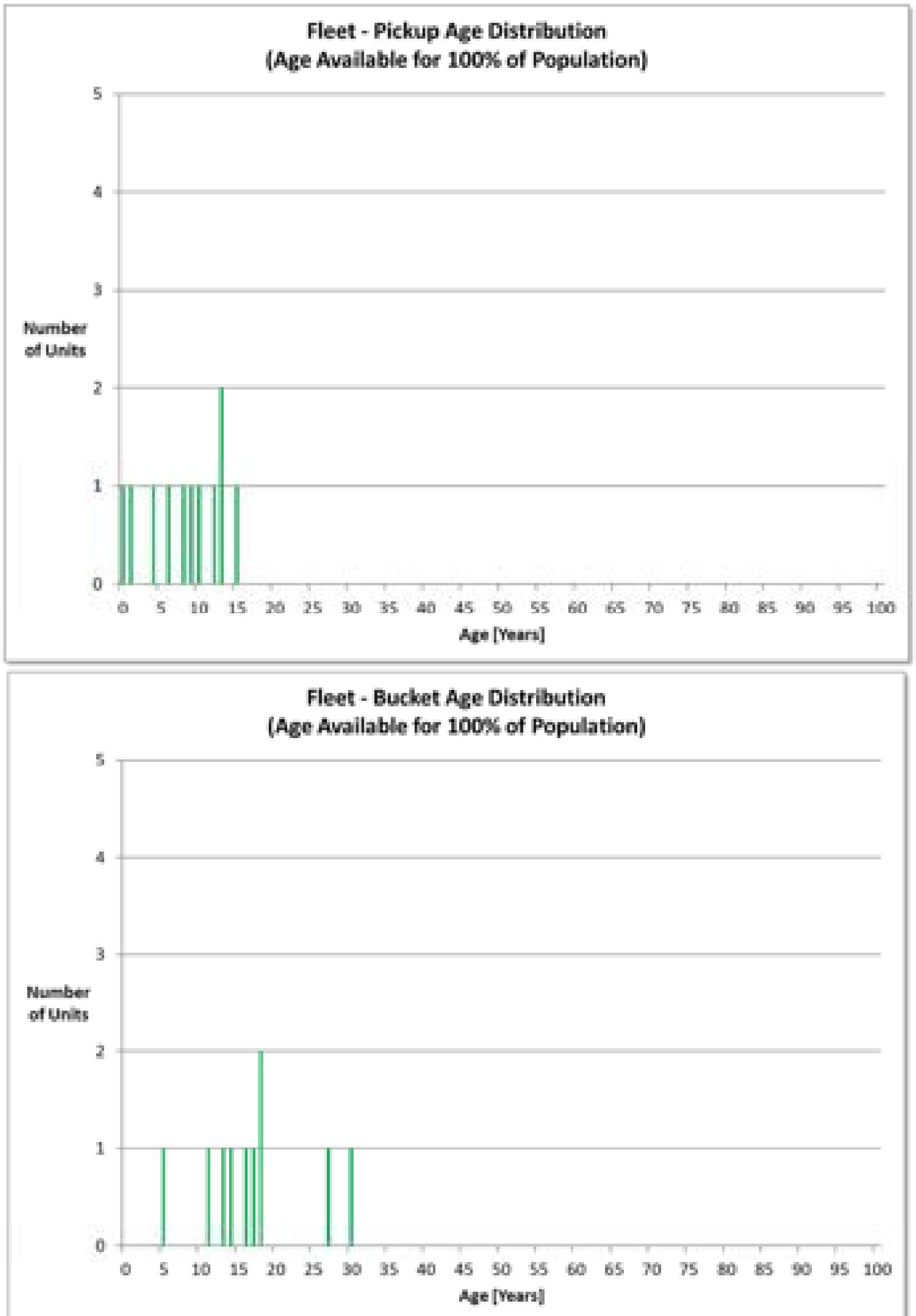

Figure 10-3 Age Distribution - Fleet Vehicles

10.3 Health Index Results

There are 11 units of Pickup Fleet Vehicles. All of them have age or other data for a Health Indexing.

There are 10 units of Bucket Fleet Vehicles. All of them have age or other data for a Health Indexing.

The average Health Index scores for this asset category are 56% and 41%, for Pickup and Bucket Fleet Vehicles respectively.

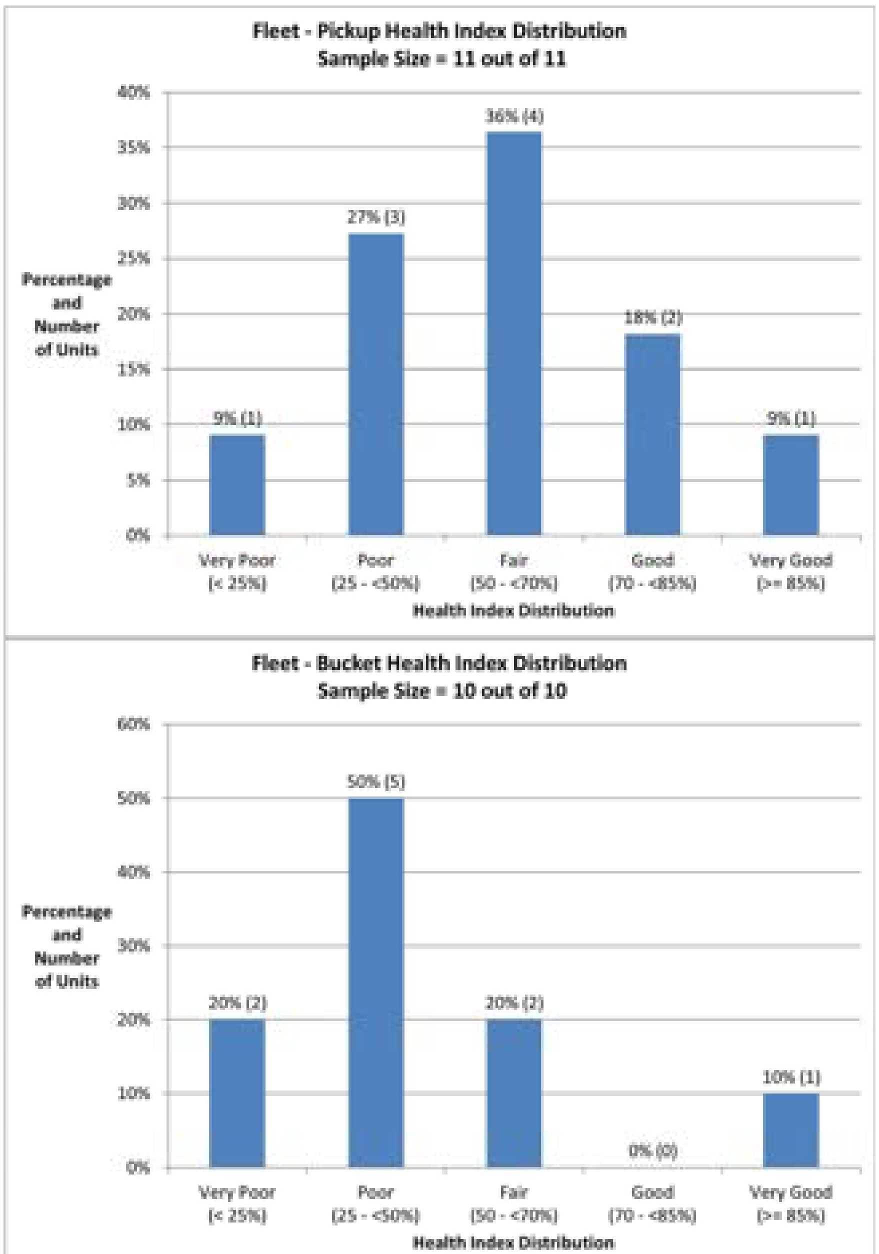

Figure 10-4 Health Index Distribution - Fleet Vehicles

10.4 Flagged-for-action Plan

The flagged-for-action plan of Fleet Vehicles is based on the asset removal rate and age distribution.

The following diagram shows the flagged-for-action plan:

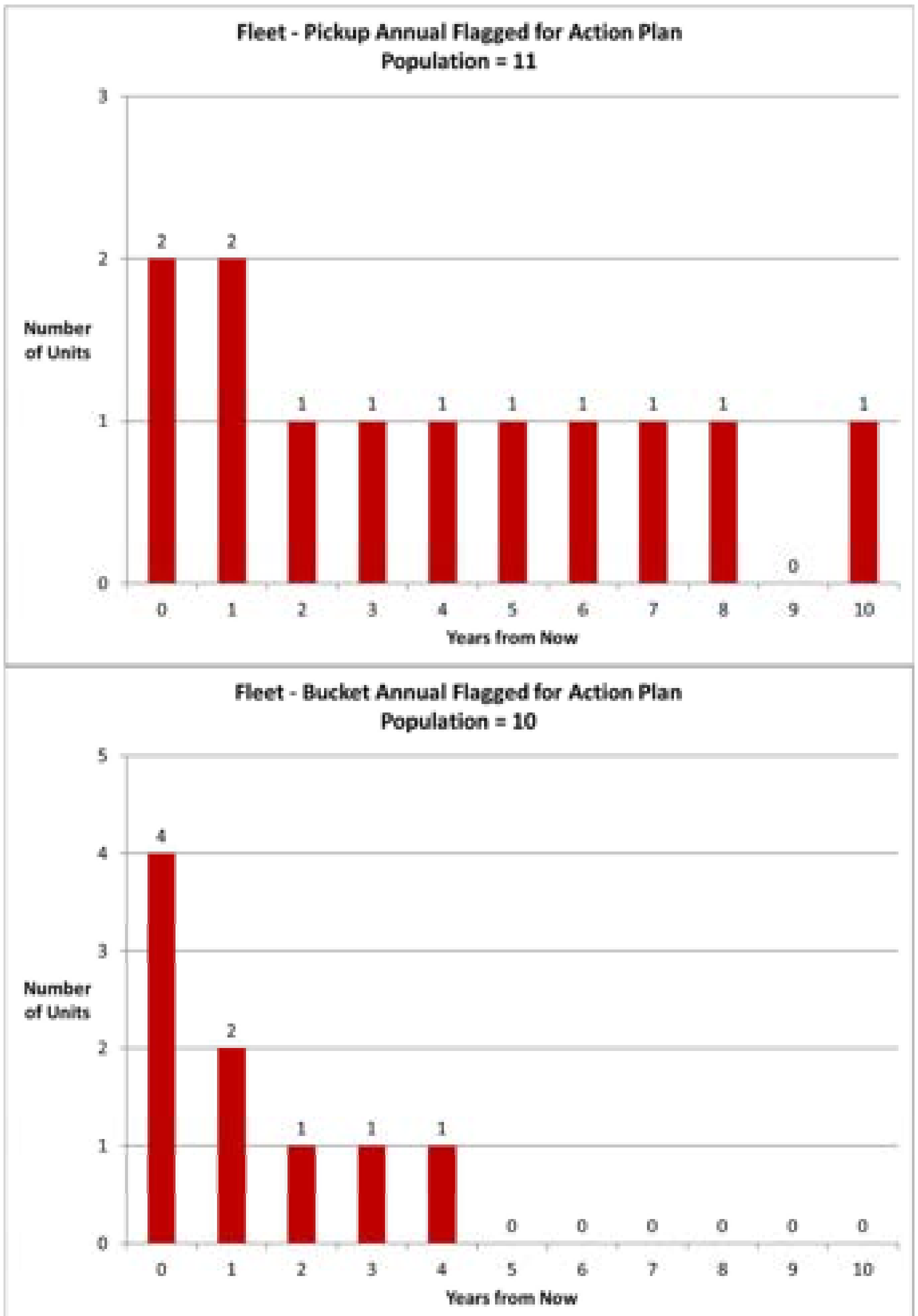

Figure 10-5 Flagged-for-action plan - Fleet Vehicles

10.5 Data Gaps

The data used for single phase Fleet Vehicles assessment include age, mileage and maintenance costs. There are no data gaps for this asset category.

11 METERS

11.1 Health Index Formula

HI assessment for this asset category is based simply on age and the cumulative likelihood of survival at a given age.

11.1.1 Condition and Sub-Condition Parameters

Table 11-1 Condition Parameter and Weights – Meters

m	Condition Parameter	WCP_m	Sub-Condition Parameters
	Age Limiting		Figure 11-1

11.1.2 Condition Criteria

<u>Age Limiting Factor</u>

The parameters of Meters age limiting curve are shown in the following table and are based on FHI's historical removal data.

Table 11-2 Age Limiting Curve Parameters - Meters

Asset Type	α	β
Meters	**12.22**	**6.96**

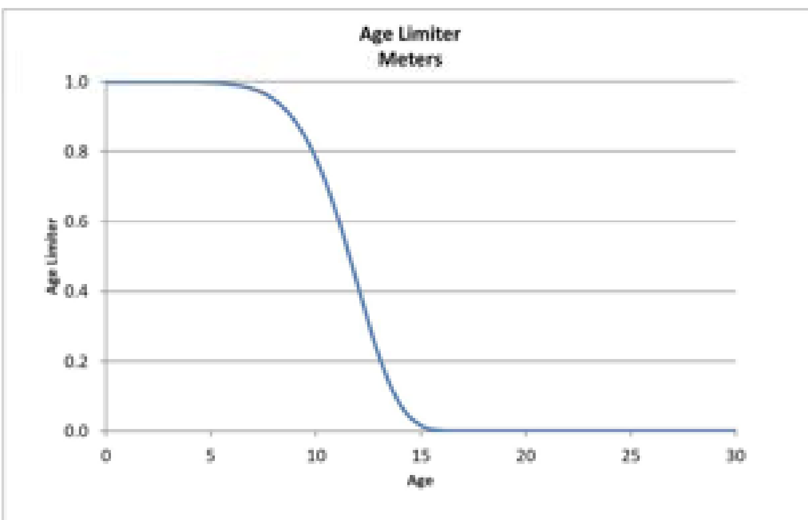

Figure 11-1 Age Limiting Factor Criteria - - Meters

11.2 Age Distribution

The average ages of Meters are 12 years, 10 years and 9 years, for residential, commercial/industrial, and primary types respectively. The age distributions for Meters is as follows:

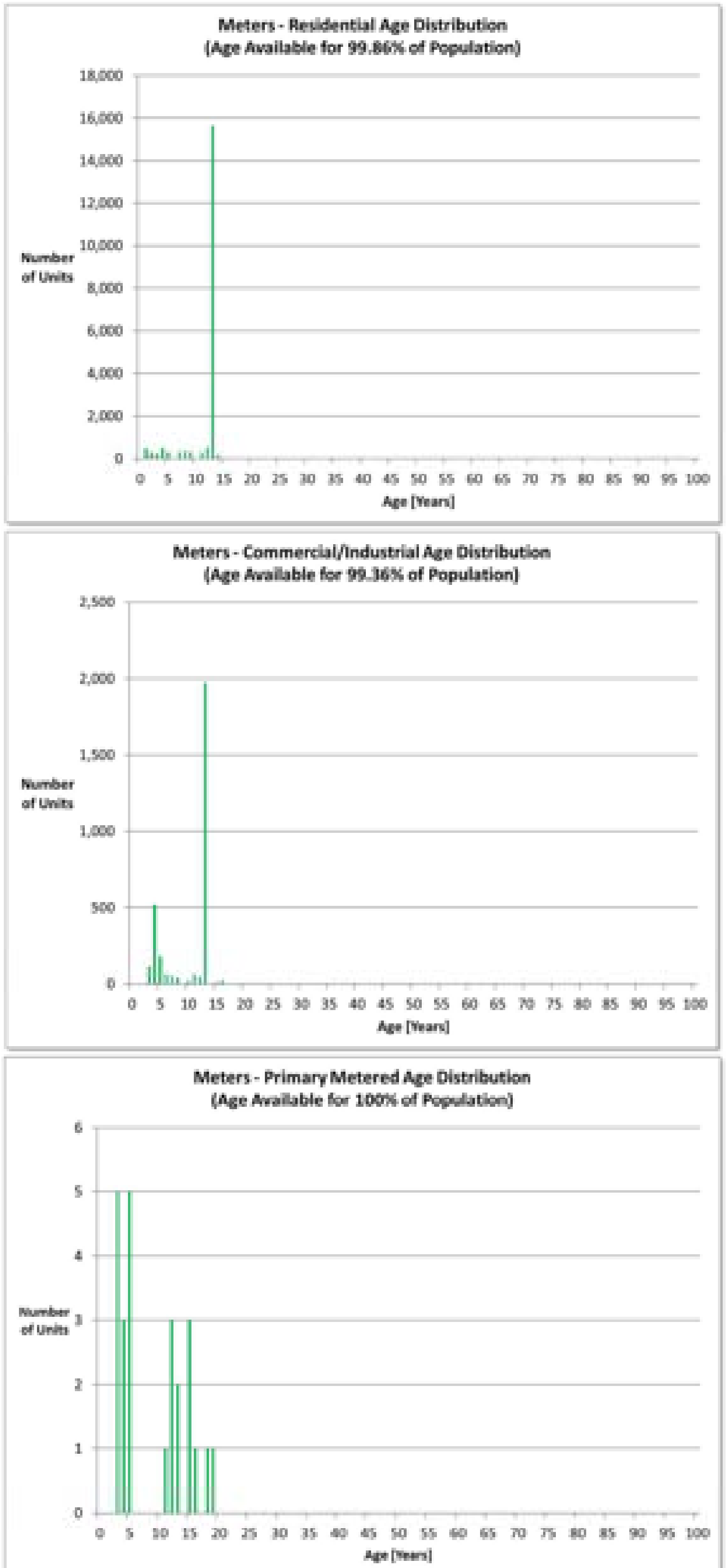

Figure 11-2 Age Distribution - Meters

11.3 Health Index Results

There are 19348 units of Residential Meters. Among them, 19320 have age data used for Health Indexing. The average Health Index for this asset category is 33%.

There are 3117 units of Commercial/Industrial Meters. Among them, 3097 have age data used for Health Indexing. The average Health Index for this asset category is 47%.

There are 25 units of Primary Meters. All of them have age data used for Health Indexing. The average Health Index for this asset category is 61%.

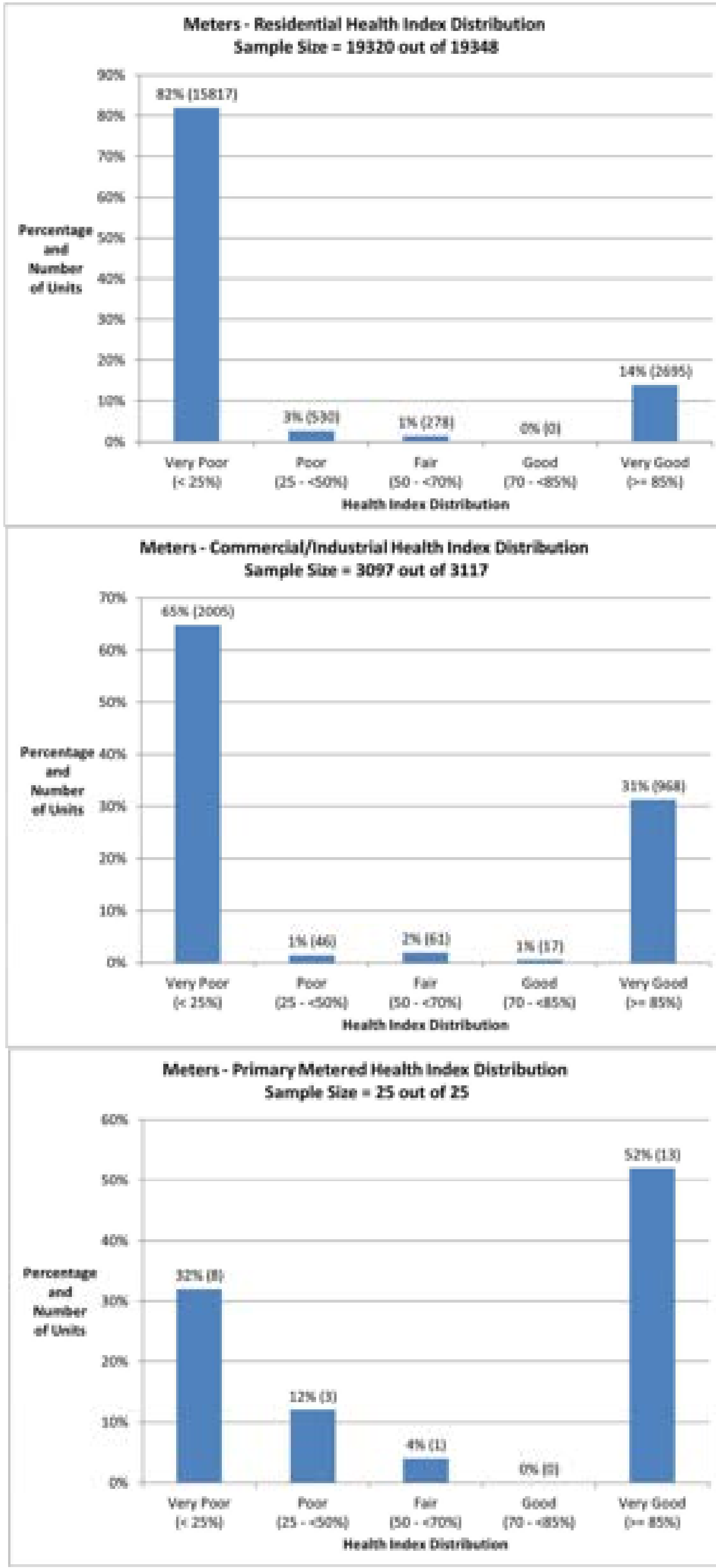

Figure 11-3 Health Index Distribution - Meters

11.4 Flagged-for-action Plan

The flagged-for-action plan for Meters is based on asset removal rate and age distribution and is extrapolated to the entire population.

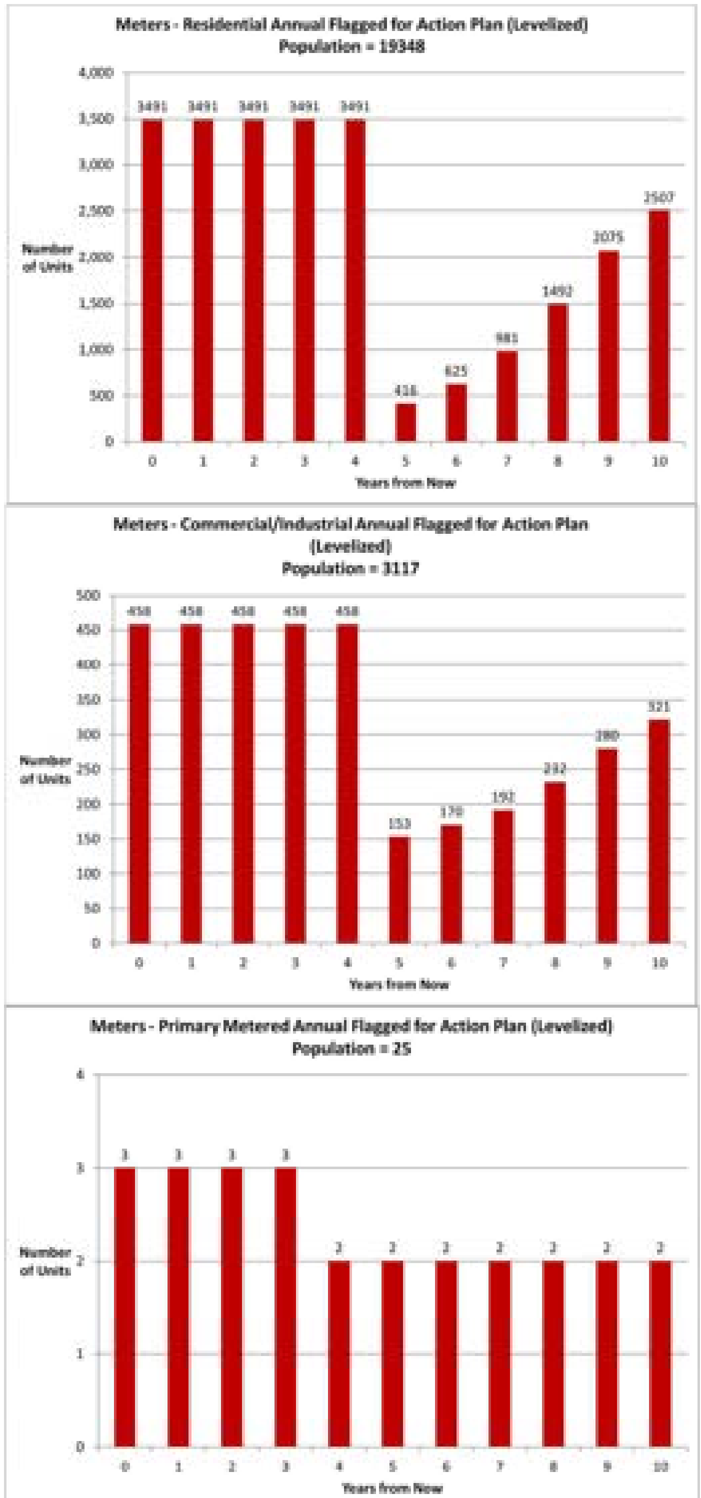

Figure 11-4 Flagged-for-action plan – Meters

11.5 Data Gaps

The data used for assessing condition of Meters assessment include age only. There are no data gaps for this asset category.