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KINECTRICS

NEWMARKET-TAY POWER DISTRIBUTION 2020 ASSET CONDITION ASSESSMENT

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Prepared for

Newmarket-Tay Power Distribution Ltd.

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1. Introduction

Newmarket-Tay Power Distribution Ltd. (NTPDL) is a local distribution company (LDC) that provides electricity to the Town of Newmarket, Township of Tay, and Town of Midland. NTPDL is an Ontario Energy Board licensed company and activities, performance standards, and rates are regulated by the Ontario Energy Board.

In keeping with a commitment to strategic and prudent investment planning, NTPDL recognized the need to perform an Asset Condition Assessment (ACA) on its key distribution assets. ACA is crucial part of asset management and provides a systematic process for determining and justifying long-term sustainment needs. Health indexing and risk assessment form the basis of ACA process. The Health Index (HI) expresses the condition of an asset as a single number, and risk assessment accounts for the consequence of asset failure. Using this process, the quantities of assets that will require attention in the next several years can be estimated.

Kinectrics Inc. (Kinectrics) performed ACAs for NTPDL's key distribution assets in 2011, in 2013, and again in 2017. This 2020 ACA marks the first year since the amalgamation of Midland PUC.

Kinectrics used NTPDL's 2020 asset information (which includes assets in Newmarket, Tay, and Midland) and Kinectrics' s up to date methodologies to develop HI distributions and estimate action plans based on the asset condition. This report presents the results of Kinectrics' assessment.

1.1 Objective and Scope of Work

The objective of the work was to conduct ACA on a subset of NTPDL's key distribution assets. The ACA was designed to quantify the extent of aging and to estimate the number of assets that likely need to be addressed in the near future.

The categories of assets included in this study are as follows:

- Substation Transformers
- Circuit Breakers
- Pole Mounted Transformers
- Pad Mounted Transformers
- Pad Mounted Switchgear
- Poles
    - Wood
    - Concrete
- Underground Cables
    - Non-Tree Retardant XLPE
    - Tree Retardant XLPE

For each asset category, the following are included:

- HI formula
- Age distribution
- HI distribution

- Condition-based flagged for action (FFA) Plan
- Prioritized list of assets requiring attention
- Assessment of data availability and a data gap analysis

2. Asset Condition Assessment Methodology

The ACA methodology involves the process of determining asset HI, as well as developing a condition based FFA Plan for each asset group. In this project, NTPDL customized algorithms were developed using existing utility data and information, as well as input from the utility technical and field staff.

2.1 Health Index

Health Indexing quantifies equipment condition based on numerous condition parameters related to the degradation factors that lead 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 values close to 0 representing an asset close to the end of its physical 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 in order 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 HI. 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 HI, condition parameters are ranked, through the assignment of *weights*, based on their contribution to asset degradation. The *condition parameter score* for a parameter is a numeric evaluation of an asset with respect to that parameter.

HI, which is a function of scores and weights, 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

$$CPS_m = \frac{\sum_{n=1}^{\forall n} \beta_n (SCPS_n \times WSCP_n) \times DR_n}{\sum_{n=1}^{\forall n} \beta_n (WSCP_n)} \times DR_m$$

Equation 2

CPS	Condition Parameter (CP) Score, 0-4
WCP	Weight of Condition Parameter
α_m / β_n	Data availability coefficient for condition/sub-condition parameter (1 if input data available; 0 if not available)
SCPS	Sub-Condition Parameter (SCP) Score, 0-4
WSCP	Weight of Sub-Condition Parameter
DR	Derating Multiplier

The scale that is used to determine an asset's score for a parameter is called the *condition criteria*. In the Kinectrics methodology, a condition criterion scoring system of 0 through 4 is used. A score of 0 is the 'worst' possible score; a score of 4 is the 'best' score, i.e. CPS_{max} = $SCPS_{max}$ = 4.

The α and β values are set to 0 if the parameter data is unavailable and 1 if the data is available. It is evident from the equations that the HI formula will, in essence, be readjusted for each unit depending on the specific data available for each unit. For example, if the HI formula for a certain asset category is based originally on 5 condition parameters (i.e. *m* = 5 in Equation 1) but a specific unit only has parameters 1 and 3 available (e.g. α_1 = 1, α_2 = 0, α_3 = 1, α_4 = 0, α_5 = 0), its HI calculation will only be based on parameters 1 and 3.

Derating (DR) Multipliers are also used to adjust a condition or sub-condition parameter score or calculated Health Index to reflect certain conditions. These may be factors that may or may not be related to asset condition but may impact asset service life. For example, certain breaker operating mechanisms may be problematic, so a DR Multiplier may be associated with operating mechanism. A certain population of wood poles may be in a region that is prone to lightning strikes. The HI of these poles may be de-rated to reflect higher likelihood of lightning.

Dominant parameters may be used as Derating multipliers. These are asset properties that are of such importance that their status has a dominant impact on the value of the Health Index. An example is oil dielectric breakdown strength of transformers. If the breakdown strength is poor, a DR Multiplier can be applied to the HI, placing the transformer in poor condition, regardless of the overall HI score.

In this methodology, the final HI assigned to an individual asset is limited by the asset's age. An *Age Limiter* (AL), which is equal to the cumulative survival probability at a given age of an asset group, is compared to the calculated HI. If the calculated HI is less than or equal to the AL, the final HI assigned is the calculated HI. If the calculated HI is more than the AL, then the final HI assigned is equal to the AL. It is important to note in using the AL that although the calculated HI (based in condition data such as test results, inspections, loading, etc.) may be high, the final HI may be low because of asset age.

The final HI score is:

$$HI_{Final} = \begin{Bmatrix} if\ (AL < HI, HI_{Final} = AL) \\ else(HI_{Final} = HI) \end{Bmatrix}$$

Equation 3

AL	Age Limiter
HI	Health Index calculated per Equation 1

As stated previously, an asset's HI is given as a percentage, with 100% representing 'as new' condition. The HI is calculated if there is age or some condition data available. The subset of the population with such data is called the *sample size*. Results are 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 HI distribution given for each asset group illustrates the overall condition of the asset group. Further, although HI is calculated for each unit, for simplicity of presentation the results are aggregated into five categories and the categorized distribution for each asset group is given. The HI 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%

2.2 Condition Based Flagged for Action Plan

In this methodology, the Flagged for Action (FFA) Plan for a given asset category shows the number of assets that may require attention or action each year within the planning period. Possible actions are to replace, refurbish, further test, monitor, implement operating solution, etc. The plan is condition or health based, meaning other factors, such as economics, obsolescence, system growth, etc. are not considered. A 'Levelized' FFA Plan smooths the peaks and valleys of the FFA Plan.

The two ways for determining the assets within FFA Plan in this methodology are the 'Life Curve' approach and the 'Risk Based' approach. The selected action is asset dependent. These are further explained in subsequent sections. The asset life curve models are first established.

Life Curves

In this project the term 'removals' is used to describe the removal of assets from service, regardless of the reason. Reasons for removal can include asset failure, proactive replacement because of condition, system growth, obsolescence, third party construction, etc.

A frequency of removals that grows exponentially with age generally provides a good overall model of asset service life. Based on Kinectrics' experience in failure rate studies of multiple power system asset groups, Kinectrics has selected the Weibull equation to model the removals as functions of asset age. The Weibull distribution has no specific characteristic shape and, as such, can model the exponentially increasing removal rate using appropriate parameters.

The Weibull distribution is a continuous probability distribution with the following probability density function equation:

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

Equation 4

f(t)	= probability density function (PDF), *i.e. likelihood that an asset will be removed from service when its age is within a particular range*
t	= time (age in years)
α, β	= constant parameters that control the shape of the curve

The corresponding cumulative distribution function is as described in the equation below. The function models cumulative likelihood of removals over time. The likelihood of survival is the complement of the likelihood of removal:

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

Equation 5

Q(t)	= cumulative distribution function (CDF), i.e. *cumulative likelihood of removals*
R(t)	= survival function

The removal rate (i.e. percentage of removals associated with a certain age) is:

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

Equation 6

λ(t)	= percent removals per year per age, i.e. *removal rate*

Different asset groups experience different removal rates. The parameters α and β define the shape of the Weibull distribution for a specific asset group. Examples of the three functions described above are shown in Figure 2-1, where α = 57.503 and β = 4.132. It can be seen from the graph and from Equation 4 that Q(40) = 0.2 and Q(75) = 0.95. In other words, the cumulative distribution functions (i.e. cumulative likelihood of removals) at age = 40 and 75 years are 20% and 95% respectively. The area beneath the red PDF curve between the purple hatched lines (at age = 45 and 60 years) equates to 41.6% of the entire area under the beneath curve. This represents a 41.6% likelihood that an asset removed from service will be between the ages of 45 to 60 years.

For each asset group, the values of these constant α and β parameters were calculated such that they reflect typical service lives of the asset groups. With assets that are run to failure, the removal curve may closely resemble the failure curve of the asset. Note however, that the removal curves will include assets that have been removed for reasons other than failure (e.g. removals because of proactive replacement based on condition, system growth, obsolescence, etc.). In this project that the life curves developed for all asset groups were based on typical industry values.

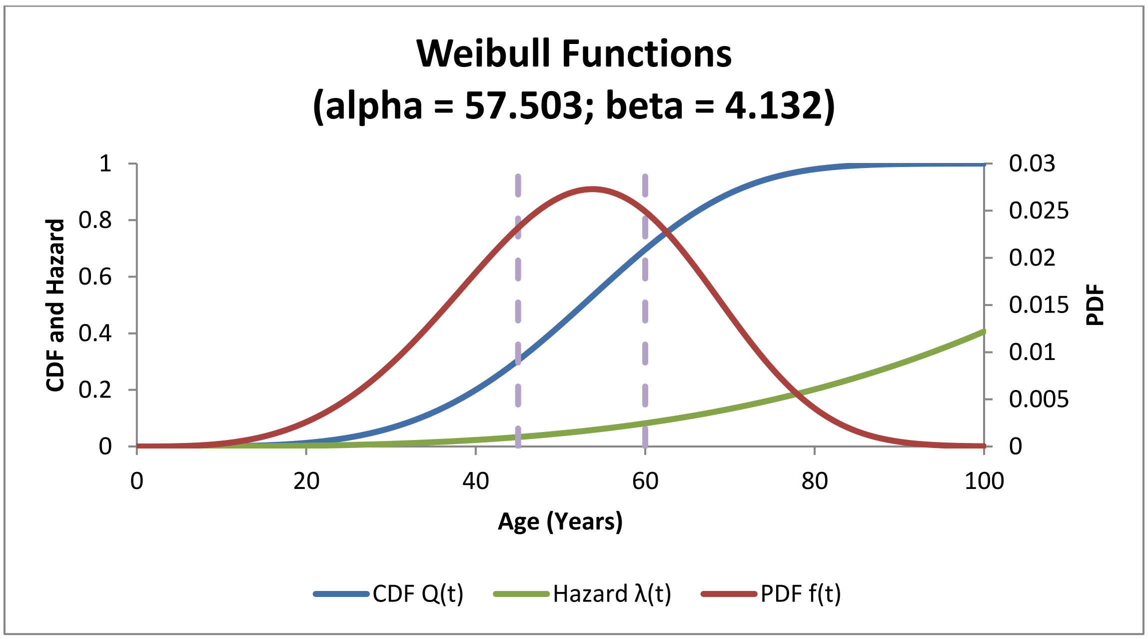

Figure 2-1 Weibull Functions

2.2.1 Flagged for Action Plan Using a Life Curve Approach

The Life Curve approach is used to estimate the number of assets to be addressed in a given year, using the asset's removal rate (Equation 6).

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 failure rates for

5, 10, and 20-year-old units for this asset class are f_5 = 0.02, f_{10} = 0.05, f_{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(f_1) + 19(f_6) + 45(f_{11}) + 45(f_{21}).

Note that in this study the 'age' used is in fact 'effective age', or condition-based age as defined by the asset HI, as opposed to the chronological age of the asset.

For the asset categories below, this probabilistic approach is used to estimate the FFA Plan. It is also important to note that the FFA Plan gives only 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.

- Pole Mounted Transformers
- Pad Mounted Transformers
- Pad Mounted Switchgear
- Poles (Wood and Concrete)
- Underground Cables (Non-TRXLPE, TRXLPE)

2.2.2 Flagged for Action Plan Using a Risk-Based Approach

For some assets costs of replacement and/or consequences of failure are significant, and as a result planning for replacement requires more consideration than only condition. For these assets, a risk-based approach is taken when developing the FFA Plan. The FFA Year (the year that a unit is flagged for action) is calculated for each asset unit.

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.

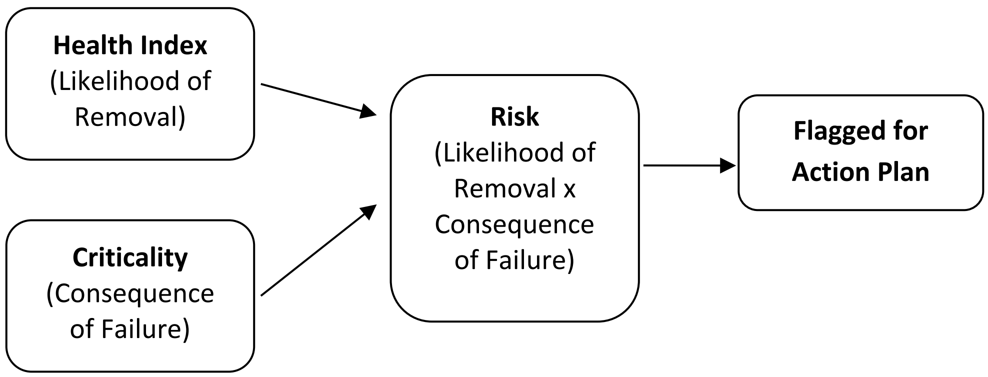

Figure 2-2 Risk Assessment Procedure

Relating Health Index to Likelihood of Removal

The health of an asset correlates to condition based likelihood of removal. The methodology that this project uses to relate HI to likelihood or removal considers asset stress as described below.

If there are no dominant sources, it is assumed in this methodology that the stress to which an asset is exposed is not constant and will have a somewhat normal frequency distribution. This is illustrated by the probability density curve of stress below. The vertical lines in the figure represent condition or strength (HI) of an asset.

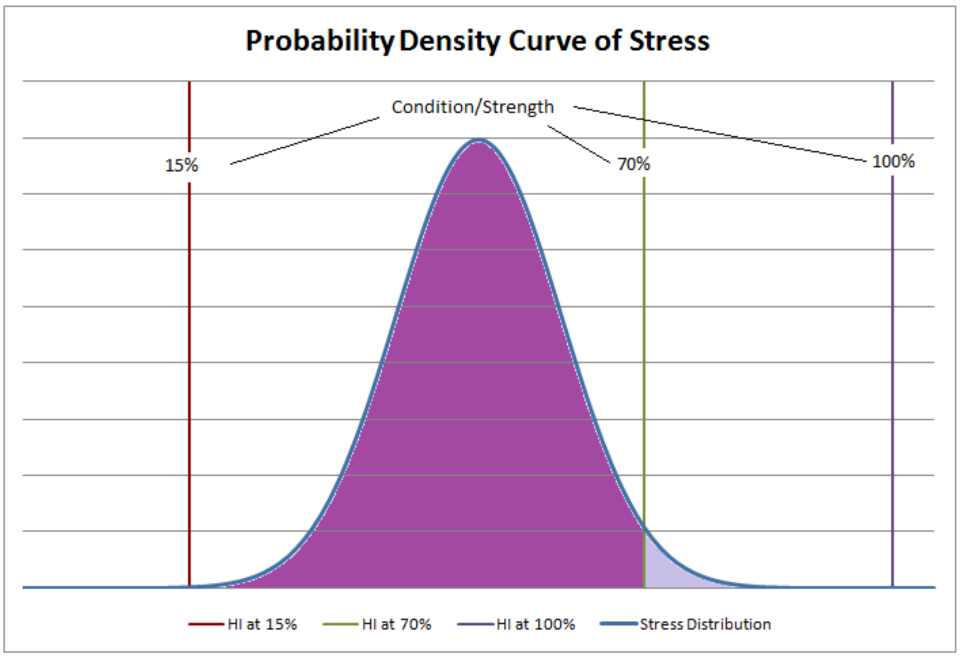

Figure 2-3 Stress Curve

An asset in as-new condition (100% strength) should be able to withstand most 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 the left of the green line. If, however, the stress is of a magnitude to the right of the green line, the asset can fail and consequently be removed from service.

To create a relationship between the HI and likelihood of removal, assume two "points" on the stress curve that correspond to two different HI values. In this example, assume that an asset that has a condition/strength (HI) of 100% can withstand <u>all</u> 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 HI is found from plotting the HI on the X-axis and the area under the probability density curve to the right of the HI line on the Y-axis, as shown on the graph of the figure below.

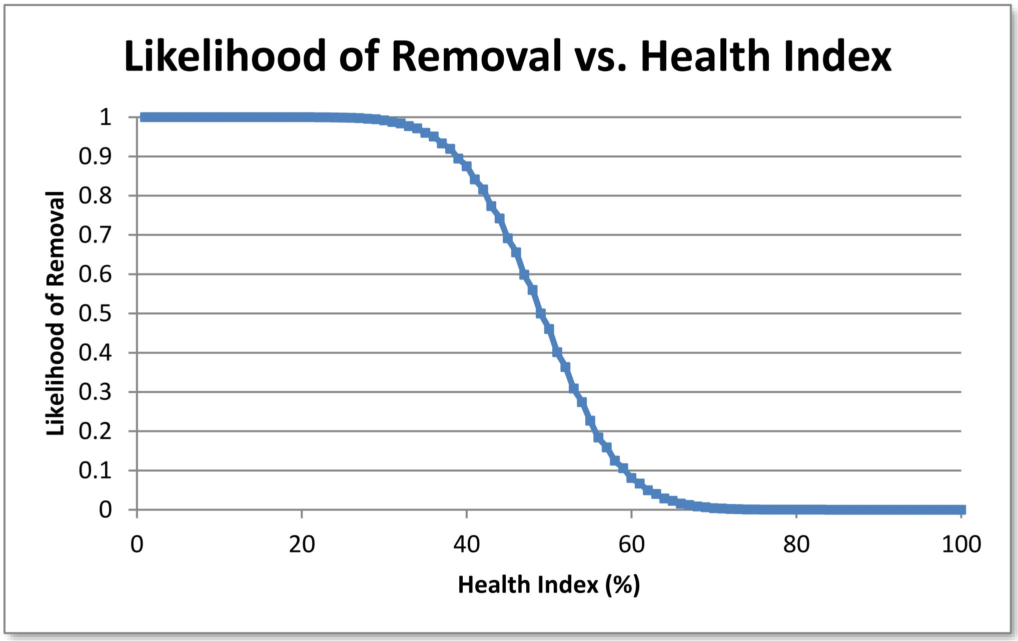

Figure 2-4 Likelihood of Removal vs. Health Index

Criticality

In this study, 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.

The asset's criticality is defined as follows:

$$\text{Criticality} = (\text{Criticality}_{max} - \text{Criticality}_{min}) * \textit{Criticality\_Index} + \text{Criticality}_{min}$$

Equation 7

Where the maximum and minimum criticality values are as follows:

$$\text{Criticality}_{max} = 1/(80\%) = 1.25$$

$Criticality_{min}$ = 1/(95%) = 1.05

This study flags an asset as a candidate for action when the risk (product of its likelihood of removal and criticality) is greater than or equal to one. The above maximum and minimum Criticality values were selected to ensure that units with highest relative importance are flagged as soon as the likelihood of removal is 80% (i.e. Consider an asset whose HI corresponds to an 80% likelihood of removal and whose Criticality = 1.25. Its risk = likelihood of removal x Criticality = 80% X 1.25 = 1. Since the risk = 1, the asset is flagged for action). Action for units that are least critical can be deferred until likelihood of removal is 95%.

As seen in Equation 6 above, a *Criticality Index* (CI) will be calculated for each asset to quantify Criticality. Similar to the HI, the CI is a sum-product of scores and weights of parameters that represent a unit's consequence of failure. CI ranges from 0% to 100%, with 100% representing the unit with the highest possible consequence of failure.

$$Criticality\_Index = \frac{\sum_{i=1}^{\forall i}(SCRP_i \times WCRP_i)}{\sum_{i=1}^{\forall i}(WCRP_i)}$$

Equation 8

SCRP Score of criticality risk parameter
WCRP Weight of criticality risk parameter

Risk

As previously mentioned, asset risk is the product of likelihood of removal and Criticality:

Risk = Likelihood of Removals x Criticality

Equation 9

Since the likelihood of removal ranges from 0 to 1 and Criticality ranges from 1.05 to 1.25 in this methodology (i.e. $Criticality_{min}$. = 1.05 and $Criticality_{max}$. = 1.25), asset Risk will range from 0 to 1.25. However, to better visualize the relative risk of each asset within an asset category, a normalized *Risk Index* for each asset is also given. The Risk Index is simply the asset's calculated Risk divided by the maximum Criticality (i.e. Risk Index = (Likelihood of Failure x Criticality) / $Criticality_{max}$). As a result the Risk Index ranges from 0% to 100%.

The risk-based approach was used to estimate the FFA Plan for Substation Transformers and Circuit Breakers. With this approach, in addition to the estimated number of assets per year that need to be addressed, the FFA Year (i.e. the years that a particular unit is flagged for action) is calculated for each asset unit.

2.3 Data Assessment

The condition data used in this study was provided by NTPDL and included the following:

- Asset Properties (e.g. age, size, voltage, location information)
- Test Results (e.g. Oil Quality, DGA, power factor, contact resistance, etc.)
- Loading information
- Inspection records

There are two dimensions for assessing the availability and completeness of data used in this study: Data Availability Indicator (DAI) and data gap.

2.3.1 Data Availability Indicator (DAI)

The Data Availability Indicator (DAI) is a measure of the amount of condition parameter data that an asset has, as measured against the condition parameters included in the HI formula. It is determined by the ratio of the weighted condition parameters score and the subset of condition parameters data available for the asset over the "best" overall weighted, total condition parameters score. The formula is given by:

$$DAI = \frac{\sum_{m=1}^{\forall m} (DAI_{CPS\,m} \times WCP_m)}{\sum_{m=1}^{\forall m} (WCP_m)}$$

Equation 10

where

$$DAI_{CPSm} = \frac{\sum_{n=1}^{\forall n} \beta_n \times WSCPn}{\sum_{n=1}^{\forall n} (WSCPn)}$$

Equation 11

DAI_{CPSm}	Data Availability Indicator for Condition Parameter m with n Sub-Condition Parameter (SCP)
β_n	Data availability coefficient for sub-condition parameter (=1 when data available, =0 when data unavailable)
$WSCP_n$	Weight of Sub-Condition Parameter n Parameters
WCP_m	Weight of Condition Parameter m

For example, consider an asset with the following condition parameters and sub-condition parameters:

Condition Parameter		Condition Parameter Weight (WCP)	Sub-Condition Parameter		Sub-Condition Parameter Weight (WSCP)	Data Available? (β = 1 if available; 0 if not)
m	Name		n	Name		
1	A	1	1	A_1	1	1
2	B	2	1	B_1	2	1
			2	B_2	4	1
			3	B_3	5	0
3	C	3	1	C_1	1	0

The DAI is calculated as follows:

$DAI_{CP1} = (1*1) / (1) = 1$
$DAI_{CP2} = (1*2 + 1*4 + 0*5) / (2 + 4 + 5) = 0.545$
$DAI_{CP3} = (0*1) / (1) = 0$
$DAI = (DAI_{CP1}*WCP_1 + DAI_{CP2}*WCP_2 + DAI_{CP3}*WCP_3) / (WCP_1 + WCP_2 + WCP_3)$
$= (1*1 + 0.545*2 + 0*3) / (1 + 2 + 3)$
$= 35\%$

An asset with all condition parameter data represented will, by definition, have a DAI value of 100%. In this case, an asset will have a DAI of 100% regardless of its HI score. Provided that the condition parameters used in the HI formula are of good quality and there are few data gaps, there will be a high degree of confidence that the HI score accurately reflects the asset's condition.

Note that where no condition data is available (i.e.no condition parameters are available) for an asset but the age is known, an HI can be calculated based on age (i.e. HI will be equal to the likelihood of survival at the assets age). For these cases, the DAI is 0%. If there is no data whatsoever the HI will not be calculated. The DAI will still be shown as 0% because 0% means no condition data is available, and the HI will be reflected as a blank.

2.3.2 Data Gaps

The HI formulas developed and used in this study are based only on NTPDL's available data. There are additional data or tests that NTPDL may not collect or perform at the present time, but such data/tests are important indicators of the deterioration and degradation of assets. While these will not be included in the HI formula, the set of unavailable data are referred to as data gaps. I.e. a data gap is the case where **none** of the units in an asset group has data. This could be because the data is not collected, certain tests are not conducted, no inspection procedures are in place to obtain condition data, etc. The situation where data is provided for only a sub-set of the population is not considered as a data gap. Consider a utility that has just implemented a wood pole testing program. The "pole strength" parameter will be added to the wood pole HI formula. Say that because the program is new, only 5% of the wood pole population presently have test data. In this case, wood pole is **not** a data gap. However, 95% of the wood pole population will have reduced DAI because they lack data pole strength data.

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	Most useful as an indicator of asset degradation	1
Medium	Important data; can indicate the need for corrective maintenance or increased monitoring	2
Low	Helpful data; least indicative of asset deterioration	3

It is generally recommended that data collection be initiated for the most critical items because such information will result in higher quality HI formulas.

The more critical and important data included in the HI formula of a certain asset group, and the higher the DAI of a particular unit in that group, the higher the confidence in the HI calculated for the particular unit.

If an asset group has significant data gaps and the data used to derive the HI is not good condition data (e.g. age only), there is less confidence that the HI 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 HI formulas for future assessments, the data gap items are presented in this report as condition parameters. Given are a description of the data, priority, and possible data sources.

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

Data Gap	Priority	Description	Source
Tank Corrosion	2	Tank surface rust or deterioration due to environmental factors	Inspections or corrective work orders.

3. Results

This section summarizes the findings of this study.

3.1 Health Index Results

A summary of the HI results is shown in Table 3-1. For each asset category the population, sample size (number of assets with sufficient data for Health Indexing), and average age are given. The average HI and HI distribution are also shown. A summary of the HI distributions for all asset categories are also graphically shown in Figure 3-1.

Three, 13% of the population, substation transformers were classified in the very poor category (details shown in Appendix A, Section 1). Two transformers were categorized as such, primarily because of age. One, however, had poor moisture test results. This transformer should be investigated as it may require closer monitoring or more immediate corrective actions to ensure proper operation.

Approximately 19% of pole mounted transformers were in the poor or very poor condition category. A major contributor to this is the age of the asset group; Approximately 54% of the population is 40 years or older.

Eleven percent (11%) of pad mounted transformers were in the poor or very poor condition category. With 18% of the population being 40 years or older, this is also an asset group that is aging. Many were units were also flagged being in poor condition overall during NTPDL inspections.

About 19% of Non-TRXLPE cables (more than 74 conductor-km) were classified as very poor. Note that this estimation was based on cable age only since there is no other data available for cables.

Also of note are the 6% of wood poles in poor or very poor condition. Because of the large population, this equates to 354 poles. The remaining asset categories had minimal or no percentage of units in poor or very poor condition.

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Table 3-1 Health Index Summary

Asset Category		Population	Sample Size		Average Health Index	Health Index Distribution					Average Age	Average DAI
			Counts	%		Very Poor (< 25%)	Poor (25 - <50%)	Fair (50 - <70%)	Good (70 - <85%)	Very Good (>= 85%)		
Substation Transformers		23	23	100%	82%	13%	0%	4%	13%	70%	29	73%
Circuit Breakers		61	61	100%	100%	0%	0%	0%	0%	100%	15	67%
Pole Mounted Transformers		1797	1318	73%	76%	3%	16%	19%	4%	58%	29	33%
Pad Mounted Transformers		4428	4187	95%	86%	5%	5%	5%	9%	75%	23	56%
Pad Mounted Switchgear		133	130	98%	83%	< 1%	4%	20%	20%	55%	19	98%
Poles	Wood	8147	6149	75%	88%	3%	3%	7%	16%	71%	29	62%
	Concrete	303	300	99%	100%	0%	0%	0%	0%	100%	9	39%
UG Cables* (conductor-km)	Non-TR XLPE	412.6	389.7	94%	80%	11%	8%	2%	10%	69%	32	0%
	TR XLPE	278.5	229.1	82%	100%	0%	0%	0%	0%	100%	18	0%

Note: In addition to the total of 691 conductor-km of cables shown, there is an additional 92 conductor-km of cables with insufficient information for assessment. The total population of underground cables is 783 conductor-km. The overall sample size for underground cables is 79%.

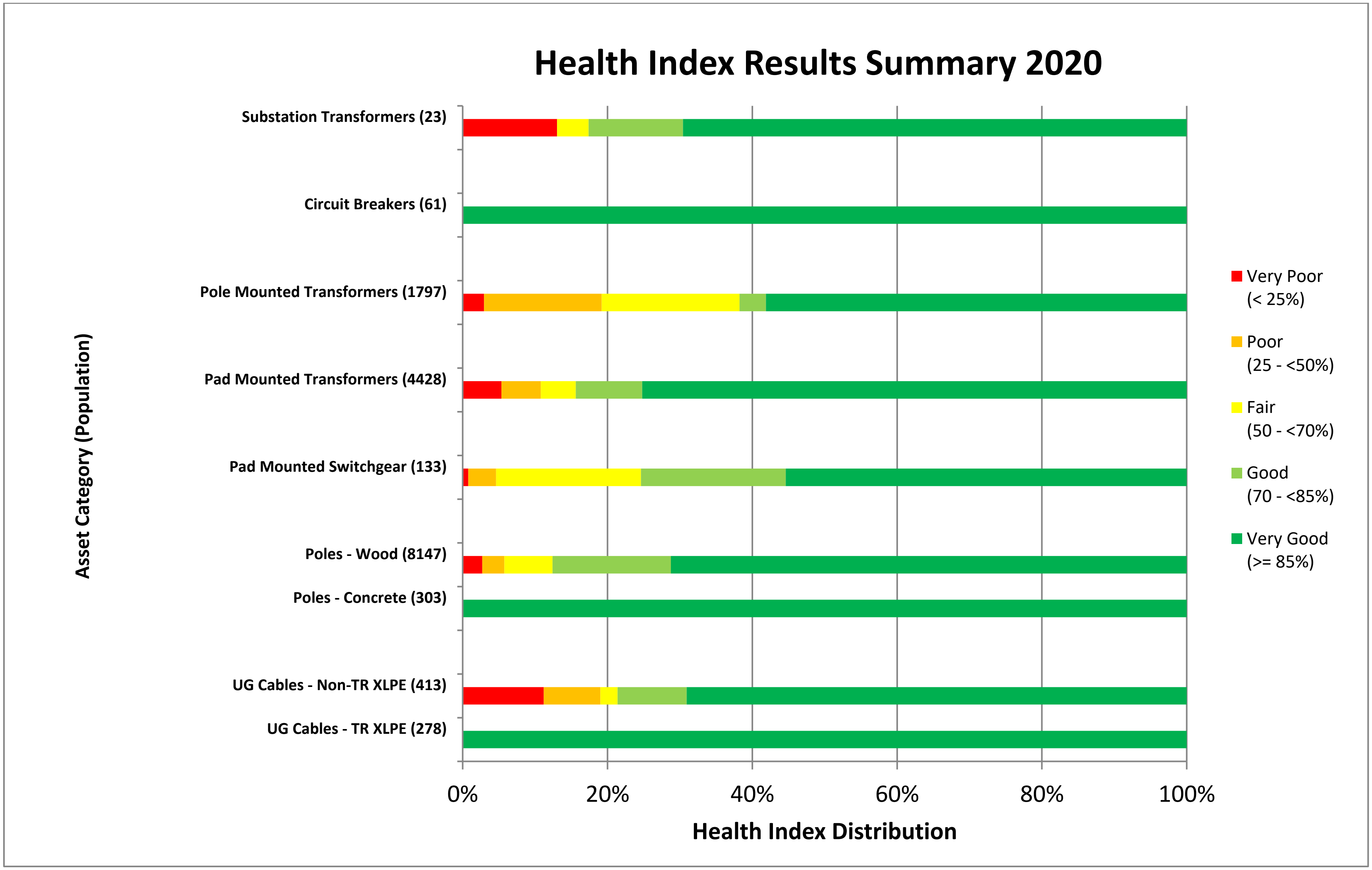

Figure 3-1 Health Index Summary (Graphical)

3.2 Condition-Based Flagged for Action (FFA) Plan

Table 3-2 and Table 3-3 show the 10-year FFA Plan and 'Levelized' FFA Plan. The FFA Plan estimates the number of units expected to require attention in a given year, whereas the 'Levelized' FFA Plan smooths out peaks and valleys to more constant rates. In both tables, the yearly average for Years 0 through 5 (i.e. sum of assets flagged for action between years 0 through 5 divided by 6) is also shown. The same results are shown graphically in Figure 3-2 and Figure 3-3.

It is evident that there may be significantly larger quantities of assets flagged for action in the first year than in subsequent years. This represents a backlog of assets that require attention. This is generally the case when there is a large quantity of assets that are at or near the end of their expected service lives. Because such assets would have higher likelihood of failure, large quantities will be flagged for intervention in the first year. Since the assessment methodology assumes that all units flagged for action are addressed, the quantities flagged for action in year 2 or later may be significantly smaller than that of the first year. In reality, only some of the units flagged for action in the first year will be dealt with while the remaining units will be addressed in subsequent years. This will eventually change the flagged for action list in the coming years as the backlog is gradually reduced.

NTPDL's most significant numbers flagged for action, in terms of number of units, in the current year were found to be for pole and pad mounted transformers, wood poles, and underground cables. In the current year, 416 distribution transformers, 266 wood poles, and 51 km of cables are flagged for attention. If levelized and averaged over the next few, the quantities to be addressed may be more manageable. For example, the number of distribution transformers is reduced to 167 per year in the next 5 years.

The 3 substation transformers classified as poor or fair were flagged for action within the next 5 years. Those that were flagged based on age should be monitored closely (test results, inspections, loading, etc.) for any change in condition. The transformer flagged because of poor high moisture should be investigated further to determine of any immediate corrective actions are required.

Table 3-2 Flagged for Action Plan

Asset Category	Years (0-10)											Now (Year 0)		Years 0 - 5 Inclusive	
	0	1	2	3	4	5	6	7	8	9	10	Number of Units	Percentage of Population	Total Number of Units	Yearly Average
Substation Transformers	0	0	1	2	0	0	0	0	0	0	0	0	0%	3	< 1
Circuit Breakers	0	0	0	0	0	0	0	0	0	0	0	0	0%	0	0
Pole Mounted Transformers	100	75	64	50	46	50	46	47	42	40	37	100	6%	385	< 65
Pad Mounted Transformers	316	133	88	73	67	68	71	76	80	84	96	316	7%	745	< 125
Pad Mounted Switchgear	2	2	1	2	2	2	4	4	2	4	5	2	2%	11	< 2
Wood Poles	266	178	125	99	83	71	65	67	62	59	59	266	3%	822	< 137
Concrete Poles	0	0	0	0	0	0	0	0	0	0	0	0	0%	0	0
UG Cables Non-TR XLPE*	50.9	22.8	18.8	17.4	16.6	16.4	16.9	17.9	18.8	19.5	19.6	50.9	12%	142.9	< 24
UG Cables TR XLPE*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0%	0	0

*conductor-km

Table 3-3 Flagged for Action Plan – Levelized

Asset Category	Years (0-10)											Now (Year 0)		Years 0 - 5 Inclusive	
	0	1	2	3	4	5	6	7	8	9	10	Number of Units	Percentage of Population	Total Number of Units	Yearly Average
Substation Transformers	0	0	1	1	1	0	0	0	0	0	0	0	0%	3	< 1
Circuit Breakers	0	0	0	0	0	0	0	0	0	0	0	0	0%	0	0
Pole Mounted Transformers	65	62	59	56	53	50	48	48	48	48	48	65	4%	345	< 58
Pad Mounted Transformers	124	115	109	104	101	100	100	101	100	100	100	124	3%	653	< 109
Pad Mounted Switchgear	2	2	3	2	3	3	3	3	3	4	3	2	2%	15	< 3
Wood Poles	137	125	115	106	99	92	86	86	87	86	88	137	2%	674	< 113
Concrete Poles	0	0	0	0	0	0	0	0	0	0	0	0	0%	0	0
UG Cables Non-TR XLPE*	22.2	22.0	21.7	21.2	21.0	20.9	20.2	20.2	19.3	19.3	19.3	22.2	5%	129	< 22
UG Cables TR XLPE*	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0%	1	< 1

*conductor-km

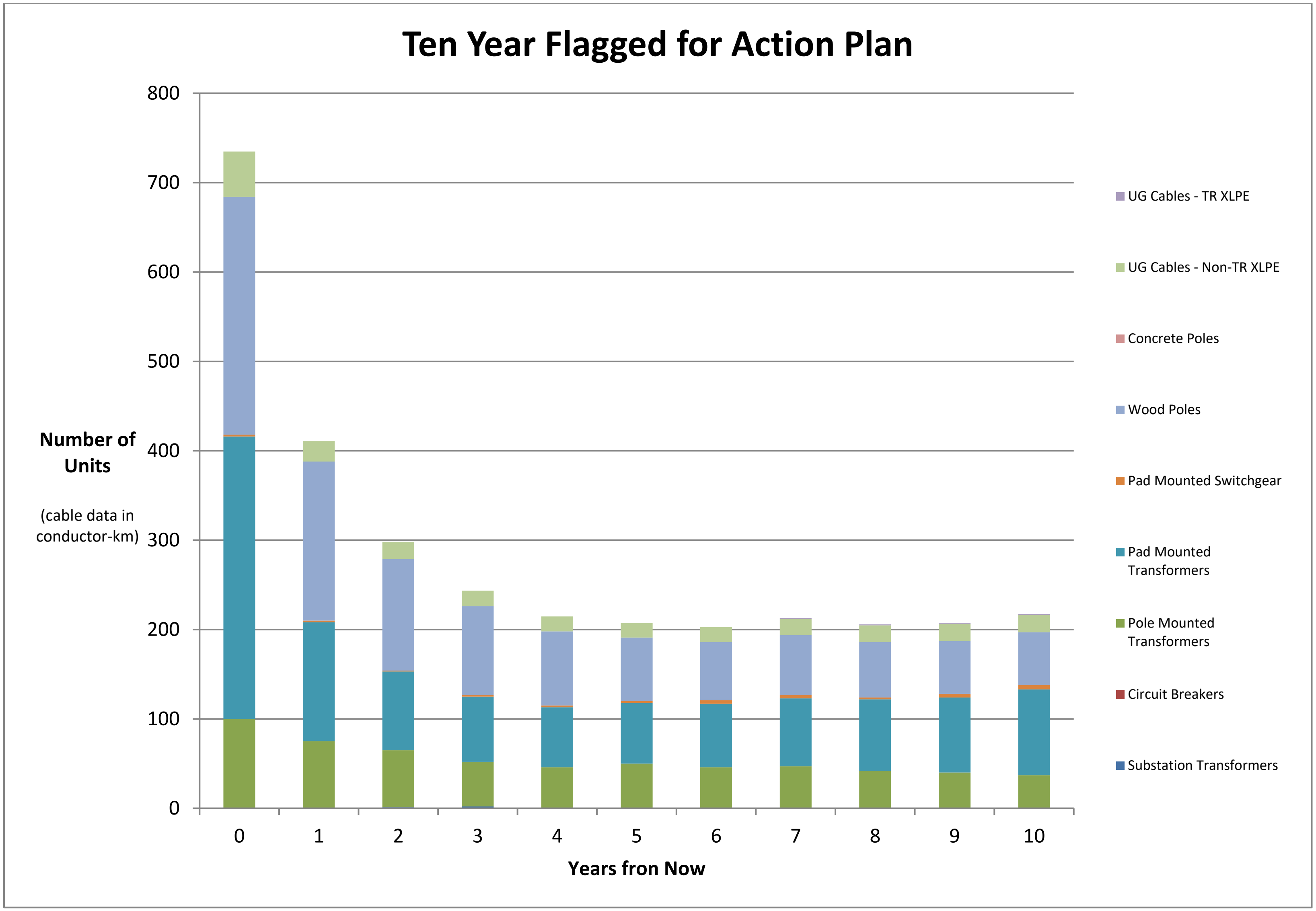

Figure 3-2 Flagged for Action Plan (Graphical)

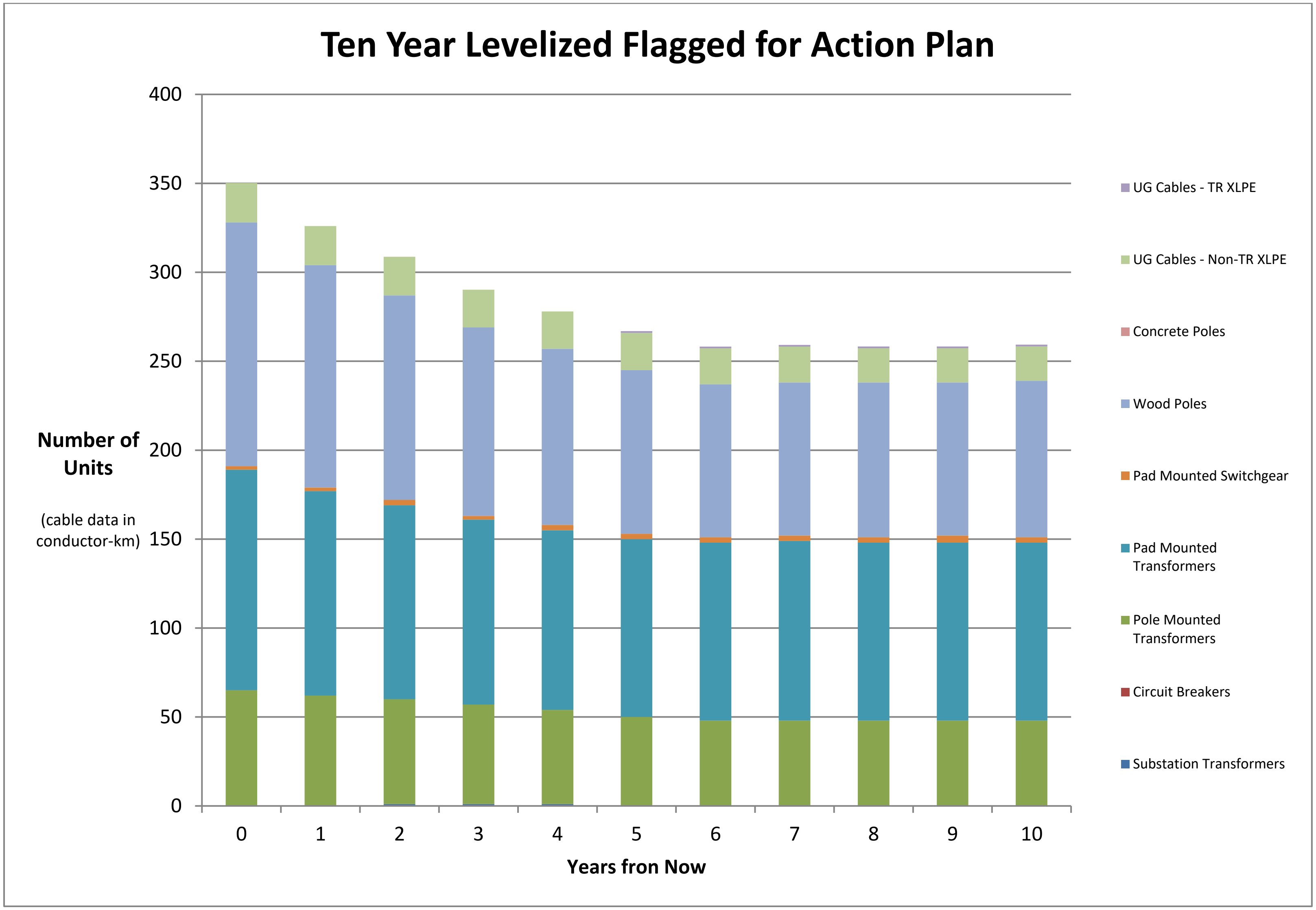

Figure 3-3 Flagged for Action Plan Levelized (Graphical)

3.3 Data Assessment

This section summarizes the data that was used for the assessment and observations and recommendations pertaining to the data used in the assessment. Note that details for each asset category are given in Appendix A.

Table 3-4 shows the data feeding the health index, average DAIs, and data gaps and observations. An overall data assessment, representing to the degree with which the data reflects asset condition, is also given. Recall from Section 2.3.1 that the DAI is a measurement that is relative to the condition information that NTPDL currently collects (and is included as an HI parameter), whereas data gaps are HI parameter information that NTPDL does not collect for any of the units within an asset group. As such, even if an asset group has a high DAI, this does not mean that ideal information for this asset group is complete. If numerous high priority data gaps exist, the degree of confidence that the HI reflects true conditions may still be low. The overall assessment is shown as either 1, 2 or 3, where a score of '1' indicates the highest relative degree of confidence in the data quality and quantity.

Substation transformers and circuit breakers were given a score of '1' because average DAIs were high and data gaps were minimal. Additionally, many of the data (and therefore parameters) were based on test results. Pad mounted transformers were also given a '1' because of relatively more comprehensive inspection records and overall hazard assessment. The DAI should, however, be improved.

Pad mounted switchgear, wood and poles were categorized as '2'. These asset groups had inspection records for overall condition and pad mounted switchgear had other basic inspection records. Additionally, this data was available for the majority of the populations.

Pole mounted transformers were categorized as a '2/3' (i.e. between 2 and 3) because while basic inspection information was available for transformers in Midland, the remainder of the population had only age information. Concrete poles were also categorized as '2/3' because although there were inspection records for overall condition, they were only available for 39% of the population.

Cables were categorized as '3' because the assessments were age-based.

There are also general observations and recommendations applicable to all asset categories:

1. For future assessments, it is suggested that work order information be collected and incorporated into the health index formulas. Total work orders and severity of each work order give an overall indication of whether a particular unit is historically problematic.

2. NTPDL should also consider collecting removal data. When building NTPDL specific asset life curves, historic removal records are essential. For each removal (permanent out of service), details such as age, nameplate information, reason for removal, HI score at the time of removal, etc. should be recorded.

3. The data used in this assessment was extracted from different locations (e.g. numerous spreadsheets or PDF files). For more efficient record keeping and ease of future assessments, NTPDL may wish to consider implementing platform that consolidates asset information and condition data (e.g. nameplate information, test results, operational information, inspection records, etc.) and that can perform live asset analytics.

Table 3-4 Data Assessment Summary

Asset Category	Basis of Health Index Formula	Average DAI	Data Gaps and Observations (H, M, L = high, medium, low priority respectively)	Overall Data Assessment
Substation Transformers	Nameplate GOQ DGA TTR Winding Resistance Power Factor Insulation Resistance Inspection Records Loading	73%		1
Circuit Breakers	Nameplate Maintenance Test (timing gests, contact resistance) Inspection Records Operation Counts	67%	*Test Result* Historical, as-found, as-left test results (e.g. timing tests, contact resistance). This will enable incorporation of trends into the health index model. (L-M)	1
Pole Mounted Transformers	Nameplate Inspection Records Infra-red inspections	33%	*Inspection Records* All inspections for Newmarket and Tay units (H) Termination condition for all regions (H) *Loading* (H)	2/3
Pad Mounted Transformers	Nameplate Inspection Records Infra-red inspections	56%	*Inspection Records* More granular inspections, i.e. Door mechanism (L) Insulation (H) Termination (H) Base and Surroundings (H) *Loading* (H)	1
Pad Mounted Switchgear	Nameplate Inspection Records	98%	*Inspection Records* More granular inspections, i.e. Enclosure (L) Fuse/Switch (H) Insulation (H) Connections (H) Base and Surroundings (L)	2

Asset Category		Basis of Health Index Formula	Average DAI	Data Gaps and Observations (H, M, L = high, medium, low priority respectively)	Overall Data Assessment
Poles	Wood	Nameplate Inspection Records	62%	*Pole Strength* (wood) (H) *Inspection Records* More granular inspections, i.e. Detailed physical condition (M) Pole Accessories, i.e. hardware, insulators, conductors, and brace (M) Environment (L)	2
	Concrete	Nameplate	39%		2/3
Under-ground Cables	Non TRXLPE	Age	Age-based	*Test Result* Dielectric tests, PD test, neutral resistance, conductor resistance, IR Scans, etc. (H) *Inspection Records* Damage on visible parts, e.g. terminations (M) *Fault Rate* Historical failure rates per segment (M)	3
	TRXLPE	Age	Age-based		

4. Conclusions and Recommendations

This section summarizes the findings of this study.

1. An ACA was conducted for a NTPDL's key distribution assets. For each asset category, the health indices were calculated and a condition based FFA Plan was developed. Asset lists, prioritized by risk or health, were developed. An assessment of the data available and data gaps was also conducted.

2. Three substation transformers were placed in the poor category and flagged for action within the next 5 years. Those that were flagged based on age should be monitored closely (test results, inspections, loading, etc.) for any change in condition. The transformers flagged because of poor test results (high moisture) should be investigated further to determine of any immediate corrective actions are required.

3. Approximately 19% of pole mounted transformers were in poor or very poor condition category. Approximately 58 pole mounted transformers a year in the next 5 years (levelized plan) may require attention (e.g. maintenance, refurbishment, replacement).

4. Approximately 11% of pad mounted transformers were in poor or very poor condition category. As such, 109 pad mounted transformers a year in the next 5 years (levelized plan) may require attention.

5. Six (6%) of wood poles were in poor or very poor condition. Because of the large population of wood poles, approximately 113 poles per year (levelized plan) may need to be addressed.

6. About 19% of Non-TRXLPE cables (74 conductor-km) were classified as very poor or poor. Note that this estimation was based on cable age since no other data was available for cables. Because the service life of non-TRXLPE cables is expected to be shorter than that of TRXLPE cables, it is estimated that approximately 22 conductor-km per year may need to be addressed.

   There are many considerations in deciding the most appropriate and cost-effective course of action (e.g. replacement, refurbishment, etc.) for underground cables. Examples are vintage, cable type, condition of concentric neutrals, etc. NTPDL may wish to collect additional information (e.g. failure rates, cause of failure from failure investigation, implement a cable testing program, etc.) to facilitate such decision making.

7. Observations pertaining to the data used in this study were made. Where they exist, data gaps were also identified for each asset category.

   Relative to the other asset categories, station transformers had the most complete data set, in terms of quality and quantity (i.e. data gap or concern and DAI). Circuit breakers also had good data and a fairly high DAI. Pad-mounted transformers had good data also, but better data collection can be done to improve the current 56% DAI.

   Pad mounted switchgear, distribution transformers, and poles inspections for overall conditions, at varying degrees of DAI.

   Underground cables were assessed based on asset age only.

   It is recommended that data be collected in a prioritized manner so that such data can be used in future assessments. It is also recommended that the DAI be improved for each asset category by ensuring that ultimately the complete health index data set is made available for each asset.

8. For future assessments, NTPDL should consider collecting and incorporating work order information. Total work orders and severity of each work order give an overall indication of whether a unit is historically problematic.

9. NTPDL should also consider collecting removal data to enable the development of NTPDL specific asset life curves. The curves used in the current assessment are currently based on a combination of NTPDL's asset demographics and typical industry experience. Using actual removal curves will result in more accurate life curves.

10. The data used in this assessment was from different locations (e.g. numerous spreadsheets or PDF files). For more efficient record keeping and ease of future assessments, NTPDL may wish to consider implementing platform that consolidates asset information and condition data (e.g. nameplate information, test results, operational information, inspection records, etc.) and that can perform live asset analytics.

11. It is important to note that the Flagged for Action plan presented in this study is based primarily on asset condition. It is worth noting that there are numerous other considerations that may influence NTPDL's asset management plan. Among these are obsolescence, system growth, corporate priorities, technological advancements, etc.

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Appendix A Results for Each Asset Category

The results for each individual asset category are detailed in this section.

1. Substation Transformers

This asset class includes NTPDL's Substation Transformers. Sizes range from 5 to 16.6 MVA, with primary voltages ranging from 44 to 46 kV. There are 23 Substation Transformers at NTPDL. Of these, all 23 had sufficient data for assessment. The average age of the poopulation is 29 years; age distribution is as follows:

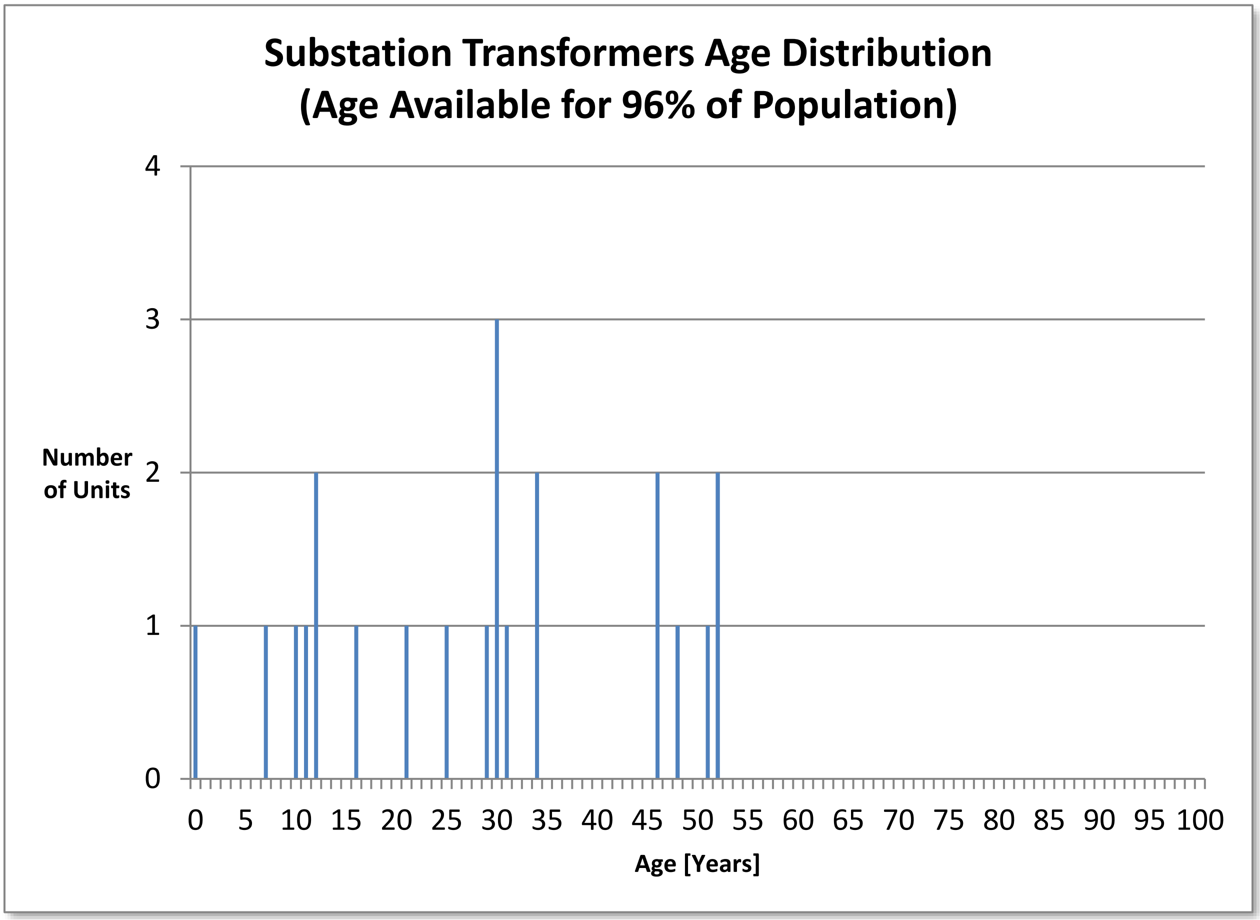

Figure A 1-1 Substation Transformers Age Distribution

1.1 Health Index

1.1.1 Health Index Formula

HI is a function of scores and weights of condition and sub-condition parameters and is calculated using Equation 1 and Equation 2 described in Section 2.1. This section defines the condition and sub-condition parameters, as well as criteria for substation transformers.

Table A 1-1 Substation Transformers Health Index Formula

Condition Parameter (CP)		Sub-Condition Parameter (SCP)			
Description	**Weight (WCP)**	**Description**	**Data Source**	**Weight (WSCP)**	**Criteria**
Internals	10	H2	DGA	5	Table A 1-2
		CH4 (Methane)	DGA	3	Table A 1-2
		C2H6 (Ethane)	DGA	3	Table A 1-2
		C2H4 (Ethylene)	DGA	3	Table A 1-2
		C2H2 (Acetylene)	DGA	5	Table A 1-2
Insulation Oil	8	Dissipation Factor	GOQ	2	Table A 1-3
		Moisture	GOQ	4	Table A 1-3
		Dielectric Strength	GOQ	5	Table A 1-3
		Interfacial Tension	GOQ	3	Table A 1-3
		Acid Number	GOQ	2	Table A 1-3
		Colour	GOQ	1	Table A 1-3
		Particle Count	GOQ	0*	NA
		Oxygen Inhibitor	GOQ	0*	NA
Windings	6	Turns Ratio	Test	1	Table A 1-4
		Winding Resistance	Test	1	Table A 1-5
		Exciting Current	Test	0*	NA
		Leakage Reactance	Test	0*	NA
Paper/ Pressboard	8	Furanic Compound	Oil Test	3	Table A 1-6
		Power Factor	Test	5	Table A 1-7
		Insulation Resistance	Test	4	Table A 1-8
		Capacitance	Test	0*	NA
		PF Tip-Up	Test	0*	NA
		DGA CO	DGA	2	Table A 1-2
		DG CO2	DGA	1	Table A 1-2
Bushings	5	Capacitance	Test	0*	NA
		Power Factor	Test	0*	NA
		Dielectric Loss	Test	0*	NA
		Oil Level (bushings only)	Visual	0*	NA
		Partial Discharge (PD)	Test	0*	NA
		Visual Appearance	Visual	1	Table A 1-9

Tap Changer	1	Visual Appearance	Visual	1	Table A 1-9
Rads, Coolers, and Valves	2	Visual Appearance	Visual	0*	NA
Fans	1	Visual Appearance	Visual	0*	Table A 1-9
Pump	0*	Visual Appearance	Visual	0*	NA
Conservator	1	Visual Appearance	Visual	0*	NA
Tank	2	Oil Leak	Visual	1	Table A 1-9
		Corrosion	Visual	1	Table A 1-9
		Oil Containment	Visual	1	Table A 1-9
Auxiliary Components	1	Pad	Visual	1	Table A 1-9
		Heater	Visual	0*	NA
		Thermostat	Visual	0*	NA
		Vent	Visual	0*	NA
		Temp Gauge	Visual	0*	NA
		Alarms	Visual	0*	NA
		Oil Temp Gauge	Visual	1	Table A 1-9
		Wires	Visual	0*	NA
		Gas Relay	Visual	1	Table A 1-9
		Control Wiring	Visual	1	Table A 1-9
		Pressure Gauge	Visual	1	Table A 1-9
		Winding Temp Gauge	Visual	1	Table A 1-9
Service Record	5	Loading		1	Table A 1-10
HI De-Rating Multiplier (DR)		GOQ, DGA		Equation A 1-1	
Age Limiter (AL)		Based on 45-55 year typical life		Figure A 1-2	
*where there is no available data for any assets, the weight of the parameter is set to 0					

Oil DGA – Transformer Oil

Table A 1-2 DGA Criteria

	Dissolved Gas	Scores					
		4	**3.2**	**2.4**	**1.6**	**0.8**	**0**
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
> 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 and CO2	**Dissolved Gas**	**Scores**					
		4		**2.67**		**1.33**	**0**
	CO (Carbon Monoxide)	X ≤ 350		350 < X ≤ 570		570 < X ≤ 1400	X > 1400
	CO2 (Carbon Dioxide)	X ≤ 2500		2500 < X < 4000		4000 < X ≤ 10000	X > 10000

General Oil Quality

Table A 1-3 General Oil Quality (GOQ)Test Criteria

Oil Quality Test		Voltage Class [kV]	Score				
			4	**3**	**2**	**1**	**0**
Water Content (D1533) [ppm]	Main Tank	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
	Tap	V ≤ 69	< 30	30-33.3	33.3-36.6	36.6-40	> 40
		V > 69	< 20	20-25	25-30	30-35	> 35
Dielectric Strength (D1816 – 1mm gap) [kV]	Main Tank	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
	Tap	V ≤ 69	> 25	21.6-25	18.3-21.6	15-18.3	< 15
		V > 69	> 30	26-30	22-26	18-22	< 18
Dielectric Strength (D877) [kV]	Main Tank	All	> 40	33.3-40	22.6-33.3	20-22.6	< 20
	Tap	All	> 25	21.6-25	18.3-21.6	15-18.3	< 15

IFT (D971) [dynes/cm]	Main Tank	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
	Tap	All	> 25	21.6-25	18.3-21.6	15-18.3	< 15
Color	Main Tank	All	< 1.5	1.5-1.8	1.8-2.1	2.1-2.5	> 2.5
	Tap	All	< 2.0	2.0-2.3	2.3-2.6	2.6-3.0	> 3.0
Acid Number (D974) [mg KOH/g]	Main Tank	V ≤ 69	< 0.05	0.05-0.1	0.1-0.15	0.15-0.2	> 0.2
		69 < V < 230	< 0.04	0.04-0.077	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
	Tap	All	< 0.05	0.05-0.1	0.1-0.15	0.15-0.2	> 0.2
Dissipation Factor (D924 - 25C)	Main Tank and Tap	All	< 0.5%	0.5%-1%	1-1.5%	1.5-2%	> 2%
Dissipation Factor (D924 - 100C)		All	< 5%	5%-10%	10%-15%	15%-20%	> 20%

Transformer Turns Ratio (TTR)

The 'turns ratio' parameter compares the TTR variation to the calculated value in all tap positions.

Table A 1-4 TTR Criteria

If	Maximum TTR variation across any tap position at any phase is greater than 0.5%
Then	**Score** = 0
Else	**Score** = 4

Winding Resistance

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

Table A 1-5 Winding Resistance Criteria

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

Degree of Polymerization

Table A 1-6 Degree of Polymerization Criteria

Score	Degree of Polymerization
0	0
1	250 $\leq$ DP < 400
2	400 $\leq$ DP < 500
2.6	500 $\leq$ DP < 600
3.2	600 $\leq$ DP < 650
3.4	650 $\leq$ DP < 700
3.6	700 $\leq$ DP < 750
3.8	750 $\leq$ DP < 800
4	DP $\geq$ 800
Where DP = (LOG(2FAL*0.88)-4.51)/(-0.0035)	

Power Factor Test

Table A 1-7 Power Factor Test Criteria

Score	Power Factor Reading (PF)	
	Fluid	Dry Type
4	PF $\leq$ 0.5%	PF $\leq$ 1.0%
3	0.5% < PF $\leq$ 1.0%	1.0% < PF $\leq$ 2.0%
2	1.0% < PF $\leq$ 1.5%	2.0% < PF $\leq$ 4.0%
1	1.5% < PF $\leq$ 2.0%	4.0% < PF $\leq$ 6.0%
0	PF > 2.0%	PF > 6.0%

Where PF is the worst-case power factor measurement.
Example: If C_H, C_L, and C_{HL} are available, PF = Max (C_H, C_L, C_{HL})

Insulation Resistance

Table A 1-8 Insulation Resistance

If (IR > kV) then **Score** = 4
Else **Score** = 0

Where

IR = measured insulation resistance in MΩ
kV = rated voltage in kV

Inspections Records

Table A 1-9 Inspection Criteria

Score	Condition Description			
4	Excellent working condition	No apparent issues	Good	OK
3	Minor wear, working as required	Mild severity		
2	Wear or failed, repaired during inspection, regular monitoring required	Medium severity	Fair	
1	Major wear or failed, repaired during inspection	Severe		
0	Immediate replacement or emergency repair required	Very severe	Poor	Not OK

Loading History

Table A 1-10 Loading History

Data: S_1, S_2, S_3, …, S_N recorded data (monthly peaks)
S_B= rated MVA N_A=Number of S_i/S_B which is lower than 0.6 N_B= Number of S_i/S_B which is between 0.6 and 0.8 N_C= Number of S_i/S_B which is between 0.8 and 1.0 N_D= Number of S_i/S_B which is between 1 and 1.2 N_E= Number of S_i/S_B which is greater than 1.2 $Score = \frac{4 * N_A + 3 * N_B + 2 * N_C + 1 * N_D}{N}$
Note: If there are 2 numbers in N_A to N_E greater than 1.5, then the Score should be multiplied by 0.6 to show the effect of overheating.

De-Rating Multiplier

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

$$DR = \min(DR_1, DR_2, DR_3)$$

Equation A 1-1

Where DR_1, DR_2, and DR_3 are as follows:

Table A 1-11 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 A 1-3
0.25	$0 \le Score_{Oil\ Quality\ Test} < 1$
0.5	$1 \le Score_{Oil\ Quality\ Test} < 2$
1	$Score_{Oil\ Quality\ Test} \ge 2$

DR_2: Dissolved Gas Trend

DR_2 is based on total dissolved combustible gas (TDCG) concentration daily rate increase.

Table A 1-12 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
	$0 \le TDCG \le 720$	$720 \le TDCG < 1920$	$1920 \le TDCG < 4630$	$TDCG > 4630$
	DR_Score			
$0 \le X < 0.33$	1	1	1	1
$0.33 \le X < 1$	0.9	0.9	0.85	0.75
$1 \le X < 1.43$	0.9	0.9	0.75	0.75
$1.43 \le X < 4.29$	0.9	0.9	0.75	0.5
$X \ge 4.29$	0.9	0.9	0.5	0.25

DR_3: CO2/CO

DR_3 is based analysis of CO and CO2 ratio using IEC 60599. The derating values are:

Table A 1-13 De-Rating Multiplier CO2:CO Ratio

DR_3	IEC 60599 CO2:CO Assessment
0.75	Paper Fault
0.85	Mild paper overheating <160 C or oil decomp
1	Not Significant

Age Limiter

The Age Limiter used is equivalent to the survival function of the asset group. As described in Section 2.2, asset removal rate is assumed to increase exponentially with age. In this project the removal rate is modeled by the Weibull curve. The cumulative distribution function, introduced in Equation 5, is:

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

where

Q(t) = likelihood of removal
R(t) = survival function
α = constant that controls shape of function
β = constant that controls scale of function

It was assumed that the likelihood of removal at 45 years is 20% and that at 55 years the likelihood of removal is 95% (i.e. Q(45) = 1-0.8=0.2; Q(55) = 1-0.5=0.95). The resultant survival curve (1 – likelihood of removals) is shown in below. This survival curve was used as the Age Limiter.

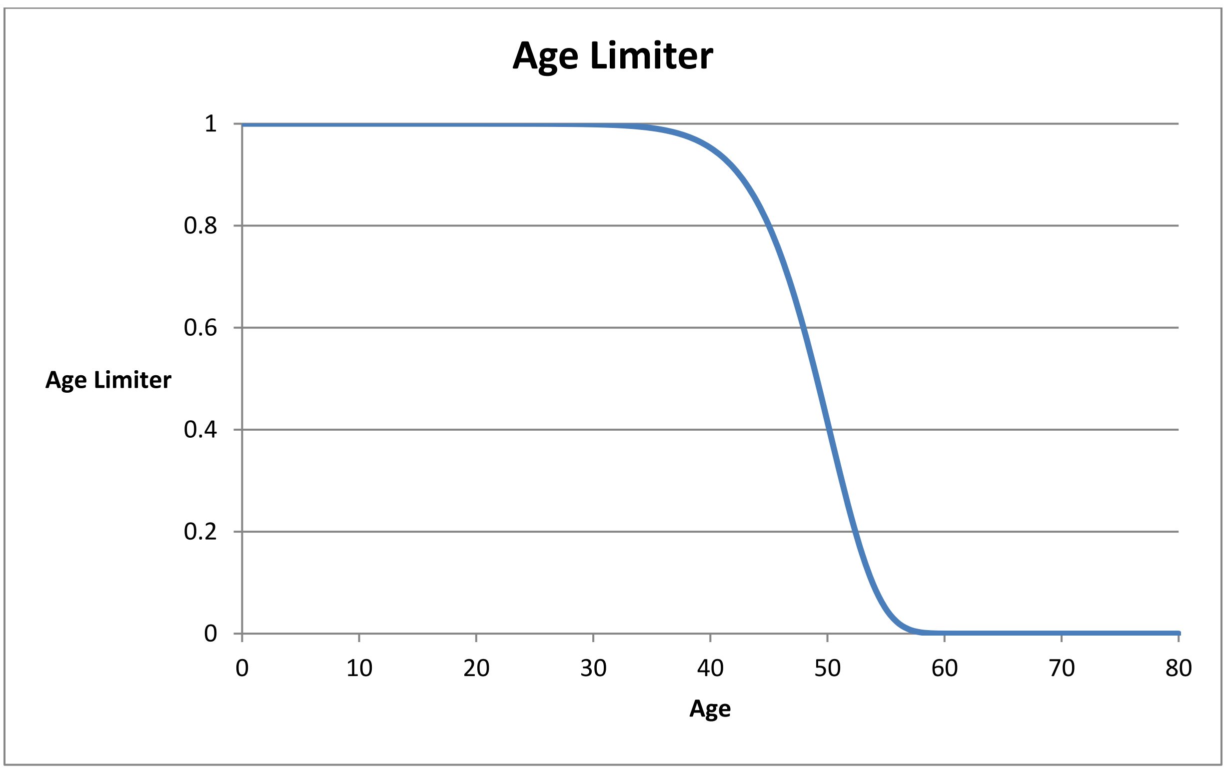

Figure A 1-2 Substation Transformers Age Limiter

1.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. The average HI for the asset group was 81.2%. Three transformers were classified as 'poor' as detailed in Table A 1-14.

From Table A 1-14 it can be seen that Port McNicoll, the first transformer on the list, was flagged because of high moisture content. Since moisture is a significant degradation mechanism for transformer insulation, further investigation is necessary so that appropriate action can be taken.

The second and third transformers, Thompson MS T1 and T2 were flagged primarily because of age as test results do not indicate any issues. However, because transformers are a critical asset that require considerable planning, units that are aging chronologically are flagged.

Although classified in the 'good' category, SCOTT had somewhat elevated carbon monoxide and carbon dioxide levels, which can be indicative of thermal degradation of cellulose. Further investigation of these units is also suggested.

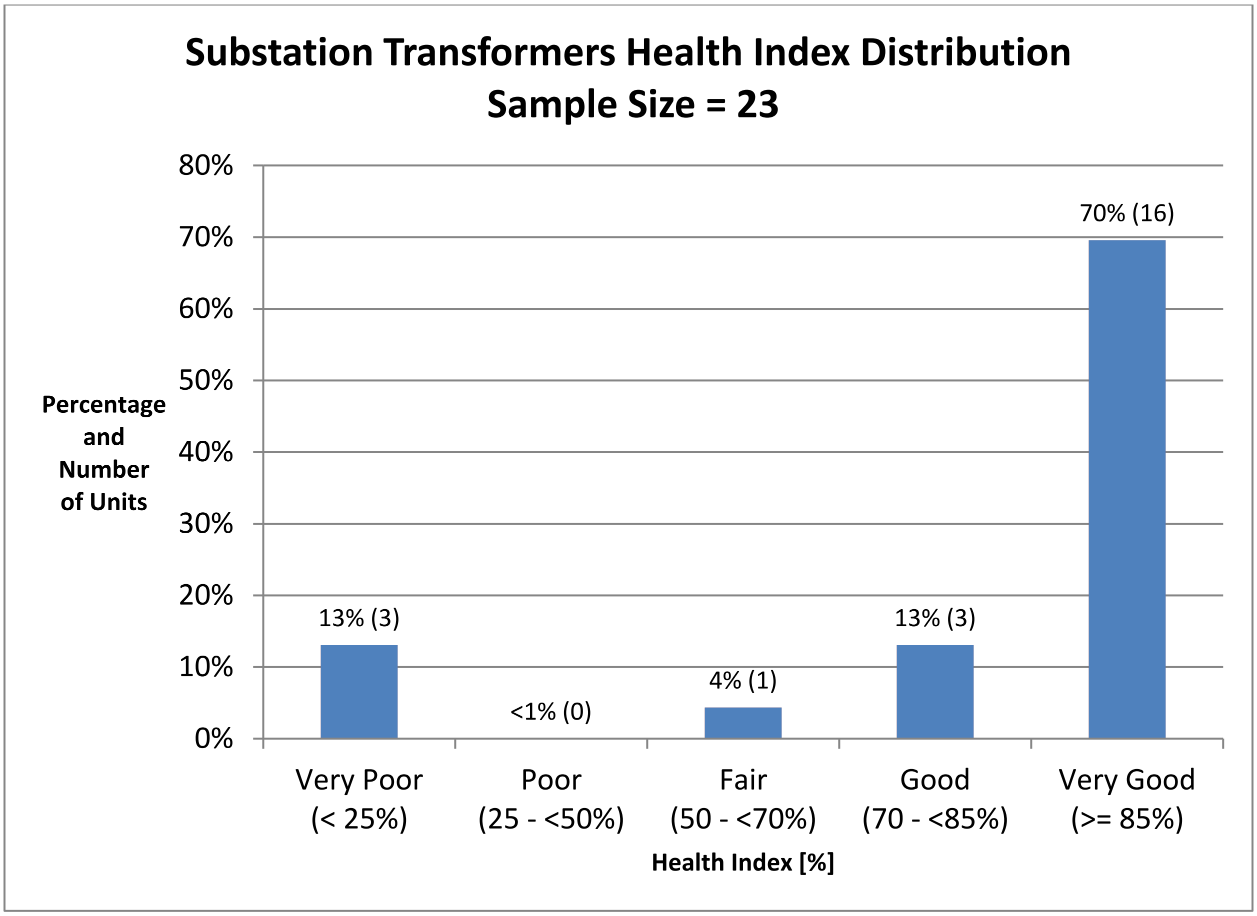

Figure A 1-3 Substation Transformers Health Index Distribution

1.2 Flagged for Action Plan

The 10-year FFA Plan was based on HI results and the associated criticality information as described in Section 2.2.1. In this study, all units were assumed to have equal criticality. As such, the Criticality Index for each unit was set to 0% (i.e. least critical). The FFA is shown below and detailed in Table A 1-14.

Port McNicoll, Thompson M.S. T1, and Thompson M.S. T2 are all flagged for action within the next 5 years. As mentioned, Thompson MS1 and Thompson MS2 were flagged because of their chronological age. As such, deferral of action may be possible. Port McNicoll has a high moisture content; this should prompt immediate investigation (e.g. monitor, more frequent testing, etc.) and, if required, action (e.g. transformer dry-out, replacement, etc.) should be planned soon.

For transformers the 'levelized' plan advances or defers depending on health and criticality.

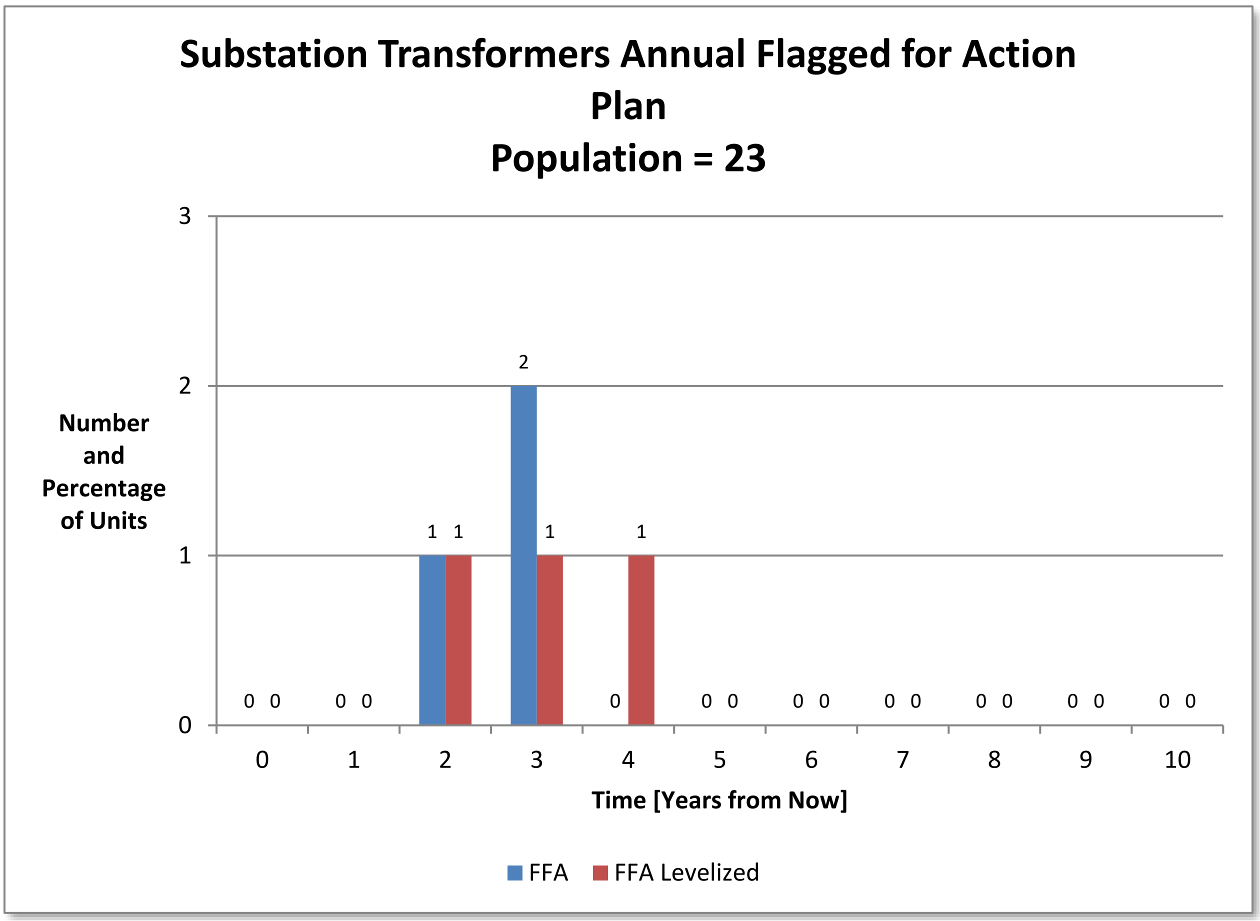

Figure A 1-4 Substation Transformers Flagged for Action Plan

1.3 Risk Based Prioritized List

The following table shows the risk-based prioritization lists for this asset category. The results are sorted by highest to lowest Risk Index. Because the FFA Plan was developed using the risk-based approach, an FFA Year was determined for each asset.

Table A 1-14 Substation Transformers Risk Based Priortized List

Asset Information							HI Calculated			HI Final		Risk Index	FFA Year	De-Rating Multiplier		HI Parameter Scores											
#	Asset ID	Region	Location	Year	Age	DAI	Calculated HI (with De-rating)	Age Limit	Age Limited	HI	HI Category	Risk Index 100% = Most Risk 0% = Least Risk	FFA Year	De-Rating Multiplier	Paper De-Rating	Internal	Oil Quality	Windings	Insulation (paper)	Bushings	LTC	Rads, Coolers, and Valves	Fans	Conservator	Tank	Auxiliary	Service Record
1	PT	NT	Port McNicoll	1969	51	42%	22.9%	32.1%	N	22.9%	VP	46%	3	0.25	High moisture	100%	75%		98%								
2	NK	NT	Thompson M.S. T1	1968	52	93%	98.2%	23.2%	Y	23.2%	VP	43%	3	1		100%	100%	100%	89%	100%	100%	100%	100%	100%	100%	100%	100%
3	NL	NT	Thompson M.S. T2	1968	52	79%	98.2%	23.2%	Y	23.2%	VP	43%	3	1		100%	100%	100%	89%	100%	100%	100%	100%	100%	100%	100%	100%
4	NCC	NT	Gilbert M.S. T2	1972	48	91%	92.3%	59.6%	Y	59.6%	F	0%	>10	0.95	DP indicates paper deterioration	100%	99%	100%	84%	100%		100%	100%	100%	100%	100%	100%
5	SCOTT	MID	SCOTT	2004	16	57%	71.1%	100.0%	N	71.1%	G	0%	>10	0.75	CO2/CO indicates paper deterioration	100%	100%		86%								90%
6	NT	NT	Simmons M.S.	1974	46	94%	98.2%	74.3%	Y	74.3%	G	0%	>10	1		100%	100%	100%	89%	100%	100%	100%	100%	100%	100%	100%	100%
7	NN	NT	Broughton M.S.	1974	46	10%	100.0%	74.3%	Y	74.3%	G	0%	>10	1													100%
8	BRANDON	MID	BRANDON	2008	12	95%	86.2%	100.0%	N	86.2%	G	0%	>10	0.9	TDCG increasing	100%	85%	100%	89%	100%	100%	100%	100%	100%	100%	100%	100%
9	MONTREAL	MID	MONTREAL	1990	30	93%	86.8%	99.9%	N	86.8%	VG	0%	>10	0.9	TDCG increasing	100%	100%	100%	78%	100%	100%	100%		100%	100%	100%	100%
10	FOURTH	MID	FOURTH	2009	11	95%	88.6%	100.0%	N	88.6%	VG	0%	>10	1		54%	100%	100%	90%	100%	100%	100%	100%	100%	100%	100%	95%
11	VHT	NT	Victoria Harbour	1991	29	42%	89.3%	99.9%	N	89.3%	VG	0%	>10	1		100%	99%		67%								
12	NCB	NT	Andrews M.S. T2	1990	30	93%	92.4%	99.9%	N	92.4%	VG	0%	>10	1		100%	100%	67%	77%	100%	100%	100%	100%	100%	100%	100%	100%
13	NH	NT	Leadbeater M.S.			89%	96.2%	100.0%	N	96.2%	VG	0%	>10	1		82%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
14	SPARE	NT	Spare	2008	12	42%	96.6%	100.0%	N	96.6%	VG	0%	>10	1		100%	100%		89%								
15	NR	NT	Andrews M.S. T1	1989	31	94%	97.9%	99.8%	N	97.9%	VG	0%	>10	1		100%	99%	100%	89%	100%	100%	100%	100%	100%	100%	100%	100%
16	NCH	NT	Twinney M.S. T1	1995	25	94%	98.2%	100.0%	N	98.2%	VG	0%	>10	1		100%	100%	100%	89%	100%	100%	100%	100%	100%	100%	100%	100%
17	QUEEN	MID	QUEEN	2013	7	70%	98.9%	100.0%	N	98.9%	VG	0%	>10	1		100%	100%	100%	94%						100%	100%	100%
18	NAM	NT	Cook M.S.	1986	34	94%	100.0%	99.4%	Y	99.4%	VG	0%	>10	1		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
19	NG	NT	Gilbert M.S. T1	1986	34	42%	100.0%	99.4%	Y	99.4%	VG	0%	>10	1		100%	100%		100%								
20	NBJ	NT	Legge M.S.	1999	21	94%	99.5%	100.0%	N	99.5%	VG	0%	>10	1		100%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	98%
21	NCI	NT	Twinney M.S. T2	1990	30	94%	99.6%	99.9%	N	99.6%	VG	0%	>10	1		100%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	98%
22	DORION	MID	DORION	2010	10	57%	100.0%	100.0%	Y	100.0%	VG	0%	>10	1		100%	100%		100%								100%
23	WT	NT	Waubashene	2020	0	29%	100.0%	100.0%	Y	100.0%	VG	0%	>10	1		100%	100%		100%								

1.4 Data Assessment

The data for transformers included age, nameplate information, inspection records, loading, oil quality, dissolved gas analysis, and power factor tests.

Since data was available for the overwhelming majority of transformers, the average DAI was high as shown in the table below.

Asset Category	Population	Average DAI
Substation Transformers	18	73%

Very good condition data is already being collected for transformers. As such, no condition parameter data gaps were identified.

2. Circuit Breakers

There are 61 Circuit Breakers at NTPDL. Of these, all 61 had sufficient data for assessment. The average age of the poopulation is 15 years; age distribution is as follows:

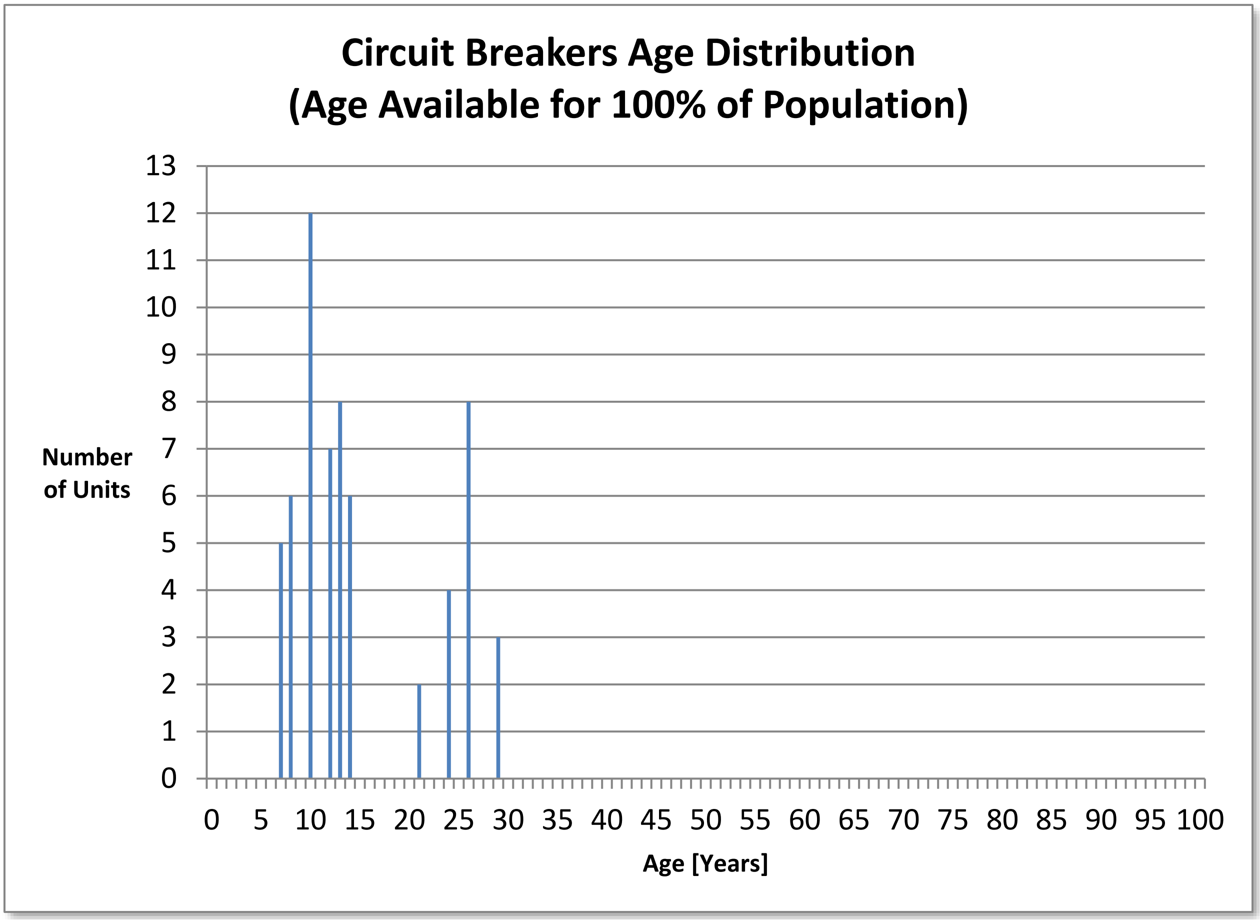

Figure A 2-1 Circuit Breakers Age Distribution

2.1 Health Index

2.1.1 Health Index Formula

HI is a function of scores and weights of condition and sub-condition parameters and is calculated using Equation 1 and Equation 2 described in Section 2.1. This section defines the condition and sub-condition parameters, as well as criteria.

Table A 2-1 Circuit Breakers Health Index Formula

Condition Parameter (CP)		**Sub-Condition Parameter (SCP)**			
Description	**Weight (WCP)**	**Description**	**Data Source**	**Weight (WSCP)**	**Criteria**
Operating Mechanism and Control	11[1] 7[2,3]	Operating Mechanism	Inspections	1	Table A 2-3
		Charging System	Inspections	1	Table A 2-3
		Electrical and Manual Operation	Inspections	1	Table A 2-3
		Mechanical Operation	Inspections	1	Table A 2-3
Contacts	3	Stationary Contact	Inspections	1	Table A 2-3
		Moving Contact	Inspections	1	Table A 2-3
		Arcing Contact	Inspections	1	Table A 2-3
		Contact Alignment	Inspections	1	Table A 2-3
		Main Contact	Inspections	1	Table A 2-3
		Closing timing	Test	1	Table A 2-4
		Trip timing	Test	1	Table A 2-4
		Contact Resistance	Test	1	Table A 2-2
Interrupters	1	Arc Chute	Inspections	1	Table A 2-3
		Vacuum Interrupter	Inspections	1[2], 0[1,3]	Table A 2-3
Insulation and Connections	1	Phase Barrier Condition	Inspections	2	Table A 2-3
		Stationary Ground Contacts	Inspections	1	Table A 2-3
		Moving Ground Contacts	Inspections	1	Table A 2-3
		Connections	Inspections	1	Table A 2-3
Racking	1	Stationary & Moving Bus Stabs	Inspections	1	Table A 2-3
		Ground Bus Stab	Inspections	1	Table A 2-3
		Racking Mechanism	Inspections	1	Table A 2-3
		Cell Alignment	Inspections	1	Table A 2-3
		Interlocks	Inspections	1	Table A 2-3
Heating and Controls	1	Cell Space Heater/Thermostat	Inspections	1	Table A 2-3
		Auxiliary Trips	Inspections	1	Table A 2-3
		Under Voltage Trips	Inspections	1	Table A 2-3
		Electrical & Manual Indicators	Inspections	1	Table A 2-3
Derating Multiplier (DR)		Based on relative number of operations			Table A 2-5
Age Limiter (AL)		Based on typical life curve			Figure A 2-2

[1] Air; [2] Vacuum; [3] SF6

Contact Resistance

The contact resistance criteria compare the measured contact resistance to assumed limits. The worst-case contact resistance of the three phases is used as the score.

Table A 2-2 Contact Resistance Criteria

Score (SCPS)	"Percent Limit" Description
4	Percent Limit ≤ 80%
3	80% < Percent Limit ≤ 100%
1	100% < Percent Limit ≤ 120%
0	Percent Limit > 120%

Where Percent Limit = (Contact Resistance) / (Allowable Limit)

Allowable Limit assume as:

CB Type	Contact Resistance Limit [μΩ]					
	V <= 69 kV	69 < V < 110 kV	110 <= V <= 230 kV	230 < V < 345 kV	345 <= V <= 765 kV	V > 765 kV
SF6	150	150	150	150	150	300
Vacuum	250	250	250	250	250	250

Inspections Records

Table A 2-3 Inspection Criteria

Score	Condition Description			
4	Excellent working condition	No apparent issues	Good	OK
3	Minor wear, working as required	Mild severity		
2	Wear or failed, repaired during inspection, regular monitoring required	Medium severity	Fair	
1	Major wear or failed, repaired during inspection	Severe		
0	Immediate replacement or emergency repair required	Very severe	Poor	Not OK

Timing Test

The timing test criteria compare the measured time to assumed limits.

Table A 2-4 Timing Test Criteria

Score (SCPS)	"Percent Limit" Description
4	Percent Limit ≤ 80%
3	80% < Percent Limit ≤ 100%
1	100% < Percent Limit ≤ 120%
0	Percent Limit > 120%

Where Percent Limit = (Trip or Close time) / (Allowable Limit)

Allowable Limit assume as:

CB Type	Trip Limit [ms]					
	V <= 69 kV	69 < V < 110 kV	110 <= V <= 230 kV	230 < V < 345 kV	345 <= V <= 765 kV	V > 765 kV
SF6	42	42	42	42	25	25
Vacuum	42	42	42	42	25	25

CB Type	Close Limit [ms]					
	V <= 69 kV	69 < V < 110 kV	110 <= V <= 230 kV	230 < V < 345 kV	345 <= V <= 765 kV	V > 765 kV
SF6	250	250	142	142	83	83
Vacuum	250	250	142	142	83	83

Derating Multiplier

The HI of breakers that have relatively higher operation counts are de-rated to reflect greater wear. The Derating multiplier is calculated as follows:

The operating counter criteria compare the measured time to assumed limits.

Table A 2-5 Operating Derating Criteria

DR	Priority Description
1	C < 10000
0.95	10000 ≤ C < 100000
0.9	100000 ≤ C < 1000000
0.85	C ≥ 1000000

Age Criteria

The Age Limiter used is equivalent to the survival function of the asset group, as described in Equation 5. It was assumed that the likelihood of removal at 50 years is 20% and that at 60 years the likelihood of removal is 95%. The resultant survival curve (1 – likelihood of removals) is shown in below. This survival curve was used as the Age Limiter.

Figure A 2-2 Circuit Breakers Age Limiter

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2.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. All were found to be in very good condition. The average HI for the asset group was nearly 99.6%.

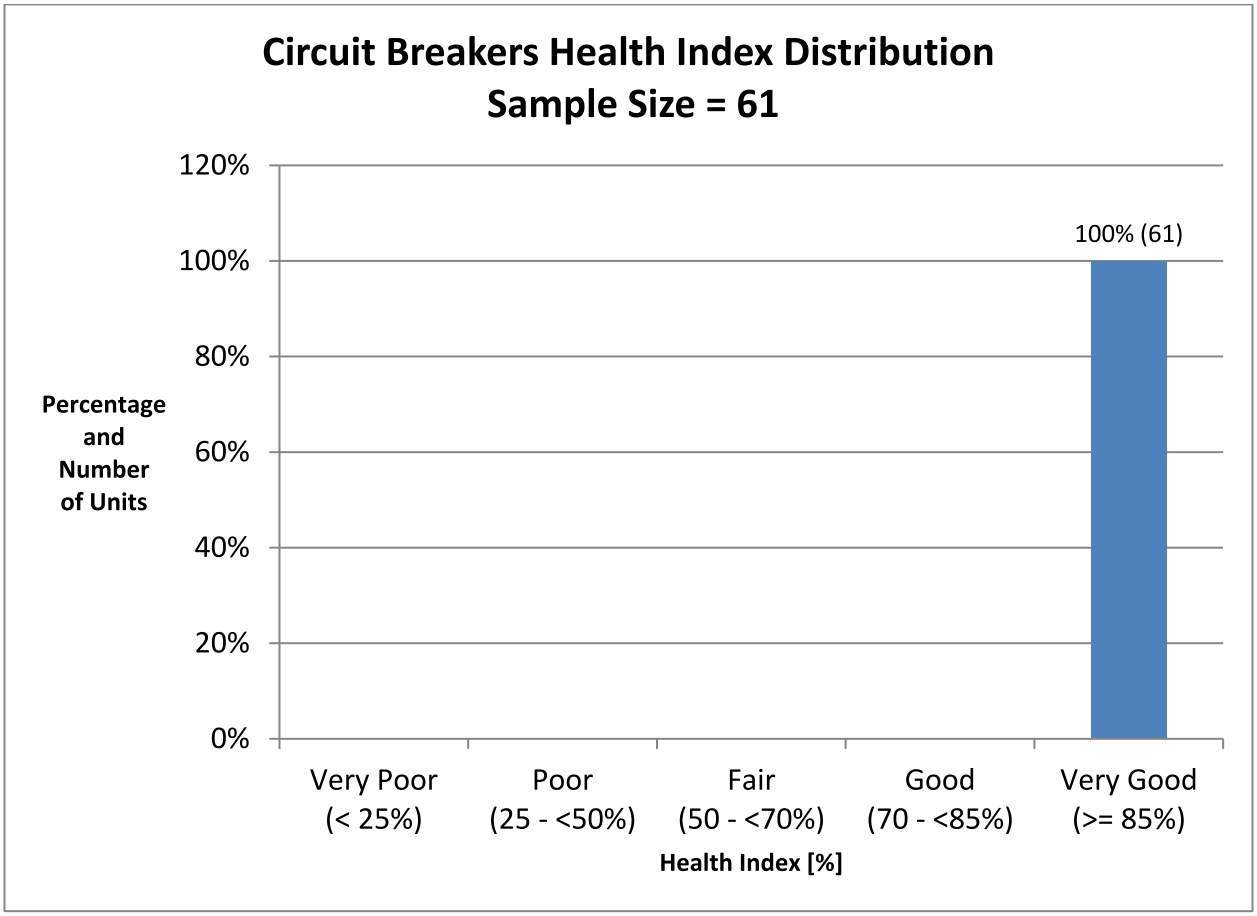

Figure A 2-3 Circuit Breakers Health Index Distribution

2.2 Flagged for Action Plan

The 10-year FFA Plan was based on HI results and the associated criticality information as described in Section 2.2.1. In this study, all units were assumed to have equal criticality. As such, the Criticality Index for each breaker was set to 0% (i.e. least critical).

No breakers were flagged for action in the next 10 years.

2.3 Risk Based Prioritized List

The following table shows the risk-based prioritization lists for this asset category. The results are sorted by highest to lowest Risk Index. Because the FFA Plan was developed using the risk-based approach, an FFA Year was determined for each asset.

Table A 2-6 Circuit Breakers Risk Based Priortized List

Asset Information								HI Calculated			Final HI						HI Parameter Scores					
#	Asset ID	Location	Type	Year Installed	Age		DAI	Calculated HI (with De-rating)	Age Limit	Age Limited	HI	HI Category	Risk Index 100% = Most Risk 0% = Least Risk	FFA Year		De-Rating Multiplier (Number of Operations)	Operating Mechanism	Contact Performance	Arc extinction	Insulation and Connections	Racking Mechanism	Heating and Controls
1	F30	NT	SF6	1994	26		100%	86.0%	1	N	86.0%	Very Good	0%	>10			100%	50%		100%	100%	
2	F21	NT	Vacuum	2006	14		94%	98.1%	1	N	98.1%	Very Good	0%	>10		1	100%	94%	100%	100%	100%	
3	F24	NT	Vacuum	2006	14		94%	98.1%	1	N	98.1%	Very Good	0%	>10		1	100%	94%	100%	100%	100%	
4	F41	NT	Vacuum	2010	10		100%	98.6%	1	N	98.6%	Very Good	0%	>10		1	100%	96%		100%	100%	
5	F42	NT	Vacuum	2010	10		100%	98.6%	1	N	98.6%	Very Good	0%	>10		1	100%	96%		100%	100%	
6	F3	NT	SF6	1991	29		100%	98.8%	1	N	98.8%	Very Good	0%	>10		1	100%	95%	100%	100%		
7	F4	NT	SF6	1991	29		100%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%	100%	100%	100%		
8	F5	NT	SF6	1991	29		0%		1	Y	100.0%	Very Good	0%	>10								
9	F10	NT	SF6	1994	26		74%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%		100%		100%	100%
10	F11	NT	SF6	1994	26		74%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%		100%		100%	100%
11	F12	NT	SF6	1994	26		74%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%		100%		100%	100%
12	F14	NT	SF6	1994	26		74%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%		100%		100%	100%
13	F33	NT	SF6	1994	26		92%	100.0%	1	Y	100.0%	Very Good	0%	>10			100%	100%	100%	100%	100%	
14	F32	NT	SF6	1994	26		91%	100.0%	1	Y	100.0%	Very Good	0%	>10			100%	100%		100%	100%	
15	F31	NT	SF6	1994	26		72%	100.0%	1	Y	100.0%	Very Good	0%	>10			100%			100%	100%	
16	F70	NT	SF6	1996	24		72%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%			100%	100%	
17	F72	NT	SF6	1996	24		72%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%			100%	100%	
18	F73	NT	SF6	1996	24		72%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%			100%	100%	
19	F71	NT	SF6	1996	24		72%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%			100%	100%	
20	F50	NT	Vacuum	1999	21		88%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%	100%	100%	100%	100%	
21	F52	NT	Vacuum	1999	21		70%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%		100%	100%	100%	
22	F23	NT	Vacuum	2006	14		94%	100.0%	1	Y	100.0%	Very Good	0%	>10			100%	100%	100%	100%	100%	
23	F25	NT	Vacuum	2006	14		94%	100.0%	1	Y	100.0%	Very Good	0%	>10			100%	100%	100%	100%	100%	
24	F28	NT	Vacuum	2006	14		88%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%	100%	100%	100%	100%	
25	F26	NT	Vacuum	2006	14		88%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%	100%	100%	100%	100%	
26	F63	NT	Vacuum	2007	13		100%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%	100%	100%	100%	100%	
27	F62	NT	Vacuum	2007	13		100%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%	100%	100%	100%	100%	
28	F61	NT	Vacuum	2007	13		100%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%	100%	100%	100%	100%	
29	SCOTT ST DS S1	MID	Vacuum	2007	13		0%		1	Y	100.0%	Very Good	0%	>10								
30	SCOTT ST DS S1	MID	Vacuum	2007	13		0%		1	Y	100.0%	Very Good	0%	>10								
31	SCOTT ST DS S2	MID	Vacuum	2007	13		0%		1	Y	100.0%	Very Good	0%	>10								
32	SCOTT ST DS S3	MID	Vacuum	2007	13		0%		1	Y	100.0%	Very Good	0%	>10								
33	SCOTT ST DS S4	MID	Vacuum	2007	13		0%		1	Y	100.0%	Very Good	0%	>10								
34	F51	NT	Vacuum	2008	12		70%	100.0%	1	Y	100.0%	Very Good	0%	>10		1	100%		100%	100%	100%	

Asset Information							HI Calculated			Final HI		Risk Index 100% = Most Risk 0% = Least Risk			HI Parameter Scores					
#	Asset ID	Location	Type	Year Installed	Age	DAI	Calculated HI (with De-rating)	Age Limit	Age Limited	HI	HI Category		FFA Year	De-Rating Multiplier (Number of Operations)	Operating Mechanism	Contact Performance	Arc extinction	Insulation and Connections	Racking Mechanism	Heating and Controls
35	F1	NT	Vacuum	2008	12	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%		
36	F2	NT	Vacuum	2008	12	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%		
37	BRANDON DS MAIN	MID	Vacuum	2008	12	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%		100%	100%	
38	BRANDON DS B1	MID	Vacuum	2008	12	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%		100%	100%	
39	BRANDON DS B2	MID	Vacuum	2008	12	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%		100%	100%	
40	BRANDON DS B3	MID	Vacuum	2008	12	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%		100%	100%	
41	DORION DS MAIN	MID	Vacuum	2010	10	0%		1	Y	100.0%	Very Good	0%	>10							
42	DROION DS D1	MID	Vacuum	2010	10	0%		1	Y	100.0%	Very Good	0%	>10							
43	DROION DS D2	MID	Vacuum	2010	10	0%		1	Y	100.0%	Very Good	0%	>10							
44	DROION DS D3	MID	Vacuum	2010	10	0%		1	Y	100.0%	Very Good	0%	>10							
45	DROION DS D4	MID	Vacuum	2010	10	0%		1	Y	100.0%	Very Good	0%	>10							
46	FOURTH ST DS MAIN	MID	Vacuum	2010	10	100%	100.0%	1	Y	100.0%	Very Good	0%	>10		100%		100%	100%	100%	
47	FOURTH ST DS F1	MID	Vacuum	2010	10	100%	100.0%	1	Y	100.0%	Very Good	0%	>10		100%		100%	100%	100%	
48	FOURTH ST DS F2	MID	Vacuum	2010	10	100%	100.0%	1	Y	100.0%	Very Good	0%	>10		100%		100%	100%	100%	
49	FOURTH ST DS F3	MID	Vacuum	2010	10	100%	100.0%	1	Y	100.0%	Very Good	0%	>10		100%		100%	100%	100%	
50	FOURTH ST DS F4	MID	Vacuum	2010	10	100%	100.0%	1	Y	100.0%	Very Good	0%	>10		100%		100%	100%	100%	
51	MONTREAL ST DS MAIN	MID	Vacuum	2012	8	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%	100%	100%
52	MONTREAL ST DS M1	MID	Vacuum	2012	8	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%	100%	100%
53	MONTREAL ST DS M2	MID	Vacuum	2012	8	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%	100%	100%
54	MONTREAL ST DS M3	MID	Vacuum	2012	8	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%	100%	100%
55	MONTREAL ST DS M4	MID	Vacuum	2012	8	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%	100%	100%
56	MONTREAL ST DS M5	MID	Vacuum	2012	8	100%	100.0%	1	Y	100.0%	Very Good	0%	>10	1	100%	100%	100%	100%	100%	100%
57	QUEEN ST DS MAIN	MID	Air	2013	7	0%		1	Y	100.0%	Very Good	0%	>10							
58	QUEEN ST DS Q1	MID	Air	2013	7	0%		1	Y	100.0%	Very Good	0%	>10							
59	QUEEN ST DS Q2	MID	Air	2013	7	0%		1	Y	100.0%	Very Good	0%	>10							
60	QUEEN ST DS Q3	MID	Air	2013	7	0%		1	Y	100.0%	Very Good	0%	>10							
61	QUEEN ST DS Q4	MID	Air	2013	7	0%		1	Y	100.0%	Very Good	0%	>10							

2.4 Data Assessment

The data for breakers included timing tests, contact resistance tests, operations counts, and inspection records.

Since data was available for the most of breakers, the average DAI was fairly high as shown in the table below. The DAI can be improved by consistently collecting timing tests information and contact resistance for all breakers in all three regions (Newmarket, Tay, and Midland).

Asset Category	Population	Average DAI
Circuit Breakers	61	67%

Very good condition data is already being collected for breakers. As such, no condition parameter data gaps were identified. However, data quality can be improved through consistent recording of as-found and as-left timing test data. Evaluation of timing, contact resistance, and operations count parameters can be improved by collecting asset-specific manufacturer or baseline values so that current readings can be compared to these baseline values.

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3. Pole Mounted Transformers

There are 1797 Pole Mounted Transformers at NTPDL. Of these, 1318 had sufficient data for assessment. fdThe average age of the population is 29 years; age distribution is as follows:

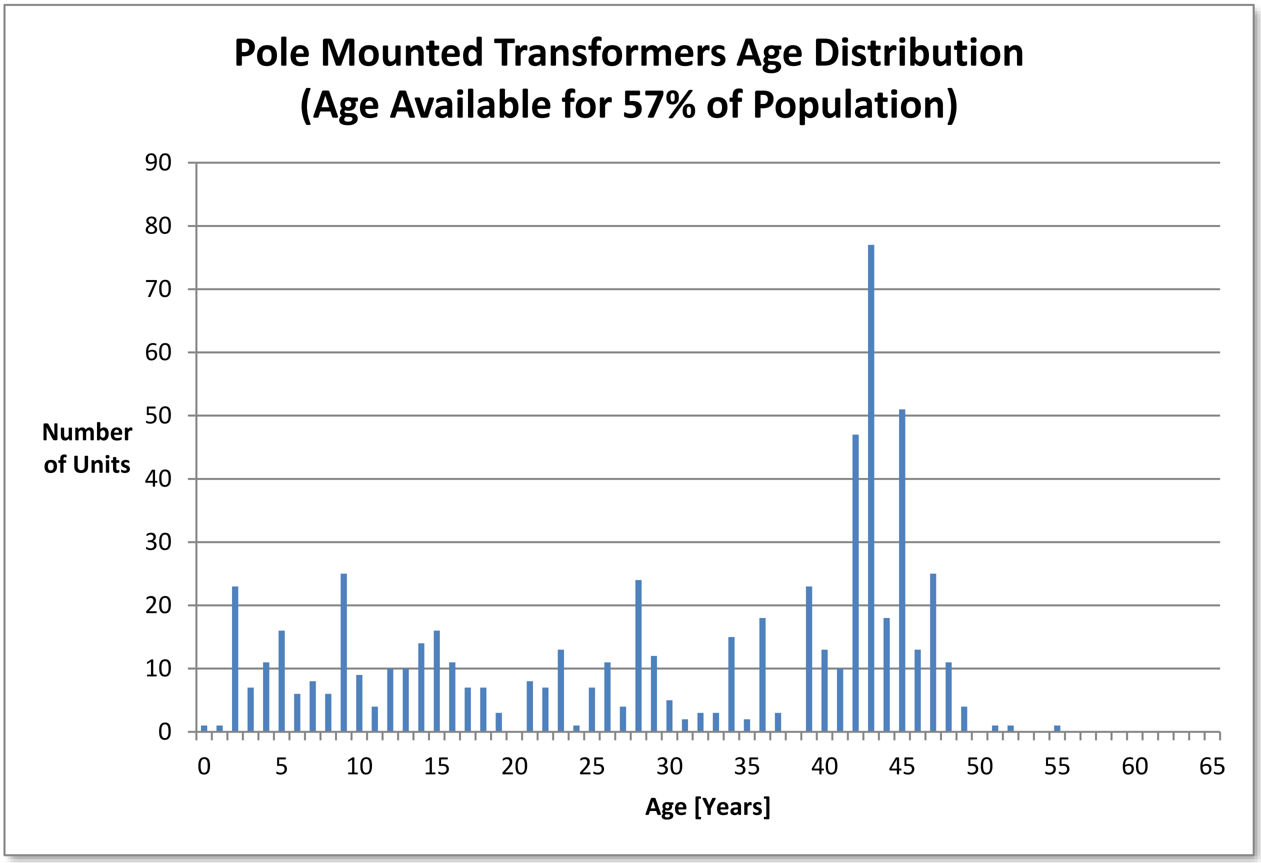

Figure A 3-1 Pole Mounted Transformers Age Distribution

3.1 Health Index

3.1.1 Health Index Formula

HI is a function of scores and weights of condition and sub-condition parameters and is calculated using Equation 1 and Equation 2 described in Section 2.1. This section defines the condition and sub-condition parameters, as well as criteria.

Table A 3-1 Pole Mounted Transformers Health Index Formula

Condition Parameter (CP)		Sub-Condition Parameter (SCP)			
Description	**Weight (WCP)**	**Description**	**Data Source**	**Weight (WSCP)**	**Criteria**
Main Tank	1	Corrosion	Inspections	3	Table A 3-2
		Oil Leak	Inspections	5	Table A 3-2
Primary Termination	0*	Termination Condition	Inspections	0*	NA
Secondary Termination	0*	Termination Condition	Inspections	0*	NA
Service Record	0*	Loading	Loading Data	0*	NA
Derating Multiplier (DR)		Based on PCB, Overall Hazard, and IR Scan			Equation A 3-1
Age Limiter (AL)		Based on typical life curve			Figure A 3-2
*where there is no available data for any assets, the weight of the parameter is set to 0					
NA = not applicable					

<u>Inspections Records</u>

Table A 3-2 Inspection Criteria

Score	Condition Description			
4	Excellent working condition	No apparent issues	Good	OK
3	Minor wear, working as required	Mild severity		
2	Wear or failed, repaired during inspection, regular monitoring required	Medium severity	Fair	
1	Major wear or failed, repaired during inspection	Severe		
0	Immediate replacement or emergency repair required	Very severe	Poor	Not OK

De-Rating Multiplier

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

$$DR = \min(DR_1, DR_2, DR_3)$$

Equation A 3-1

Where DR_1, DR_2, and DR_3 are as follows:

DR_1: IR Scan

Table A 3-3 De-Rating Multiplier IR Scan

De-Rating Multiplier	Description
0.9	Possible deficiency; warrants investigation.
0.8	Indicates probable deficiency; repair as time permits.
0.7	Monitor until corrective measures can be accomplished.
0.5	Major discrepancy; repair immediately.

DR_2: Overall Hazard Assessment

Table A 3-4 De-Rating Multiplier Overall Hazard

De-Rating Multiplier	Description
1	Good
0.5	Average
0	Poor

DR_3: PCB Content

Table A 3-5 De-Rating Multiplier PCB Content

De-Rating Multiplier	PCB Content (PPM)
1	0-50
0.25	> 50

Age Limiter

The Age Limiter used is equivalent to the survival function of the asset group, as described in Equation 5. It was assumed that the likelihood of removal at 40 years is 20% and that at 60 years the likelihood of removal is 95%. The resultant survival curve (1 – likelihood of removals) is shown in below. This survival curve was used as the Age Limiter.

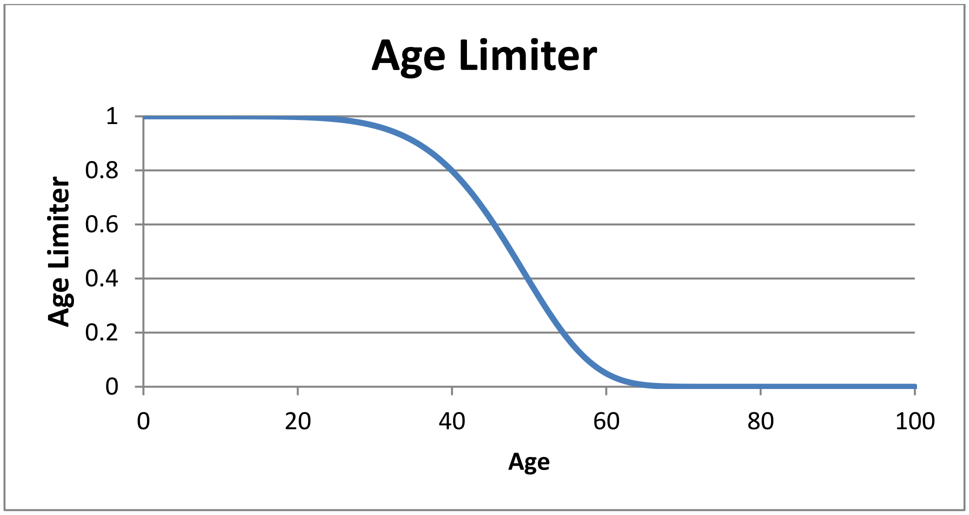

Figure A 3-2 Pole Mounted Transformers Age Limiter

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3.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. Approximately 19% of the sample size was found to be in poor/very poor condition. The average HI for the asset group was 76.2%.

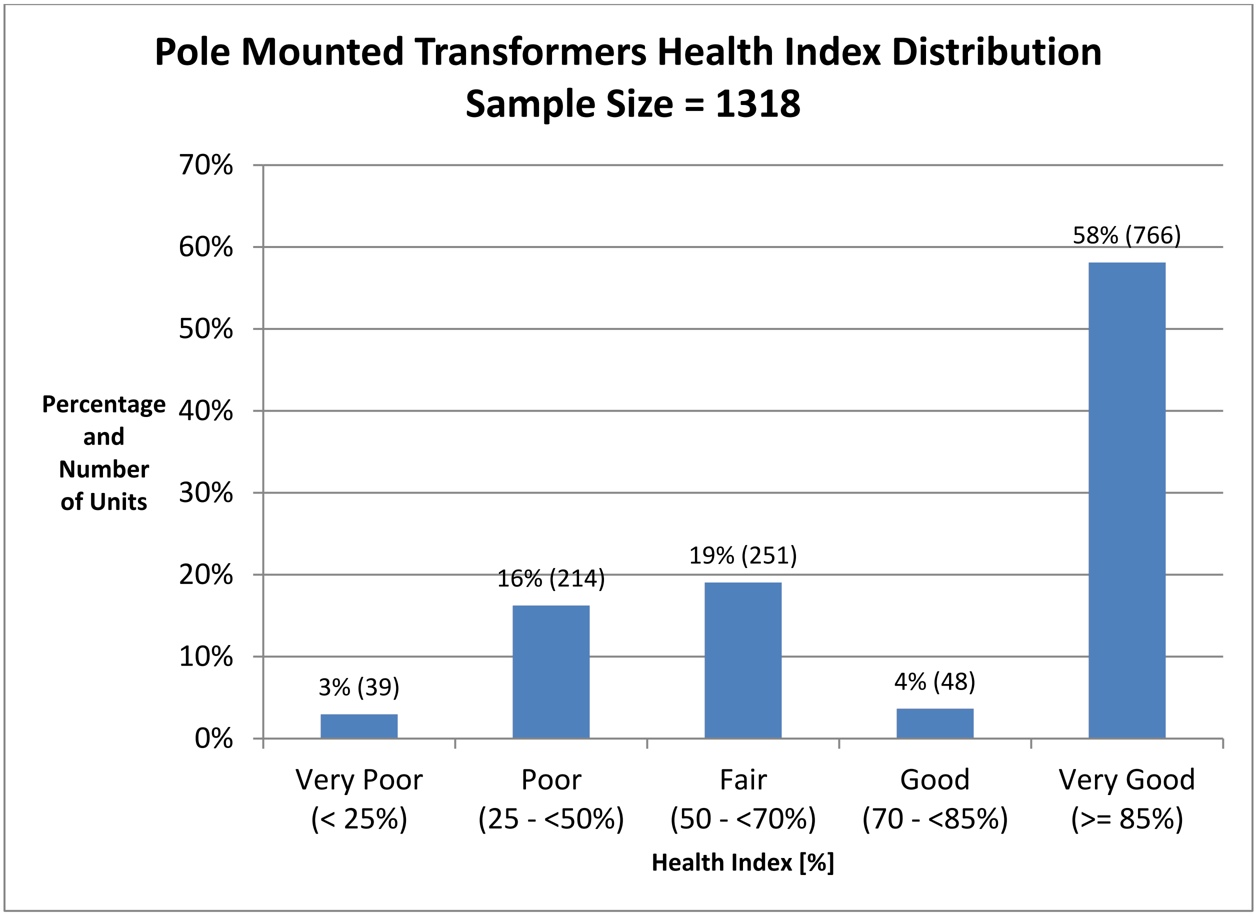

Figure A 3-3 Pole Mounted Transformers Health Index Distribution

3.2 Flagged for Action Plan

The flagged for action plan, which was derived using the life curve method in Section 2.2 shows the expected number of assets to be addressed each year. The plan accounts for the entire asset population, i.e. the results from ‘sample size’ (assets with HI) were extrapolated to the population. As it may not always be feasible to address assets per this plan, a ‘levelized’ plan for better pacing of investments is also provided.

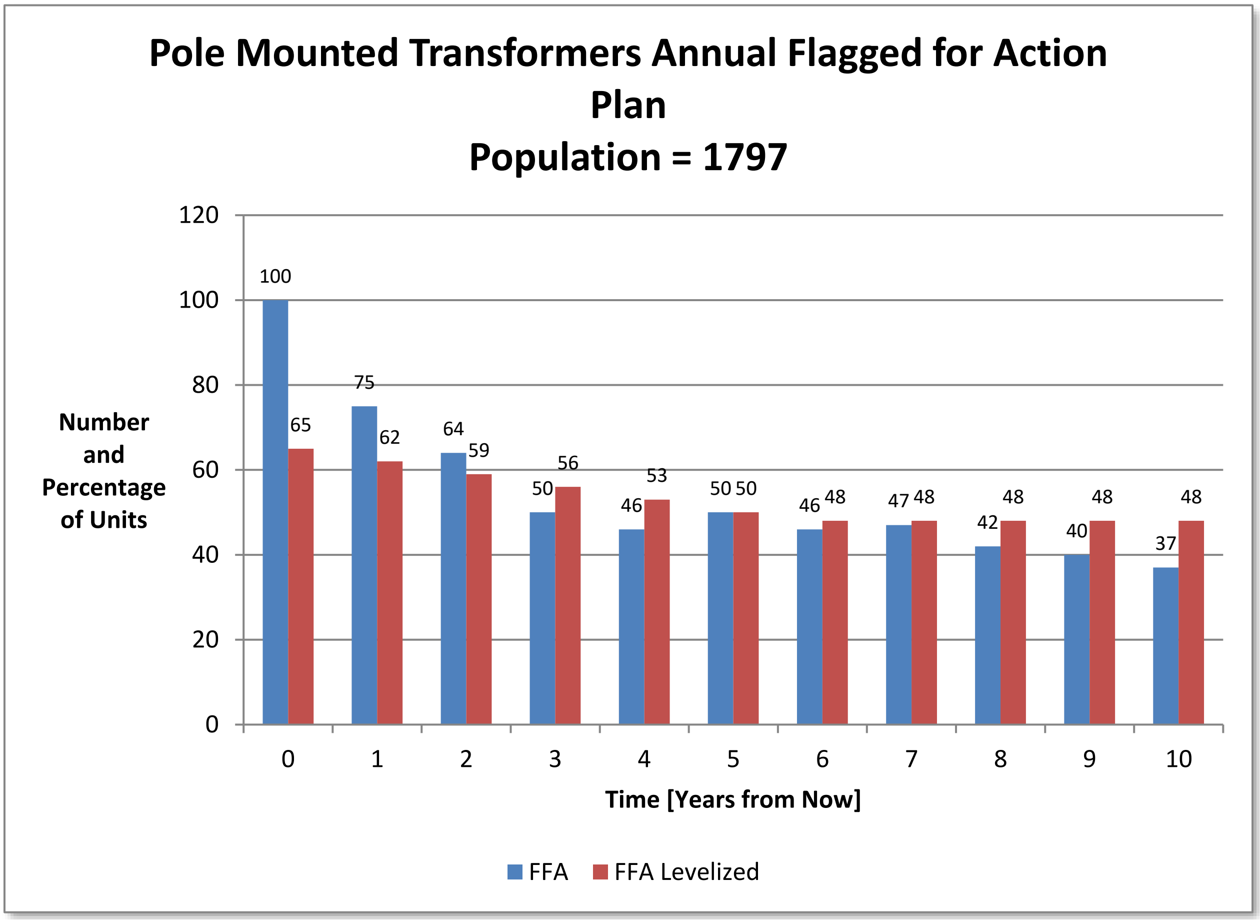

Figure A 3-4 Pole Mounted Transformers Flagged for Action Plan

3.3 Health Index Based Prioritized List

The following table shows the “worst” 100 assets. The results are sorted by lowest to highest HI.

Table A 3-6 Pole Mounted Transformers Risk Based Priortized List

Asset Information					Condition Data DAI	Final HI		HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by ‘Not Available’ (NA).			
#	Asset ID	Region	Year Installed/ Manufactured	Age		HI	HI Category	Main Tank	Primary Cable Termination	Secondary Cable Termination	Service Record
1	0928	MID	1996	24	100%	0.0%	Very Poor	38%	NA	NA	NA
2	0683	MID	1966	54	100%	0.0%	Very Poor	63%	NA	NA	NA
3	0791	MID	2008	12	100%	0.0%	Very Poor	63%	NA	NA	NA
4	2001	MID	1970	50	100%	0.0%	Very Poor	63%	NA	NA	NA
5	0031	MID	1973	47	100%	0.0%	Very Poor	100%	NA	NA	NA
6	2272B	MID	1989	31	100%	0.0%	Very Poor	63%	NA	NA	NA
7	2272R	MID	1989	31	100%	0.0%	Very Poor	63%	NA	NA	NA
8	2272W	MID	1969	51	100%	0.0%	Very Poor	63%	NA	NA	NA
9	1100	MID	1952	68	0%	0.1%	Very Poor		NA	NA	NA
10	1037	NT	1962	58	0%	8.8%	Very Poor		NA	NA	NA
11	1416W	MID	1963	57	100%	11.4%	Very Poor	63%	NA	NA	NA
12	1416B	MID	1963	57	100%	11.4%	Very Poor	63%	NA	NA	NA
13	1416R	MID	1963	57	100%	11.4%	Very Poor	63%	NA	NA	NA
14	0585	MID	1963	57	100%	11.4%	Very Poor	100%	NA	NA	NA
15	0012B	MID	1963	57	100%	11.4%	Very Poor	100%	NA	NA	NA
16	1113	MID	1964	56	0%	14.4%	Very Poor		NA	NA	NA
17	0912	MID	1964	56	100%	14.4%	Very Poor	63%	NA	NA	NA
18	1086	MID	1964	56	100%	14.4%	Very Poor	100%	NA	NA	NA
19	0656	MID	1964	56	100%	14.4%	Very Poor	100%	NA	NA	NA
20	1560	MID	1964	56	100%	14.4%	Very Poor	100%	NA	NA	NA
21	1599	MID	1964	56	100%	14.4%	Very Poor	100%	NA	NA	NA
22	0530R	MID	1964	56	100%	14.4%	Very Poor	100%	NA	NA	NA
23	0530W	MID	1964	56	100%	14.4%	Very Poor	100%	NA	NA	NA
24	0530B	MID	1964	56	100%	14.4%	Very Poor	100%	NA	NA	NA
25	2438	MID	1979	41	100%	15.6%	Very Poor	63%	NA	NA	NA
26	1052R	MID	1970	50	100%	15.6%	Very Poor	63%	NA	NA	NA
27	1257	NT	1965	55	0%	17.8%	Very Poor		NA	NA	NA
28	1419	MID	1974	46	100%	18.8%	Very Poor	38%	NA	NA	NA
29	2148	NT	1966	54	0%	21.5%	Very Poor		NA	NA	NA
30	0584R	MID	1966	54	100%	21.5%	Very Poor	63%	NA	NA	NA
31	0584W	MID	1966	54	100%	21.5%	Very Poor	63%	NA	NA	NA
32	0584B	MID	1966	54	100%	21.5%	Very Poor	63%	NA	NA	NA
33	1081	MID	1966	54	100%	21.5%	Very Poor	100%	NA	NA	NA

Asset Information					Condition Data DAI	Final HI			HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).			
#	Asset ID	Region	Year Installed/ Manufactured	Age		HI	HI Category		Main Tank	Primary Cable Termination	Secondary Cable Termination	Service Record
34	0776	MID	1966	54	100%	21.5%	Very Poor		100%	NA	NA	NA
35	1210	MID	1966	54	100%	21.5%	Very Poor		100%	NA	NA	NA
36	1418	MID	1966	54	100%	21.5%	Very Poor		100%	NA	NA	NA
37	7201	MID	1966	54	100%	21.5%	Very Poor		100%	NA	NA	NA
38	3275	MID	1966	54	100%	21.5%	Very Poor		100%	NA	NA	NA
39	1454	MID	1966	54	100%	21.5%	Very Poor		100%	NA	NA	NA
40	7202	MID	1974	46	100%	25.0%	Poor		100%	NA	NA	NA
41	3724	MID	1989	31	100%	25.0%	Poor		100%	NA	NA	NA
42	5321	MID	1979	41	100%	25.0%	Poor		100%	NA	NA	NA
43	4604	MID	1989	31	100%	25.0%	Poor		100%	NA	NA	NA
44	0405	MID	1998	22	100%	25.0%	Poor		100%	NA	NA	NA
45	3517	MID	1974	46	100%	25.0%	Poor		100%	NA	NA	NA
46	0193B	MID	1975	45	100%	25.0%	Poor		100%	NA	NA	NA
47	0003	MID	1967	53	0%	25.6%	Poor			NA	NA	NA
48	0900	MID	1967	53	0%	25.6%	Poor			NA	NA	NA
49	0948	MID	1967	53	0%	25.6%	Poor			NA	NA	NA
50	0023	MID	1967	53	0%	25.6%	Poor			NA	NA	NA
51	1060	MID	1967	53	0%	25.6%	Poor			NA	NA	NA
52	0949	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
53	3898	MID	1967	53	100%	25.6%	Poor		63%	NA	NA	NA
54	0966	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
55	0183	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
56	0665	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
57	0297	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
58	0985	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
59	1080R	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
60	1080W	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
61	1080B	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
62	0463W	MID	1967	53	100%	25.6%	Poor		100%	NA	NA	NA
63	1244	NT	1968	52	0%	29.9%	Poor			NA	NA	NA
64	1694	NT	1968	52	0%	29.9%	Poor			NA	NA	NA
65	242	NT	1968	52	0%	29.9%	Poor			NA	NA	NA
66	614	NT	1968	52	0%	29.9%	Poor			NA	NA	NA
67	0910	MID	1996	24	100%	31.3%	Poor		63%	NA	NA	NA
68	0891	MID	1990	30	100%	31.3%	Poor		63%	NA	NA	NA
69	0950	MID	1987	33	100%	31.3%	Poor		63%	NA	NA	NA
70	0578	MID	1974	46	100%	31.3%	Poor		63%	NA	NA	NA
71	0577	MID	1987	33	100%	31.3%	Poor		63%	NA	NA	NA
72	0945	MID	1970	50	100%	31.3%	Poor		63%	NA	NA	NA

Asset Information					Condition Data DAI	Final HI		HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).			
#	Asset ID	Region	Year Installed/ Manufactured	Age		HI	HI Category	Main Tank	Primary Cable Termination	Secondary Cable Termination	Service Record
73	0720	MID	1970	50	100%	31.3%	Poor	63%	NA	NA	NA
74	0719	MID	1998	22	100%	31.3%	Poor	63%	NA	NA	NA
75	0252	MID	1998	22	100%	31.3%	Poor	63%	NA	NA	NA
76	0288	MID	1970	50	100%	31.3%	Poor	63%	NA	NA	NA
77	0385	MID	1996	24	100%	31.3%	Poor	63%	NA	NA	NA
78	0122	MID	1998	22	100%	31.3%	Poor	63%	NA	NA	NA
79	0173	MID	2008	12	100%	31.3%	Poor	63%	NA	NA	NA
80	0170W	MID	2011	9	100%	31.3%	Poor	63%	NA	NA	NA
81	0170B	MID	2011	9	100%	31.3%	Poor	63%	NA	NA	NA
82	0170R	MID	2011	9	100%	31.3%	Poor	63%	NA	NA	NA
83	1039	MID	1995	25	100%	31.3%	Poor	63%	NA	NA	NA
84	2779	MID	1976	44	100%	31.3%	Poor	63%	NA	NA	NA
85	1650	MID	2007	13	100%	31.3%	Poor	63%	NA	NA	NA
86	0890	MID	1998	22	100%	31.3%	Poor	63%	NA	NA	NA
87	0572	MID	1987	33	100%	31.3%	Poor	63%	NA	NA	NA
88	0567R	MID	1989	31	100%	31.3%	Poor	63%	NA	NA	NA
89	0567W	MID	1969	51	100%	31.3%	Poor	63%	NA	NA	NA
90	0567B	MID	1969	51	100%	31.3%	Poor	63%	NA	NA	NA
91	2395W	MID	1987	33	100%	31.3%	Poor	63%	NA	NA	NA
92	2395B	MID	1987	33	100%	31.3%	Poor	63%	NA	NA	NA
93	2395R	MID	1987	33	100%	31.3%	Poor	63%	NA	NA	NA
94	0194W	MID	2011	9	100%	31.3%	Poor	63%	NA	NA	NA
95	0194B	MID	2011	9	100%	31.3%	Poor	63%	NA	NA	NA
96	0194R	MID	2011	9	100%	31.3%	Poor	63%	NA	NA	NA
97	0773W	MID	1976	44	100%	31.3%	Poor	63%	NA	NA	NA
98	0773B	MID	1976	44	100%	31.3%	Poor	63%	NA	NA	NA
99	0773R	MID	1976	44	100%	31.3%	Poor	63%	NA	NA	NA
100	0020W	MID	1974	46	100%	31.3%	Poor	63%	NA	NA	NA

3.4 Data Assessment

The only available data for pole mounted transformers was age and inspections. However, inspections were only available for units in Midland. Problematic infrared scan, overall condition inspection assessment, and PCB content were used as a de-rating multiple.

Since inspections was available for Midland, the average DAI 33%.

Asset Category	Population	Average DAI
Pole Mounted Transformers	1797	33%

Table A 3-7 Pole Mounted Transformers Data Gaps

Data Gap	Priority	Description	Source
Connections	H	Terminations	Visual inspection, IR scans
Loading	H	Loading history	Operations records

4. Pad Mounted Transformers

There are 4428 Pad Mounted Transformers at NTPDL. Of these, 4187 had sufficient data for assessment. The average age of the population is 23 years; age distribution is as follows:

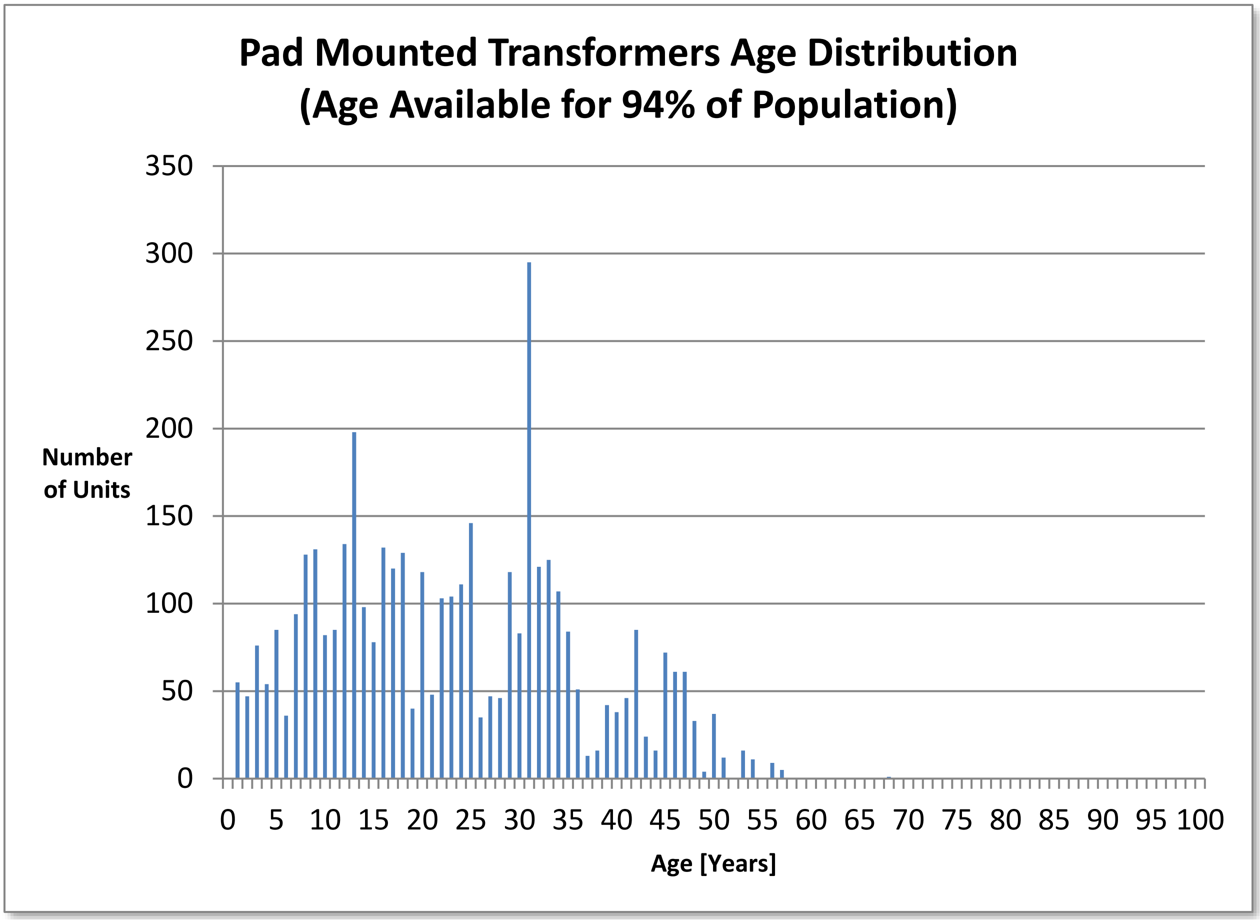

Figure A 4-1 Pad Mounted Transformers Age Distribution

4.1 Health Index

4.1.1 Health Index Formula

HI is a function of scores and weights of condition and sub-condition parameters and is calculated using Equation 1 and Equation 2 described in Section 2.1. This section defines the condition and sub-condition parameters, as well as criteria.

Table A 4-1 Pad Mounted Transformers Health Index Formula

Condition Parameter (CP)		Sub-Condition Parameter (SCP)			
Description	**Weight (WCP)**	**Description**	**Data Source**	**Weight (WSCP)**	**Criteria**
Main Tank	5	Corrosion	Inspections	3	Table A 4-2
		Oil leak	Inspections	5	Table A 4-2
		Paint	Inspections	3	Table A 4-2
		Skirt	Inspections	1	Table A 4-2
Door Mechanism	1	Locks	Inspections	1	Table A 4-2
		Handles	Inspections	0*	NA
		Hinges	Inspections	1	Table A 4-2
		Latches	Inspections	0*	NA
Insulation	3	Barriers	Inspections	1	NA
		Insulators	Inspections	1	NA
Primary Termination	0*	Termination Condition	Inspections	0*	NA
Secondary Termination	0*	Termination Condition	Inspections	0*	NA
Base and Surroundings	2	Base / Foundation	Inspections	1	Table A 4-2
		Grade Change	Inspections	0*	Table A 4-2
		Placement	Inspections	0*	Table A 4-2
		Grounding	Inspections	0*	Table A 4-2
		Access	Inspections	0*	Table A 4-2
Service Record	0*	Loading	Loading Data	0*	NA
Derating Multiplier (DR)		Based on PCB, Overall Hazard, and IR Scan			Equation A 4-1
Age Limiter (AL)		Based on typical life curve			Figure A 4-2
*where there is no available data for any assets, the weight of the parameter is set to 0					
NA = not applicable					

Inspections Records

Table A 4-2 Inspection Criteria

Score	Condition Description			
4	Excellent working condition	No apparent issues	Good	OK
3	Minor wear, working as required	Mild severity		
2	Wear or failed, repaired during inspection, regular monitoring required	Medium severity	Fair	
1	Major wear or failed, repaired during inspection	Severe		
0	Immediate replacement or emergency repair required	Very severe	Poor	Not OK

De-Rating Multiplier

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

$$DR = \min\left(DR_1, DR_2, DR_3\right)$$

Equation A 4-1

Where DR_1, DR_2, and DR_3 are as follows:

DR_1: IR Scan

Table A 4-3 De-Rating Multiplier IR Scan

De-Rating Multiplier	Description
0.9	Possible deficiency; warrants investigation.
0.8	Indicates probable deficiency; repair as time permits.
0.7	Monitor until corrective measures can be accomplished.
0.5	Major discrepancy; repair immediately.

DR_2: Overall Hazard Assessment

Table A 4-4 De-Rating Multiplier Overall Hazard

De-Rating Multiplier	Description
1	Good
0.5	Average
0	Poor

DR_3: PCB Content

Table A 4-5 De-Rating Multiplier PCB Content

De-Rating Multiplier	PCB Content (PPM)
1	0-50
0.25	> 50

Age Limiter

The Age Limiter used is equivalent to the survival function of the asset group, as described in Equation 5. It was assumed that the likelihood of removal at 40 years is 20% and that at 50 years the likelihood of removal is 95%. The resultant survival curve (1 – likelihood of removals) is shown in below. This survival curve was used as the Age Limiter.

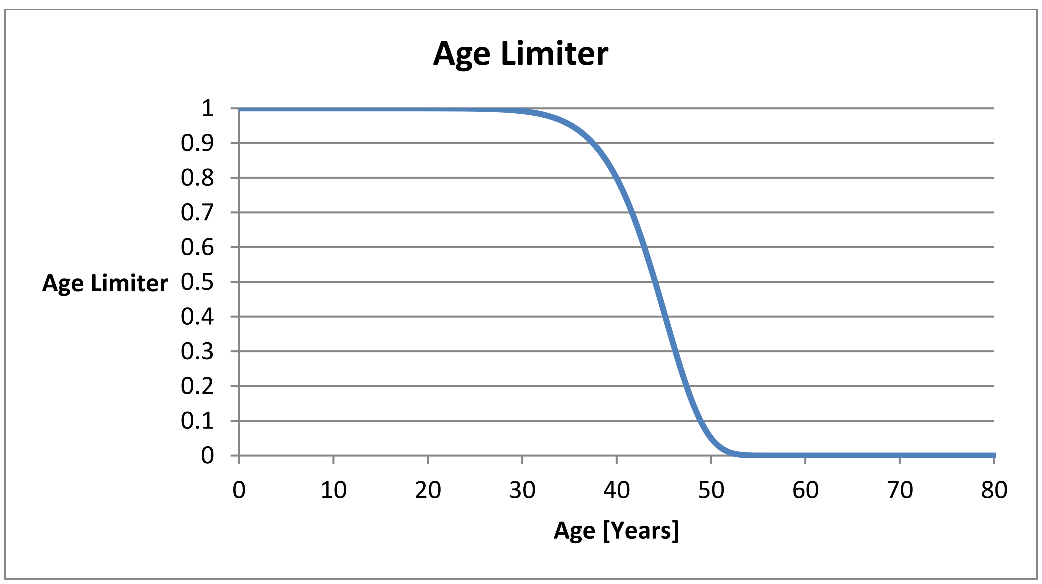

Figure A 4-2 Pad Mounted Transformers Age Limiter

4.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. Nearly 11% of the sample size was found to be in poor/very poor condition. The average HI for the asset group was 85.9%.

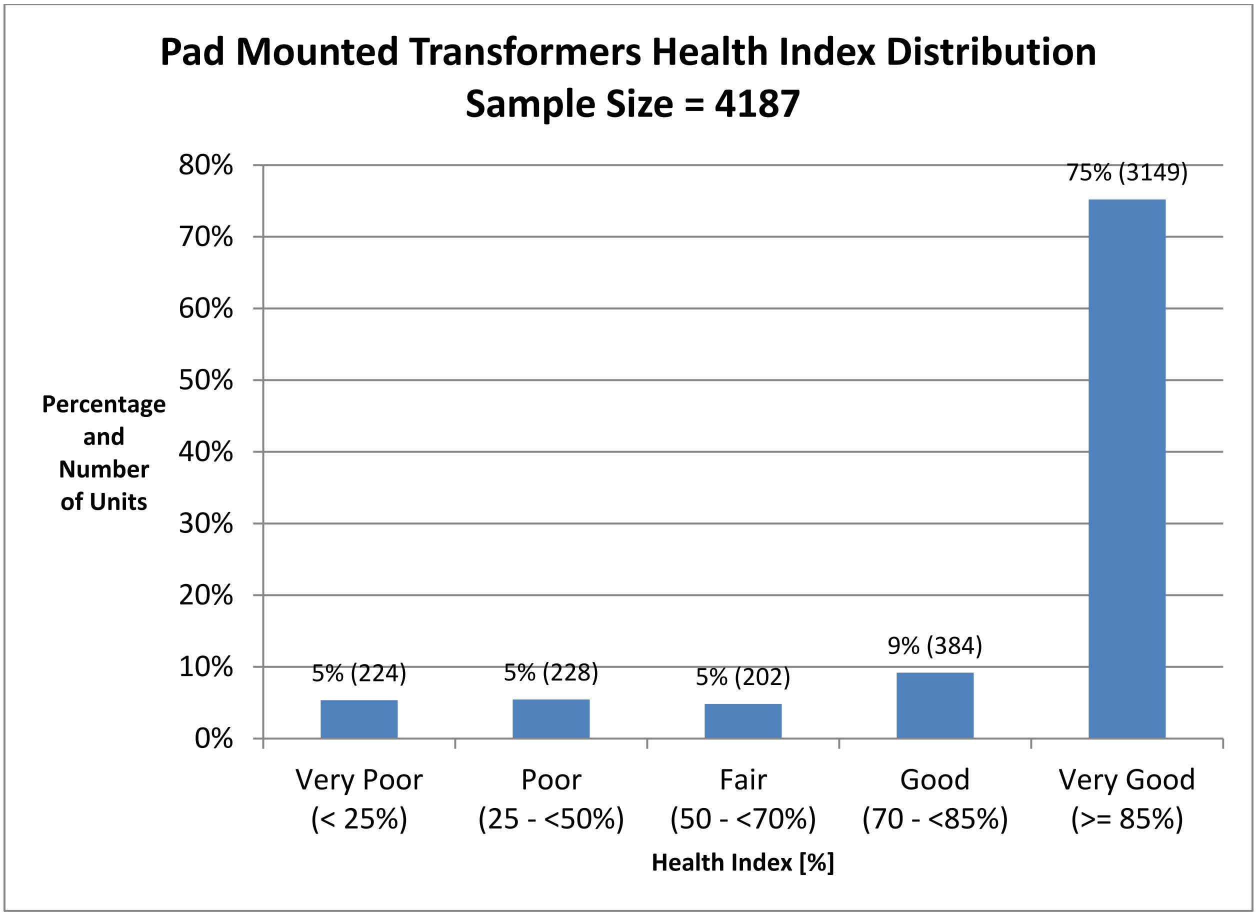

Figure A 4-3 Pad Mounted Transformers Health Index Distribution

4.2 Flagged for Action Plan

The flagged for action plan, which was derived using the life curve method in Section 2.2 shows the expected number of assets to be addressed each year. The plan accounts for the entire asset population, i.e. the results from 'sample size' (assets with HI) were extrapolated to the population. As it may not always be feasible to address assets per this plan, a 'levelized' plan for better pacing of investments is also provided.

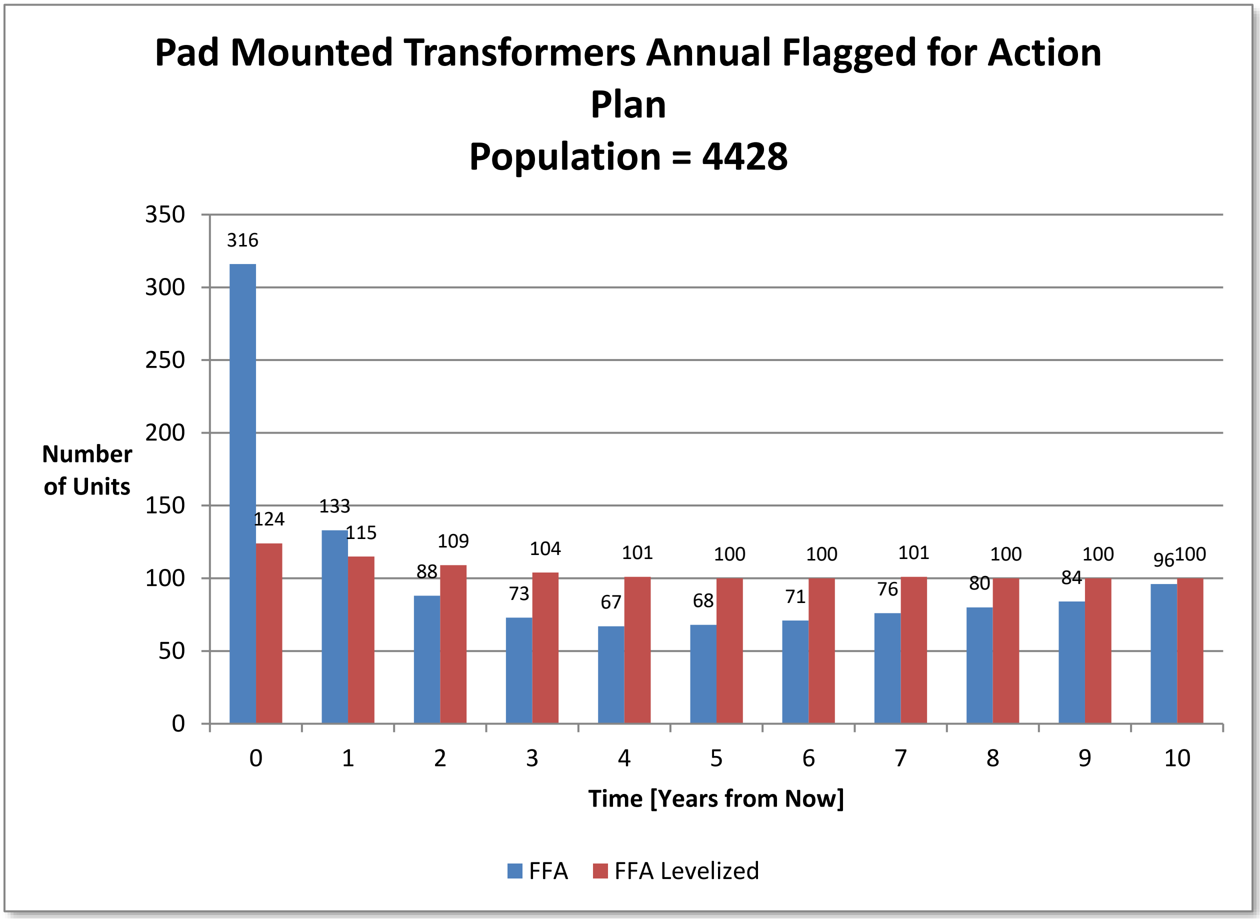

Figure A 4-4 Pad Mounted Transformers Flagged for Action Plan

4.3 Health Index Based Prioritized List

The following table shows the “worst” 100 assets. The results are sorted by lowest to highest HI.

Table A 4-6 Pad Mounted Transformers Risk Based Priortized List

Asset Information					Final HI		HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by ‘Not Available’ (NA).						
#	Asset ID	Location	Install / Manuf Date	Age	HI	HI Category	Main Tank	Door Mechanism	Insulation	Primary Cable Termination	Service Record	Environment	Service Record
1	1016B	MID	1973	47	0.0%	Very Poor	0%	0%	NA	NA	NA	NA	NA
2	0811W	MID	1986	34	0.0%	Very Poor	0%	0%	NA	NA	NA	NA	NA
3	0947W	MID	1990	30	0.0%	Very Poor	0%	100%	NA	NA	NA	NA	NA
4	0904R	MID	1990	30	0.0%	Very Poor	0%	100%	NA	NA	NA	NA	NA
5	2517	NT	1997	23	0.0%	Very Poor	0%	0%	NA	NA	NA	NA	NA
6	1021W	MID	1997	23	0.0%	Very Poor	0%	100%	NA	NA	NA	NA	NA
7	0172B	MID	1987	33	0.0%	Very Poor	39%	100%	NA	NA	NA	NA	NA
8	0082	MID	1990	30	0.0%	Very Poor	39%		NA	NA	NA	NA	NA
9	0928	MID	1996	24	0.0%	Very Poor	39%		NA	NA	NA	NA	NA
10	0683	MID	1966	54	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
11	2272W	MID	1969	51	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
12	2001	MID	1970	50	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
13	1025W	MID	1973	47	0.0%	Very Poor	61%	0%	NA	NA	NA	NA	NA
14	2272B	MID	1989	31	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
15	2272R	MID	1989	31	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
16	0791	MID	2008	12	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
17	0031	MID	1973	47	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
18	1100	MID	1952	68	0.0%	Very Poor			NA	NA	NA	NA	NA
19	1416W	MID	1963	57	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
20	1416B	MID	1963	57	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
21	1416R	MID	1963	57	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
22	0585	MID	1963	57	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
23	0012B	MID	1963	57	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
24	0912	MID	1964	56	0.0%	Very Poor	61%		NA	NA	NA	NA	NA
25	1560	MID	1964	56	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
26	1599	MID	1964	56	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
27	0656	MID	1964	56	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
28	1086	MID	1964	56	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
29	0530R	MID	1964	56	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
30	0530W	MID	1964	56	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
31	0530B	MID	1964	56	0.0%	Very Poor	100%		NA	NA	NA	NA	NA
32	1113	MID	1964	56	0.0%	Very Poor			NA	NA	NA	NA	NA
33	0584R	MID	1966	54	0.1%	Very Poor	61%		NA	NA	NA	NA	NA

Asset Information					Final HI			HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).						
#	Asset ID	Location	Install / Manuf Date	Age	HI	HI Category		Main Tank	Door Mechanism	Insulation	Primary Cable Termination	Service Record	Environment	Service Record
34	0584W	MID	1966	54	0.1%	Very Poor		61%		NA	NA	NA	NA	NA
35	0584B	MID	1966	54	0.1%	Very Poor		61%		NA	NA	NA	NA	NA
36	3275	MID	1966	54	0.1%	Very Poor		100%		NA	NA	NA	NA	NA
37	7201	MID	1966	54	0.1%	Very Poor		100%		NA	NA	NA	NA	NA
38	1081	MID	1966	54	0.1%	Very Poor		100%		NA	NA	NA	NA	NA
39	0776	MID	1966	54	0.1%	Very Poor		100%		NA	NA	NA	NA	NA
40	1210	MID	1966	54	0.1%	Very Poor		100%		NA	NA	NA	NA	NA
41	1454	MID	1966	54	0.1%	Very Poor		100%		NA	NA	NA	NA	NA
42	1418	MID	1966	54	0.1%	Very Poor		100%		NA	NA	NA	NA	NA
43	3898	MID	1967	53	0.3%	Very Poor		61%		NA	NA	NA	NA	NA
44	0297	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
45	0985	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
46	1080R	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
47	0183	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
48	0665	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
49	0463W	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
50	0949	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
51	0966	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
52	1080W	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
53	1080B	MID	1967	53	0.3%	Very Poor		100%		NA	NA	NA	NA	NA
54	0023	MID	1967	53	0.3%	Very Poor				NA	NA	NA	NA	NA
55	0900	MID	1967	53	0.3%	Very Poor				NA	NA	NA	NA	NA
56	0948	MID	1967	53	0.3%	Very Poor				NA	NA	NA	NA	NA
57	0003	MID	1967	53	0.3%	Very Poor				NA	NA	NA	NA	NA
58	1060	MID	1967	53	0.3%	Very Poor				NA	NA	NA	NA	NA
59	0582R	MID	1969	51	2.3%	Very Poor		61%		NA	NA	NA	NA	NA
60	0567W	MID	1969	51	2.3%	Very Poor		61%		NA	NA	NA	NA	NA
61	0567B	MID	1969	51	2.3%	Very Poor		61%		NA	NA	NA	NA	NA
62	0126B	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
63	0427B	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
64	0742	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
65	1051	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
66	5539	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
67	1003	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
68	0126R	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
69	0622B	MID	1969	51	2.3%	Very Poor		100%		NA	NA	NA	NA	NA
70	0288	MID	1970	50	5.0%	Very Poor		61%		NA	NA	NA	NA	NA
71	0720	MID	1970	50	5.0%	Very Poor		61%		NA	NA	NA	NA	NA
72	0945	MID	1970	50	5.0%	Very Poor		61%		NA	NA	NA	NA	NA

Asset Information					Final HI			HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).						
#	Asset ID	Location	Install / Manuf Date	Age	HI	HI Category		Main Tank	Door Mechanism	Insulation	Primary Cable Termination	Service Record	Environment	Service Record
73	1052R	MID	1970	50	5.0%	Very Poor		61%		NA	NA	NA	NA	NA
74	1052W	MID	1970	50	5.0%	Very Poor		61%		NA	NA	NA	NA	NA
75	1052B	MID	1970	50	5.0%	Very Poor		61%		NA	NA	NA	NA	NA
76	106	NT	1970	50	5.0%	Very Poor		88%	100%	NA	NA	NA	NA	NA
77	0237	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
78	0301	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
79	0700	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
80	0019	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
81	0126W	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
82	1124	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
83	0812	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
84	0667	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
85	0673	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
86	0638	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
87	0694	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
88	0954	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
89	0220	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
90	1027	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
91	0348	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
92	3838	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
93	1068R	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
94	0712	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
95	0929	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
96	0940	MID	1970	50	5.0%	Very Poor		100%		NA	NA	NA	NA	NA
97	120	NT	1970	50	5.0%	Very Poor				NA	NA	NA	NA	NA
98	121	NT	1970	50	5.0%	Very Poor				NA	NA	NA	NA	NA
99	0380	MID	1970	50	5.0%	Very Poor				NA	NA	NA	NA	NA
100	0029	MID	1970	50	5.0%	Very Poor				NA	NA	NA	NA	NA

4.4 Data Assessment

Age and inspection records were available for pad mounted transformers. Many transformers had some inspection and/or age, so the DAI was 56%. The important data gaps are information about connections and insulation and loading. It is recommended that inspections be conducted and collected for all units to increase the DAI.

Asset Category	Population	Average DAI
Pad Mounted Transformers	4428	56%

The data gaps for this asset category are as follows:

Table A 4-7 Pad Mounted Transformers Data Gaps

Data Gap	Priority	Description	Source
Door Mechanism	L	Handles, latches	Visual inspection
Insulation	H	Insulators, barrier boards	Visual Inspections
Connections	H	Terminations, elbows, inserts	Visual inspections, IR scans
Base and Surroundings	L	Grade change, poor placement, poor access, poor grounding connection	Visual inspection
Loading	H	Loading history	Operations records

5. Pad Mounted Switchgear

There are 133 Pad Mounted Switchgear at NTPDL. Of these, 130 had sufficient data for assessment. The average age of the population is 19 years; age distribution is as follows:

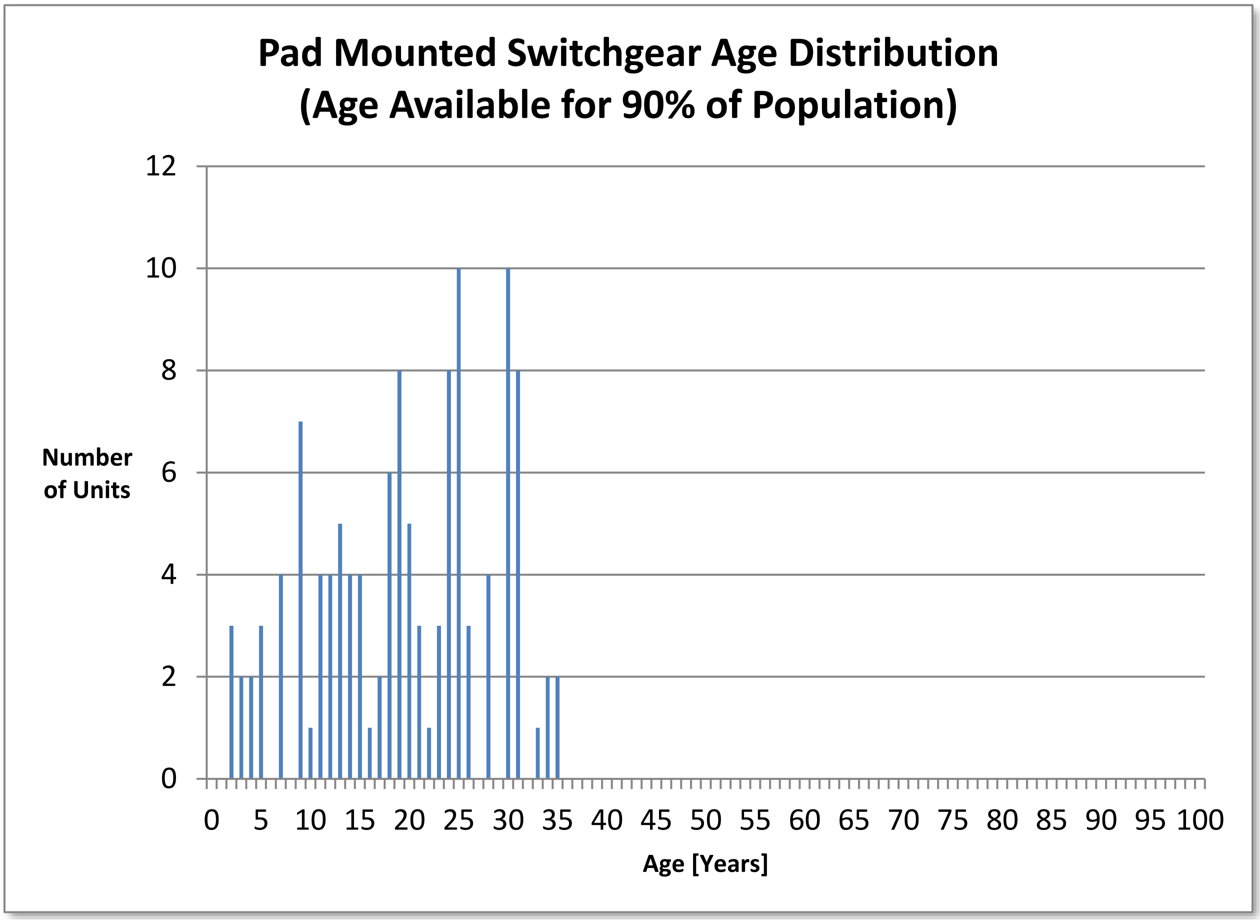

Figure A 5-1 Pad Mounted Switchgear Age Distribution

5.1 Health Index

5.1.1 Health Index Formula

HI is a function of scores and weights of condition and sub-condition parameters and is calculated using Equation 1 and Equation 2 described in Section 2.1. This section defines the condition and sub-condition parameters, as well as criteria.

Table A 5-1 Pad Mounted Switchgear Health Index Formula

Condition Parameter (CP)		Sub-Condition Parameter (SCP)			
Description	**Weight (WCP)**	**Description**	**Data Source**	**Weight (WSCP)**	**Table**
Enclosure	3	Corrosion (Enclosure)	Inspections	1	Table A 5-2
		Door	Inspections	0*	NA
		Paint	Inspections	0*	NA
Inside	5	Inside	Inspections	1	Table A 5-2
Switch / Fuse	0*	Switch	Inspections	0*	NA
		Fuse	Inspections	0*	NA
Insulation	0*	Insulator	Inspections	0*	NA
		Barriers Boards	Inspections	0*	NA
Connections	0*	Termination Condition	Inspections	0*	NA
Base and Surroundings	2	Base / Foundation	Inspections	1	Table A 5-2
		Grade Change	Inspections	0*	NA
		Placement	Inspections	0*	NA
		Grounding	Inspections	0*	NA
		Access	Inspections	0*	NA
HI De-Rating Multiplier (DR)		Hazard Assessment			Table A 5-1
Age Limiter (AL)		Based on typical life curve			Figure A 4-2
*where there is no available data for any assets, the weight of the parameter is set to 0					

Inspections Records

Table A 5-2 Inspection Criteria

Score	Condition Description			
4	Excellent working condition	No apparent issues	Good	OK
3	Minor wear, working as required	Mild severity		
2	Wear or failed, repaired during inspection, regular monitoring required	Medium severity	Fair	
1	Major wear or failed, repaired during inspection	Severe		
0	Immediate replacement or emergency repair required	Very severe	Poor	Not OK

Age Limiter

The Age Limiter used is equivalent to the survival function of the asset group, as described in Equation 5. It was assumed that the likelihood of removal at 30 years is 20% and that at 45 years the likelihood of removal is 95% (i.e. Q(40) = 1-0.8=0.2; Q(60) = 1-0.5=0.95). The resultant survival curve (1 – likelihood of removals) is shown below. This survival curve was used as the Age Limiter.

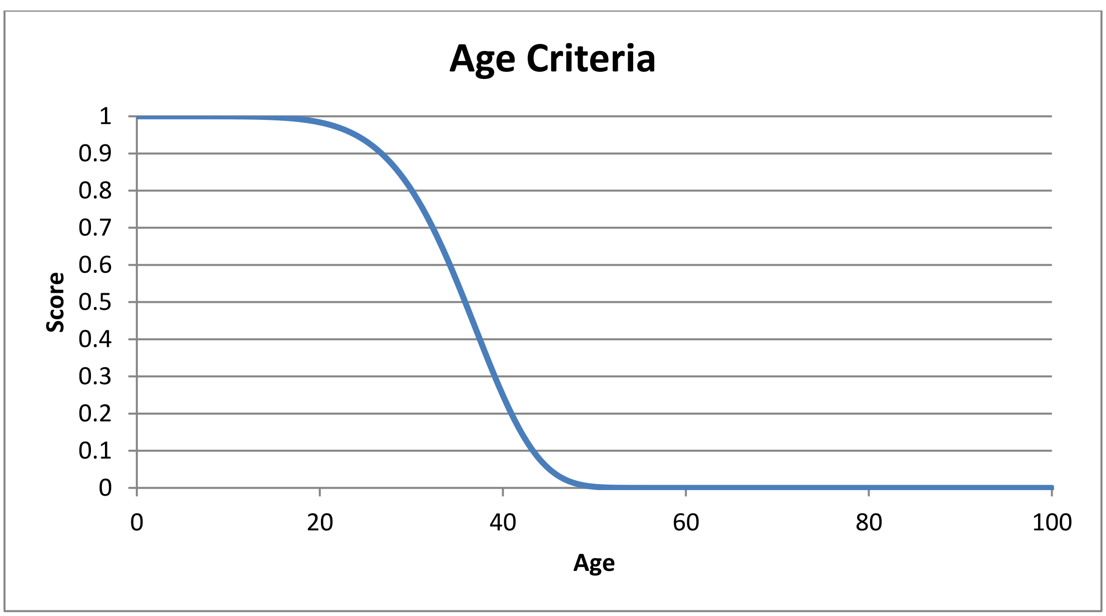

Figure A 5-2 Pad Mounted Switchgear Age Limiter

De-Rating Multiplier

The de-rating is based on NTPDL Overall hazard assessment scan results:

Table A 5-3 Pad Mounted Switchgear De-Rating Multiplier Criteria

De-Rating Multiplier	Overall Hazard Score
1	0
0.9	1
0.75	2
0.5	3
0.25	4

5.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. Fewer than 5% of the sample size was found to be in poor/very poor condition. The average HI for the asset group was 83.3%.

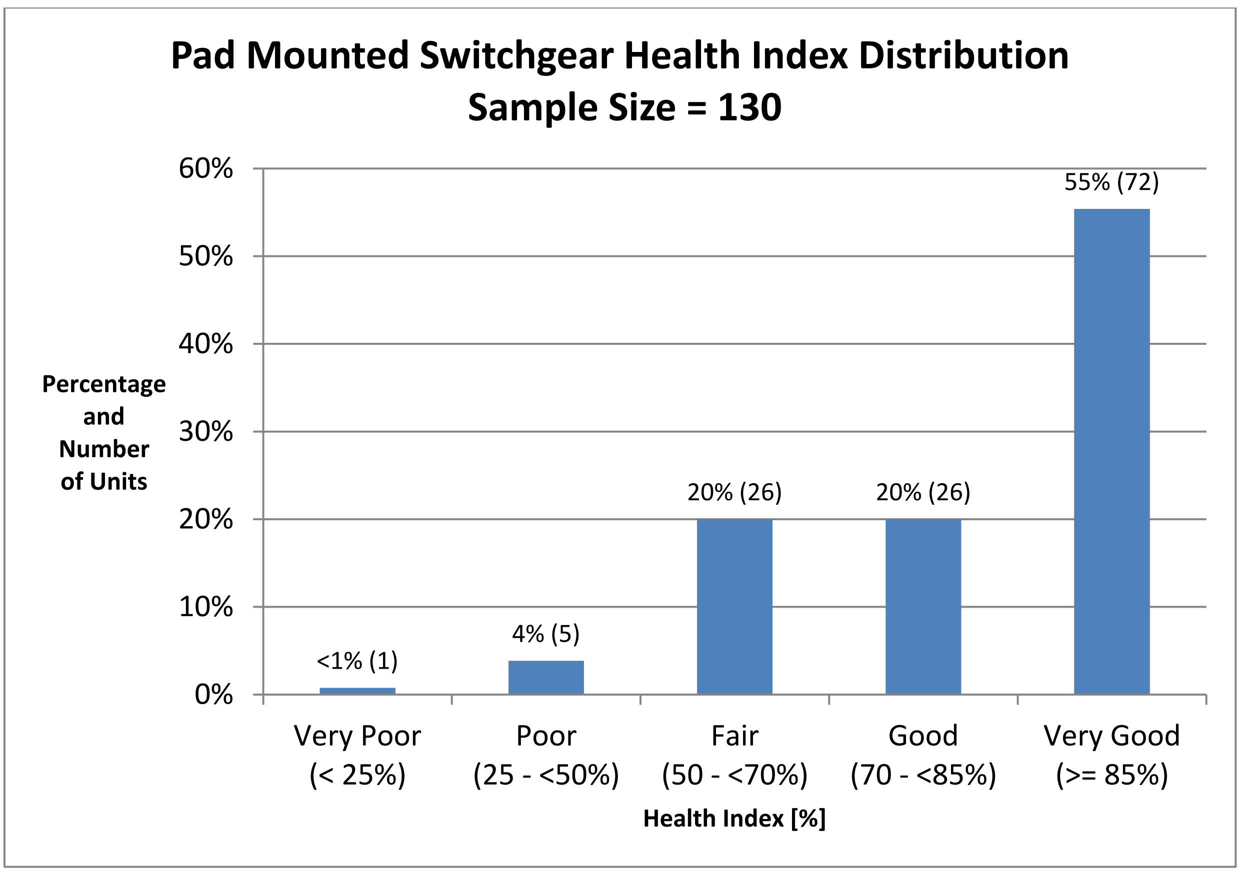

Figure A 5-3 Pad Mounted Switchgear Health Index Distribution

5.2 Flagged for Action Plan

The flagged for action plan, which was derived using the life curve method in Section 2.2 shows the expected number of assets to be addressed each year. The plan accounts for the entire asset population, i.e. the results from 'sample size' (assets with HI) were extrapolated to the population. As it may not always be feasible to address assets per this plan, a 'levelized' plan for better pacing of investments is also provided.

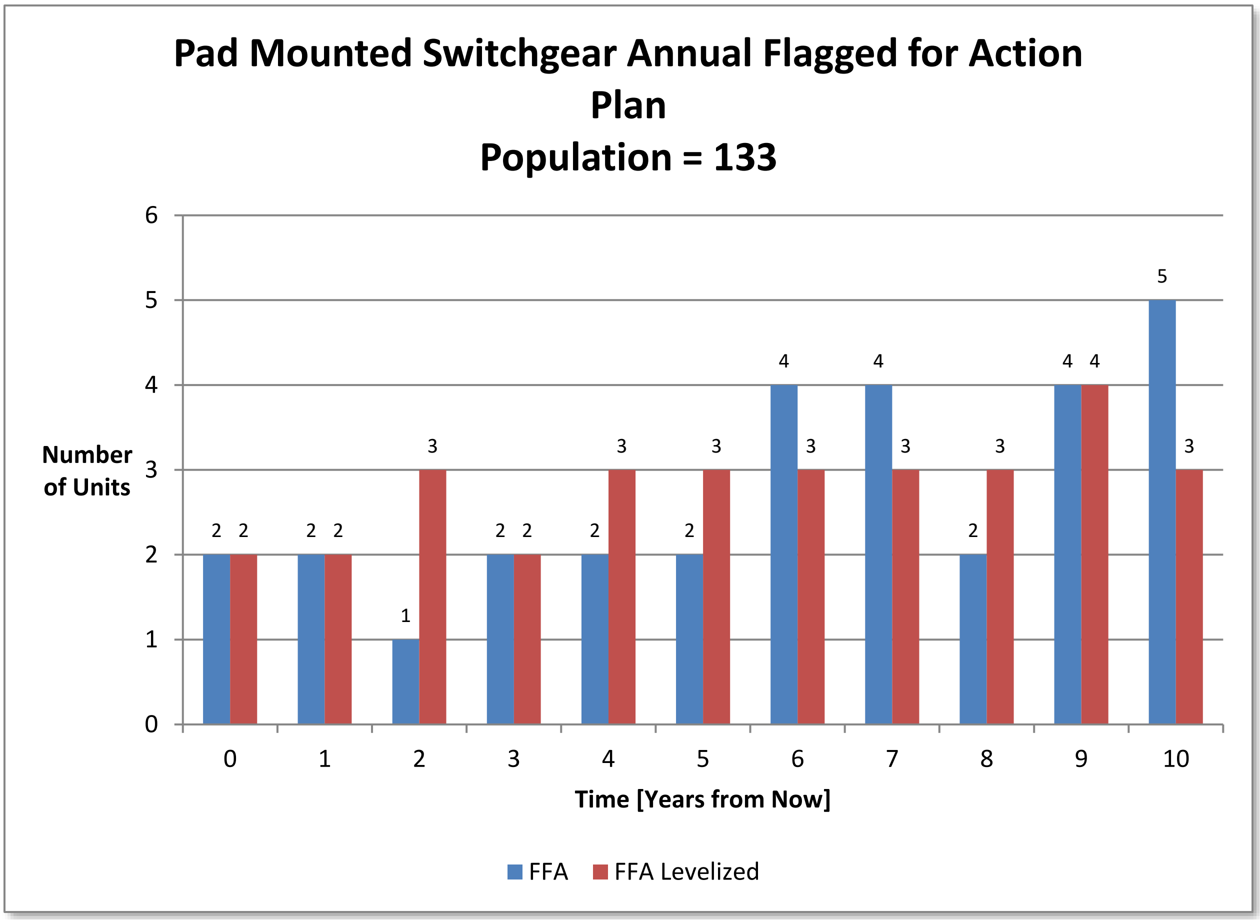

Figure A 5-4 Pad Mounted Switchgear Flagged for Action Plan

5.3 Health Index Based Prioritized List

The following table shows the list of pad mounted switchgear, sorted by lowest to highest HI.

Table A 5-4 Pad Mounted Switchgear Risk Based Priortized List

Asset Information					Condition Data DAI	Final HI			HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).					
#	Asset ID	Location	Install or Manuf Date	Age		HI	HI Category		Enclosure	Inside	Connections	Fuse / Switch	Insulation	Base and Surroundings
1	40	NT	1992	28	100%	20.8%	Very Poor		0%	50%	NA	NA	NA	100%
2	25	NT	1989	31	100%	25.0%	Poor		0%	100%	NA	NA	NA	100%
3	4	NT	1985	35	100%	28.1%	Poor		0%	75%	NA	NA	NA	75%
4	63	NT	1997	23	100%	33.3%	Poor		100%	100%	NA	NA	NA	0%
5	9	NT			100%	37.5%	Poor		0%	100%	NA	NA	NA	100%
6	22	NT	2008	12	100%	37.5%	Poor		50%	100%	NA	NA	NA	100%
7	95	NT	2008	12	100%	50.0%	Fair		50%	50%	NA	NA	NA	50%
8	2	NT	1985	35	100%	55.4%	Fair		100%	100%	NA	NA	NA	100%
9	11	NT	1986	34	100%	56.3%	Fair		75%	75%	NA	NA	NA	75%
10	88	NT			100%	56.3%	Fair		50%	100%	NA	NA	NA	100%
11	14	NT	1989	31	100%	60.0%	Fair		50%	50%	NA	NA	NA	100%
12	10	NT	1986	34	100%	61.2%	Fair		50%	100%	NA	NA	NA	100%
13	79	NT	2001	19	100%	62.5%	Fair		100%	0%	NA	NA	NA	100%
14	5	NT			100%	63.8%	Fair		75%	50%	NA	NA	NA	75%
15	96	NT			100%	63.8%	Fair		75%	50%	NA	NA	NA	75%
16	31	NT	1990	30	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
17	50	NT	1995	25	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
18	52	NT	1995	25	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
19	67	NT	1997	23	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
20	71	NT	2001	19	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
21	72	NT	2002	18	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
22	77	NT	2001	19	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
23	80	NT	1996	24	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
24	81	NT	2002	18	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
25	86	NT			100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
26	93	NT	2005	15	100%	65.6%	Fair		75%	100%	NA	NA	NA	100%
27	3	NT	1987	33	100%	66.7%	Fair		75%	100%	NA	NA	NA	100%
28	36	NT	1990	30	100%	67.5%	Fair		50%	100%	NA	NA	NA	100%
29	47	NT	1995	25	100%	67.5%	Fair		50%	100%	NA	NA	NA	100%
30	107	NT	2007	13	100%	67.5%	Fair		75%	75%	NA	NA	NA	75%
31	45	NT	1990	30	100%	68.8%	Fair		100%	50%	NA	NA	NA	100%
32	60	NT	1996	24	100%	68.8%	Fair		100%	50%	NA	NA	NA	100%
33	18	NT	1996	24	100%	75.0%	Good		100%	100%	NA	NA	NA	25%

Asset Information					Condition Data DAI	Final HI			HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).					
#	Asset ID	Location	Install or Manuf Date	Age		HI	HI Category		Enclosure	Inside	Connections	Fuse / Switch	Insulation	Base and Surroundings
34	26	NT	1989	31	100%	75.0%	Good		100%	100%	NA	NA	NA	100%
35	44	NT	1990	30	100%	75.0%	Good		100%	100%	NA	NA	NA	100%
36	46	NT	1994	26	100%	75.0%	Good		100%	100%	NA	NA	NA	100%
37	97	NT			100%	75.0%	Good		100%	100%	NA	NA	NA	100%
38	110	NT	2009	11	100%	75.0%	Good		100%	100%	NA	NA	NA	50%
39	112	NT	2011	9	100%	75.0%	Good		100%	100%	NA	NA	NA	50%
40	13	NT	1989	31	100%	76.2%	Good		100%	100%	NA	NA	NA	100%
41	15	NT	1989	31	100%	76.2%	Good		100%	100%	NA	NA	NA	100%
42	17	NT	1989	31	100%	76.2%	Good		100%	100%	NA	NA	NA	100%
43	19	NT	1989	31	100%	76.2%	Good		75%	100%	NA	NA	NA	100%
44	28	NT	1989	31	100%	76.2%	Good		100%	100%	NA	NA	NA	100%
45	12	NT	1990	30	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
46	54	NT	1995	25	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
47	58	NT	1996	24	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
48	59	NT	1996	24	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
49	66	NT	2001	19	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
50	68	NT	2001	19	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
51	74	NT	1999	21	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
52	98	NT	2003	17	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
53	102	NT	2006	14	100%	78.8%	Good		75%	100%	NA	NA	NA	100%
54	30	NT	1990	30	100%	80.2%	Good		100%	100%	NA	NA	NA	100%
55	33	NT	1990	30	100%	80.2%	Good		100%	100%	NA	NA	NA	100%
56	37	NT	1990	30	100%	80.2%	Good		100%	100%	NA	NA	NA	100%
57	38	NT	1990	30	100%	80.2%	Good		100%	100%	NA	NA	NA	100%
58	42	NT	1990	30	100%	80.2%	Good		100%	100%	NA	NA	NA	100%
59	SC003	MID	2000	20	100%	85.0%	Very Good		50%	100%	NA	NA	NA	100%
60	SC010	MID	2010	10	100%	85.0%	Very Good		50%	100%	NA	NA	NA	100%
61	41	NT	1992	28	100%	86.8%	Very Good		100%	100%	NA	NA	NA	100%
62	99	NT	1992	28	100%	86.8%	Very Good		100%	100%	NA	NA	NA	100%
63	103	NT	1992	28	100%	86.8%	Very Good		100%	100%	NA	NA	NA	100%
64	51	NT	1995	25	100%	87.5%	Very Good		75%	100%	NA	NA	NA	100%
65	94	NT	2003	17	100%	87.5%	Very Good		100%	75%	NA	NA	NA	75%
66	100	NT			100%	87.5%	Very Good		75%	100%	NA	NA	NA	100%
67	21	NT	1995	25	100%	90.0%	Very Good		100%	100%	NA	NA	NA	100%
68	89	NT			100%	90.0%	Very Good		100%	100%	NA	NA	NA	100%
69	90	NT			100%	90.0%	Very Good		100%	100%	NA	NA	NA	100%
70	32	NT	1994	26	100%	91.6%	Very Good		100%	100%	NA	NA	NA	100%
71	53	NT	1994	26	100%	91.6%	Very Good		100%	100%	NA	NA	NA	100%

Asset Information					Condition Data DAI	Final HI			HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).					
#	Asset ID	Location	Install or Manuf Date	Age		HI	HI Category		Enclosure	Inside	Connections	Fuse / Switch	Insulation	Base and Surroundings
72	20	NT	1995	25	100%	93.4%	Very Good		100%	100%	NA	NA	NA	100%
73	48	NT	1995	25	100%	93.4%	Very Good		100%	100%	NA	NA	NA	100%
74	49	NT	1995	25	100%	93.4%	Very Good		100%	100%	NA	NA	NA	100%
75	SC011	MID	1995	25	100%	93.4%	Very Good		100%	100%	NA	NA	NA	100%
76	56	NT	1996	24	100%	94.9%	Very Good		100%	100%	NA	NA	NA	100%
77	57	NT	1996	24	100%	94.9%	Very Good		100%	100%	NA	NA	NA	100%
78	61	NT	1996	24	100%	94.9%	Very Good		100%	100%	NA	NA	NA	100%
79	64	NT	1997	23	100%	96.1%	Very Good		100%	100%	NA	NA	NA	100%
80	73	NT	1998	22	100%	97.0%	Very Good		100%	100%	NA	NA	NA	100%
81	35	NT	1999	21	100%	97.8%	Very Good		100%	100%	NA	NA	NA	100%
82	84	NT	1999	21	100%	97.8%	Very Good		100%	100%	NA	NA	NA	100%
83	SC001	MID	2000	20	100%	98.4%	Very Good		100%	100%	NA	NA	NA	100%
84	SC002	MID	2000	20	100%	98.4%	Very Good		100%	100%	NA	NA	NA	100%
85	SC004	MID	2000	20	100%	98.4%	Very Good		100%	100%	NA	NA	NA	100%
86	SC005	MID	2000	20	100%	98.4%	Very Good		100%	100%	NA	NA	NA	100%
87	65	NT	2001	19	100%	98.8%	Very Good		100%	100%	NA	NA	NA	100%
88	76	NT	2001	19	100%	98.8%	Very Good		100%	100%	NA	NA	NA	100%
89	78	NT	2001	19	100%	98.8%	Very Good		100%	100%	NA	NA	NA	100%
90	6	NT	2002	18	100%	99.2%	Very Good		100%	100%	NA	NA	NA	100%
91	75	NT	2002	18	100%	99.2%	Very Good		100%	100%	NA	NA	NA	100%
92	82	NT	2002	18	100%	99.2%	Very Good		100%	100%	NA	NA	NA	100%
93	83	NT	2002	18	100%	99.2%	Very Good		100%	100%	NA	NA	NA	100%
94	1	NT	2004	16	100%	99.6%	Very Good		100%	100%	NA	NA	NA	100%
95	27	NT	2005	15	100%	99.7%	Very Good		100%	100%	NA	NA	NA	100%
96	91	NT	2005	15	100%	99.7%	Very Good		100%	100%	NA	NA	NA	100%
97	92	NT	2005	15	100%	99.7%	Very Good		100%	100%	NA	NA	NA	100%
98	101	NT	2006	14	100%	99.8%	Very Good		100%	100%	NA	NA	NA	100%
99	SC006	MID	2006	14	100%	99.8%	Very Good		100%	100%	NA	NA	NA	100%
100	SC007	MID	2006	14	100%	99.8%	Very Good		100%	100%	NA	NA	NA	100%

5.4 Data Assessment

Age and basic inspection records were available for pad mounted switchgear. Additionally, an overall NTPDL hazard/risk score was assigned to each unit. Most transformers had some inspection and/or age available, so the DAI was 98%. However, the available inspection records were not very detailed, leaving the data gaps shown below.

Asset Category	Population	Average DAI
Pad Mounted Switchgear	133	98%

The data gaps for this asset category are related to inspection granularity and include the following:

Table A 5-5 Pad Mounted Switchgear Data Gaps

Data Gap	Priority	Description	Source
Enclosure (door, paint)	L	Peeling paint, deteriorating door, hinges, etc.	Visual inspection
Fuse	H	Issues with fuse	Visual inspection (live-front gear)
Switch	H	Issues with switches	Visual inspection (live-front gear)
Insulation	H	Insulators, barrier boards	Visual Inspections
Connections	H	Terminations or elbows and inserts	Visual inspections, IR scans
Base and Surroundings	L	Grade change, poor placement, poor access, poor grounding connection	Visual inspection

6. Poles

This section summarizes the ACA results for NTPDL's Wood and Concrete Poles.

6.1 Wood Poles

There are 8147 Wood Poles at NTPDL. Of these, 6149 had sufficient data for assessment. The average age of the population is 29 years; age distribution is as follows:

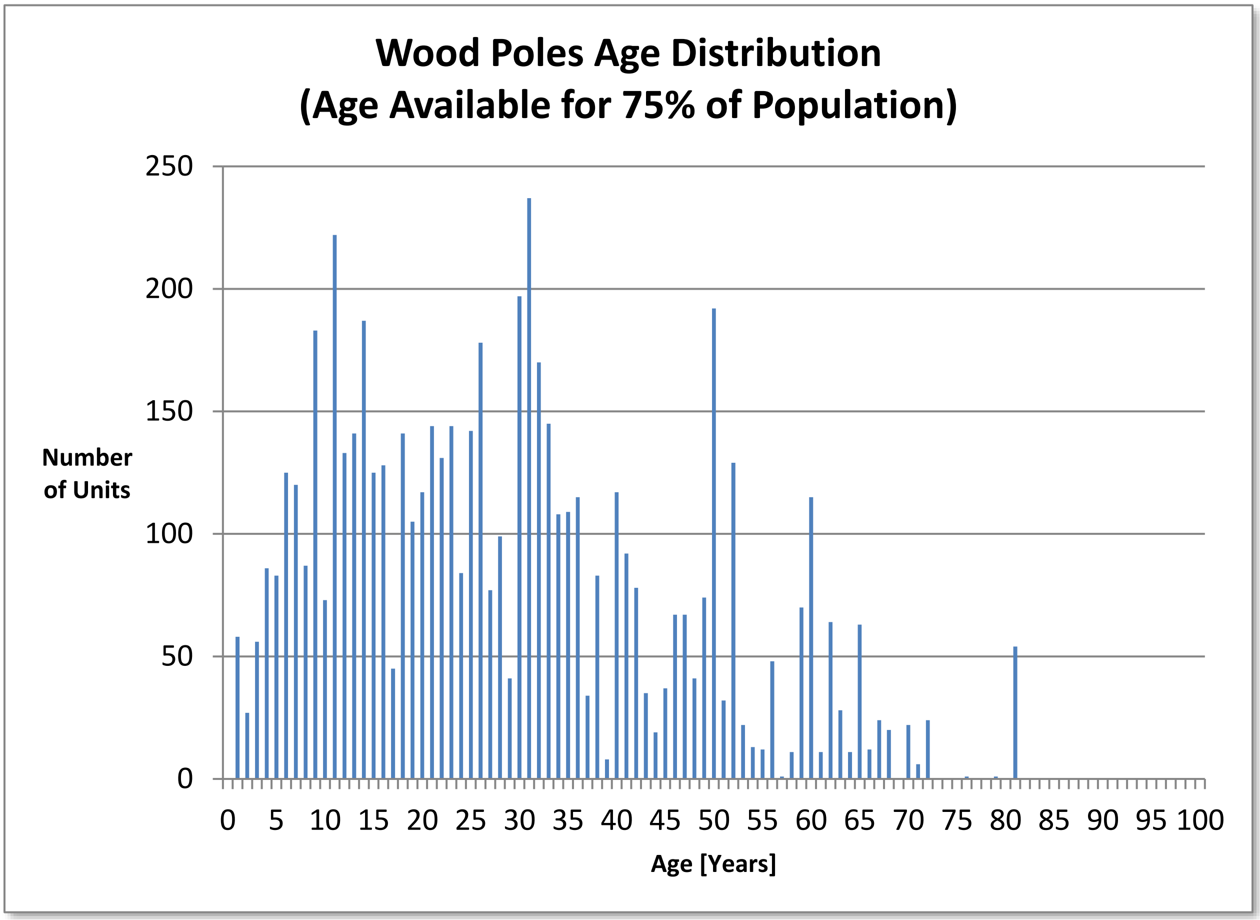

Figure A 6-1 Wood Poles Age Distribution

6.1.1 Health Index

6.1.1.1 Health Index Formula

HI is a function of scores and weights of condition and sub-condition parameters and is calculated using Equation 1 and Equation 2 described in Section 2.1. This section defines the condition and sub-condition parameters, as well as criteria.

Wood Poles

Table A 6-1 Wood Poles Health Index Formula

Condition Parameter (CP)		Sub-Condition Parameter (SCP)			
Description	**Weight (WCP)**	**Description**	**Data Source**	**Weight (WSCP)**	**Criteria**
Pole	7	Pole Strength	Test	0*	NA
		Pole Appearance	Inspections	1	Table A 6-2
		Hammer Test	Inspections	1	Table A 6-2
Crossarm	0*	Crossarm	Inspections	0*	NA
Guy Assembly	4	Guy Assembly	Inspections	1	Table A 6-2
Hardware	0*	Hardware	Inspections	0*	NA
Insulators	0*	Insulators	Inspections	0*	NA
Conductor	0*	Conductor	Inspections	0*	NA
Brace	0*	Brace	Inspections	0*	NA
Grounding	2	Grounding	Inspections	1	Table A 6-2
Environment	0*	Environment	Inspections	0*	NA
Age Limiter (AL)		Based on typical life curve			Figure A 6-2
HI De-Rating Multiplier (DR)**		Hazard Assessment and proximity to major road			Equation A 6-1
*where there is no available data for any assets, the weight of the parameter is set to 0					
** Note that for poles in Newmarket and Tay, the HI formula is based only on the overall hazard assessments from inspections.					

Inspections Records

Table A 6-2 Inspection Criteria

Score	Condition Description			
4	Excellent working condition	No apparent issues	Good	OK
3	Minor wear, working as required	Mild severity		
2	Wear or failed, repaired during inspection, regular monitoring required	Medium severity	Fair	
1	Major wear or failed, repaired during inspection	Severe		
0	Immediate replacement or emergency repair required	Very severe	Poor	Not OK

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 A 6-1

Table A 6-3 Poles De-Rating Multiplier Criteria

De-Rating Multiplier	Description	
	DR_1	DR_2
	Overall Hazard Score	Location
1	4	-
0.9	3	-
0.8	-	On a major road
0.75	2	-
0.5	1	-
0.25	0	-

Age Limiter

The Age Limiter used is equivalent to the survival function of the asset group, as described in Equation 5. It was assumed that the likelihood of removal for wood poles at 55 years is 20% and that at 75 years the likelihood of removal is 95%. For concrete poles, the assumed 20% and 95% of removal ages are 60 and 80 years respectively. The resultant survival curves (1 – likelihood of removals) are shown below. This survival curve was used as the Age Limiter.

Figure A 6-2 Poles Age Limiter

6.1.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. Approximately 6% of the sample size was found to be in poor/very poor condition. The average HI for the asset group was 87.9%.

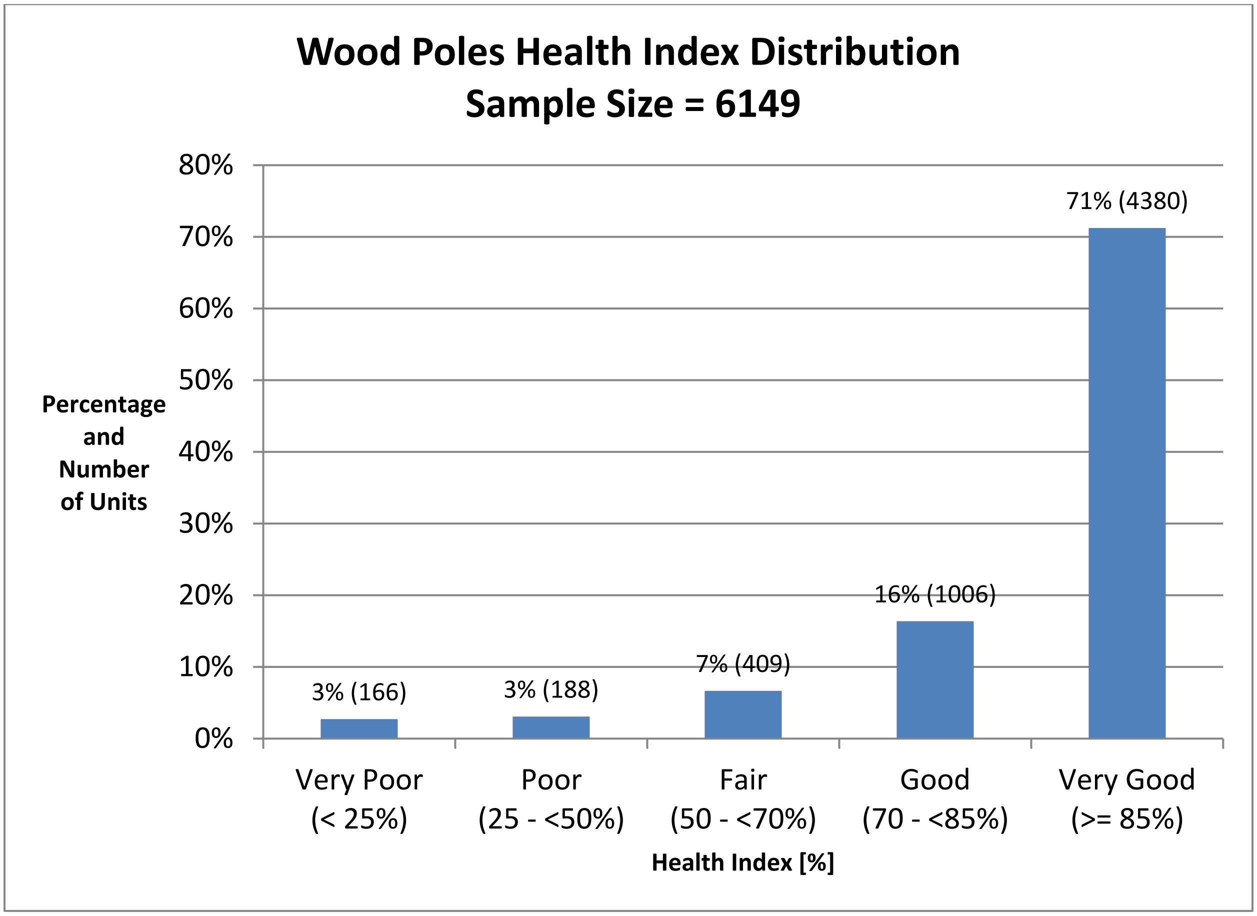

Figure A 6-3 Wood Poles Health Index Distribution

6.1.2 Flagged for Action Plan

The flagged for action plan, which was derived using the life curve method in Section 2.2 shows the expected number of assets to be addressed each year. The plan accounts for the entire asset population, i.e. the results from 'sample size' (assets with HI) were extrapolated to the population. As it may not always be feasible to address assets per this plan, a 'levelized' plan for better pacing of investments is also provided.

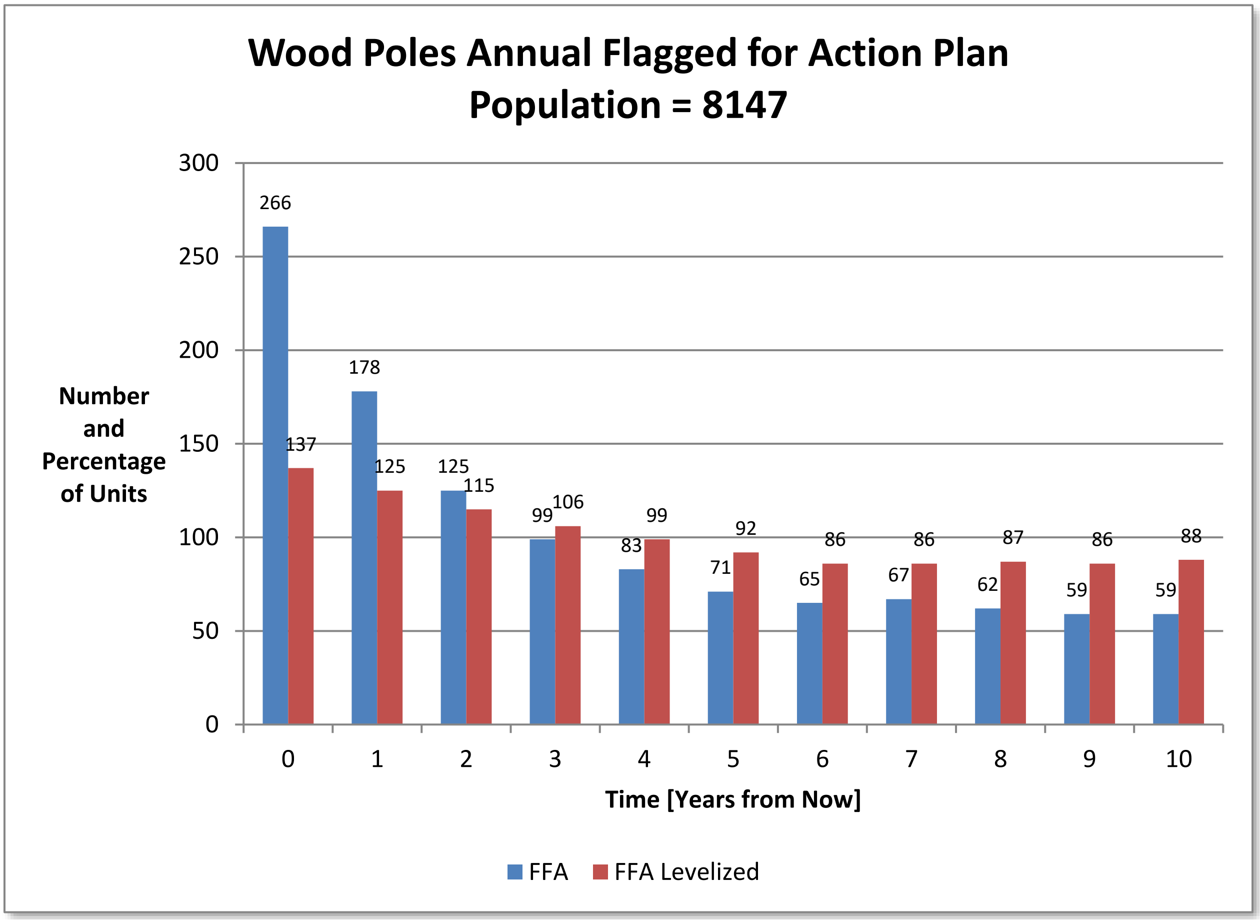

Figure A 6-4 Wood Poles Flagged for Action Plan

6.1.3 Health Index Based Prioritized List

The following table shows the list of very poor and poor wood poles, sorted by lowest to highest HI.

Table A 6-4 Wood Poles Risk Based Priortized List

Asset Information					Condition Data DAI	Final HI		HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).								
#	Asset ID	Location	Asset Year	Age		HI	HI Category	Pole	Crossarms	Guy Assembly	Hardware	Insulators	Conductor	Brace	Grounding	Environment
1	0162	MID	1952	68	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
2	0161	MID	1952	68	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
3	0174	MID	1952	68	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
4	0180	MID	1952	68	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
5	0319	MID	1953	67	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
6	0250	MID	1955	65	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
7	0476	MID	1955	65	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
8	1454	MID	1974	46	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
9	0211	MID	1985	35	100%	0.0%	Very Poor	13%	NA	NA	NA	NA	NA	NA	NA	NA
10	1277	MID	1949	71	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
11	0047	MID	1950	70	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
12	0133	MID	1952	68	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
13	0134	MID	1952	68	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
14	0173	MID	1952	68	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
15	0179	MID	1952	68	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
16	0242	MID	1952	68	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
17	0241	MID	1952	68	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
18	0248	MID	1952	68	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
19	0095	MID	1953	67	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
20	0118	MID	1953	67	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
21	0119	MID	1953	67	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
22	0144	MID	1955	65	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
23	0234	MID	1955	65	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
24	0473	MID	1955	65	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
25	0316	MID	1955	65	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
26	0203	MID	1955	65	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
27	1011	MID	1958	62	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
28	0078	MID	1960	60	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
29	1282	MID	1974	46	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
30	0115	MID	1977	43	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
31	1966	MID	2011	9	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA
32	0300	MID	2012	8	100%	0.0%	Very Poor	25%	NA	NA	NA	NA	NA	NA	NA	NA

Asset Information					Condition Data DAI	Final HI		HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).								
#	Asset ID	Location	Asset Year	Age		HI	HI Category	Pole	Crossarms	Guy Assembly	Hardware	Insulators	Conductor	Brace	Grounding	Environment
33	0238	MID	1952	68	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
34	0229	MID	1952	68	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
35	0192	MID	1952	68	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
36	0194	MID	1952	68	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
37	0479	MID	1953	67	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
38	1206	MID	1954	66	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
39	0062	MID	1955	65	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
40	0232	MID	1955	65	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
41	0474	MID	1955	65	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
42	0475	MID	1955	65	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
43	0317	MID	1955	65	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
44	1437	MID	1974	46	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
45	0122	MID	1974	46	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
46	1625	MID	1977	43	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
47	0184	MID	1979	41	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
48	1344	MID	1980	40	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
49	0908	MID	2013	7	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
50	0910	MID	2013	7	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
51	0948	MID	2013	7	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
52	0949	MID	2013	7	100%	0.0%	Very Poor	50%	NA	NA	NA	NA	NA	NA	NA	NA
53	0564	MID	1974	46	100%	0.0%	Very Poor	100%	NA	NA	NA	NA	NA	NA	NA	NA
54	0306	MID	2012	8	100%	0.0%	Very Poor	100%	NA	NA	NA	NA	NA	NA	NA	NA
55	1507	MID	2013	7	100%	0.0%	Very Poor	100%	NA	NA	NA	NA	NA	NA	NA	NA
56	0143	MID	2017	3	100%	0.0%	Very Poor	100%	NA	NA	NA	NA	NA	NA	NA	NA
57	P41109	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
58	P41110	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
59	P41112	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
60	P41114	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
61	P41115	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
62	P41116	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
63	P41118	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
64	P41119	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
65	P41121	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
66	P41122	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
67	P41124	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
68	P41126	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
69	P41127	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
70	P41129	NT	1939	81	0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA

Asset Information						Condition Data DAI	Final HI		HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).								
#	Asset ID	Location	Asset Year	Age			HI	HI Category	Pole	Crossarms	Guy Assembly	Hardware	Insulators	Conductor	Brace	Grounding	Environment
71	P41130	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
72	P41131	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
73	P41132	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
74	P41134	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
75	P41135	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
76	P41136	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
77	P41137	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
78	P41140	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
79	P41143	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
80	P41144	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
81	P41146	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
82	P41148	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
83	P41149	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
84	P41150	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
85	P41151	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
86	P41153	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
87	P41154	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
88	P41155	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
89	P41156	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
90	P41157	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
91	P41160	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
92	P41161	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
93	P41162	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
94	P41163	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
95	P41164	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
96	P41165	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
97	P41167	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
98	P41169	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
99	P41171	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA
100	P41172	NT	1939	81		0%	0.4%	Very Poor		NA	NA	NA	NA	NA	NA	NA	NA

6.2 Concrete Poles

There are 303 Concrete Poles at NTPDL. Of these, 300 had sufficient data for assessment. The average age of the population is 9 years; age distribution is as follows:

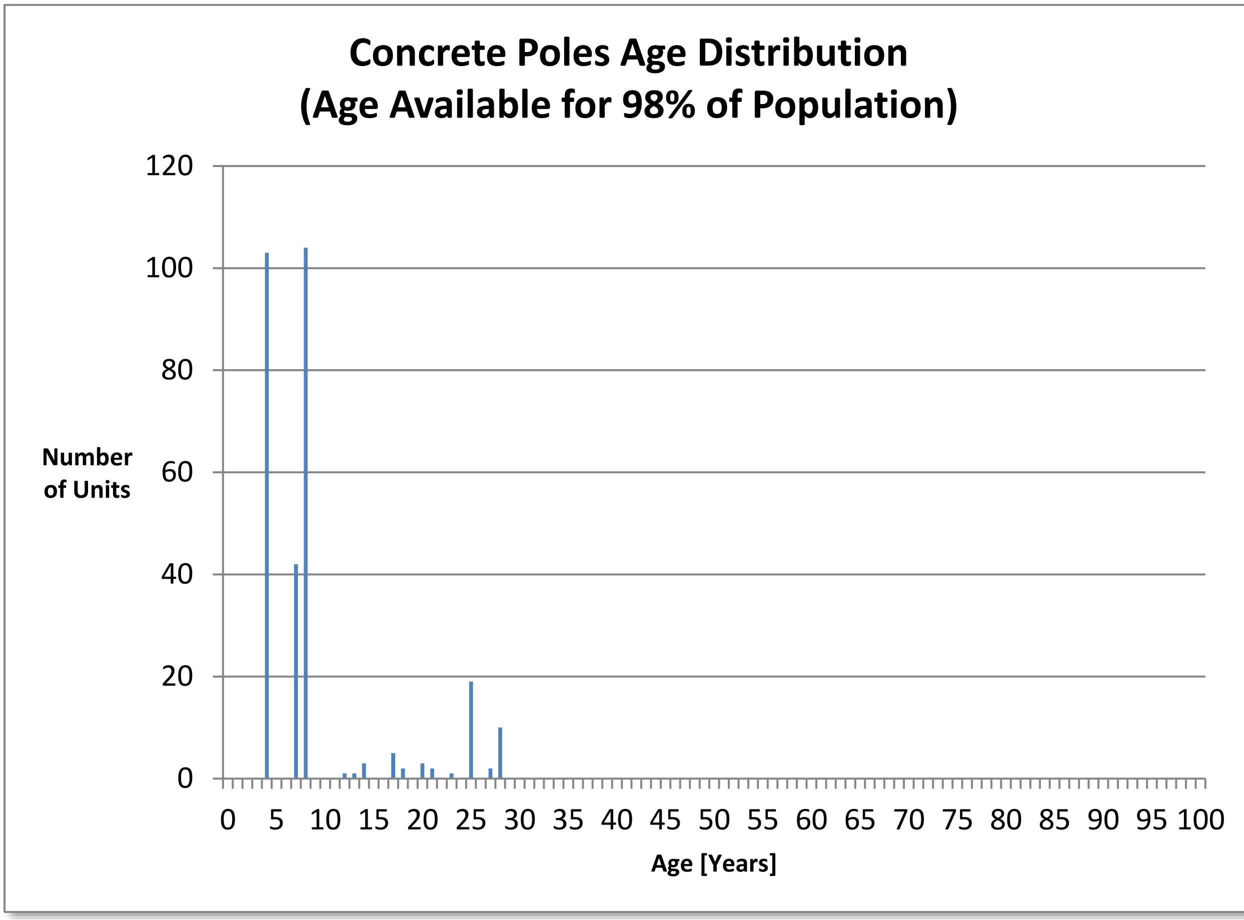

Figure A 6-5 Concrete Poles Age Distribution

6.2.1 Health Index

6.2.1.1 Health Index Formula

The condition and sub-condition parameters are as follows:

Table A 6-5 Concrete Poles Health Index Formula

Condition Parameter (CP)		Sub-Condition Parameter (SCP)			
Description	**Weight (WCP)**	**Description**	**Data Source**	**Weight (WSCP)**	**Criteria**
Pole	7	Pole Strength	Test	0*	NA
		Pole Appearance	Inspections	1	Table A 6-2
Crossarm	0*	Crossarm	Inspections	0*	NA
Guy Assembly	4	Guy Assembly	Inspections	1	Table A 6-2
Hardware	0*	Hardware	Inspections	0*	NA
Insulators	0*	Insulators	Inspections	0*	NA
Conductor	0*	Conductor	Inspections	0*	NA
Brace	0*	Brace	Inspections	0*	NA
Grounding	2	Grounding	Inspections	1	Table A 6-2
Environment	0*	Environment	Inspections	0*	NA
Age Limiter (AL)		Based on typical life curve			Figure A 6-2
HI De-Rating Multiplier (DR)**		Hazard Assessment and proximity to major road			Equation A 6-1
*where there is no available data for any assets, the weight of the parameter is set to 0					
** Note that for poles in Newmarket and Tay, the HI formula is based only on the overall hazard assessments from inspections.					

6.2.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. None were found to be in poor/very poor condition. The average HI for the asset group was 100%.

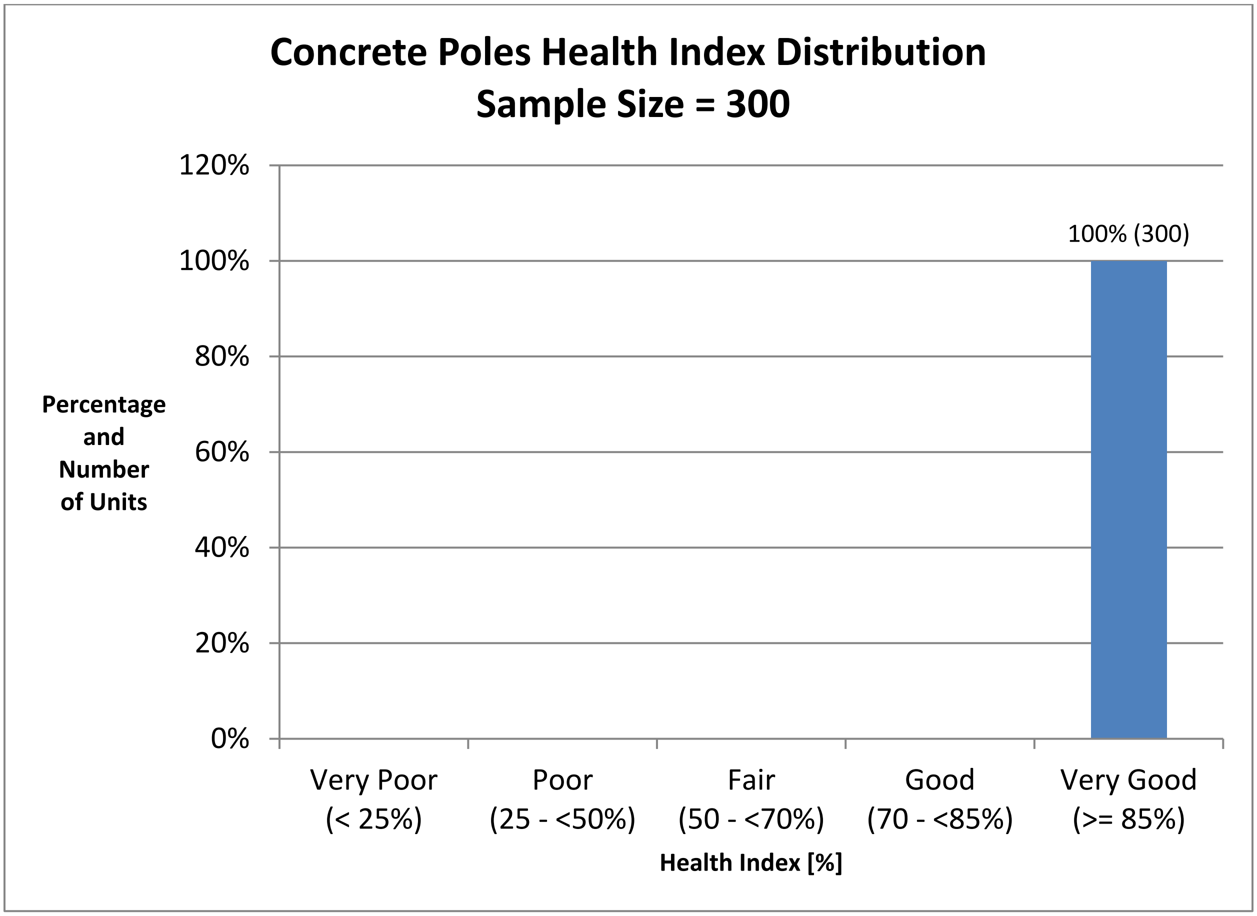

Figure A 6-6 Concrete Poles Health Index Distribution

6.2.1.3 Flagged for Action Plan

In this study, the 10-year FFA Plan was estimated based on the life curve approach detailed in Section 2.2. No poles were flagged for action in the next 10 years.

6.2.2 Health Index Based Prioritized List

The following table shows 'worst' 100 concrete poles, sorted by lowest to highest HI.

Table A 6-6 Concrete Poles Risk Based Priortized List

Asset Information					Final HI		Pole	HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).							
#	Asset ID	Location	Asset Year	Age	HI	HI Category	Pole	Crossarms	Guy Assembly	Hardware	Insulators	Conductor	Brace	Grounding	Environment
1	3524	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
2	3525	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
3	3526	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
4	3527	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
5	3528	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
6	3529	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
7	3530	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
8	3531	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
9	3532	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
10	3533	MID	1992	28	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
11	P20015	NT	1993	27	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
12	P20718	NT	1993	27	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
13	P20001	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
14	P20002	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
15	P20003	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
16	P20004	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
17	P20005	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
18	P20006	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
19	P20007	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
20	P20008	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
21	P20009	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
22	P20012	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
23	P20013	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
24	P20014	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
25	P20016	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
26	P20017	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
27	P20019	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
28	P22615	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
29	P22709	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
30	P23628	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
31	P23767	NT	1995	25	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
32	P20000	NT	1997	23	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA

Asset Information					Final HI		Pole	HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).							
#	Asset ID	Location	Asset Year	Age	HI	HI Category	Pole	Crossarms	Guy Assembly	Hardware	Insulators	Conductor	Brace	Grounding	Environment
33	P22064	NT	1999	21	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
34	P24049	NT	1999	21	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
35	P21915	NT	2000	20	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
36	P21916	NT	2000	20	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
37	P23669	NT	2000	20	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
38	3546	MID	2002	18	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
39	3544	MID	2002	18	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
40	P20018	NT	2003	17	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
41	P22796	NT	2003	17	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
42	P23173	NT	2003	17	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
43	3542	MID	2003	17	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
44	3545	MID	2003	17	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
45	P20010	NT	2006	14	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
46	P20011	NT	2006	14	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
47	P21560	NT	2006	14	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
48	3523	MID	2007	13	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
49	3543	MID	2008	12	100.0%	Very Good	100%	NA	NA	NA	NA	NA	NA	NA	NA
50	P21656	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
51	P21657	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
52	P21658	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
53	P21666	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
54	P21667	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
55	P21668	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
56	P21669	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
57	P21670	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
58	P21671	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
59	P21672	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
60	P21673	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
61	P21674	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
62	P21675	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
63	P21676	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
64	P21677	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
65	P21678	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
66	P21679	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
67	P21680	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
68	P21681	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA

Asset Information					Final HI		Pole	HI Parameters Blanks cells indicate no data for a particular unit. Data Gaps denoted by 'Not Available' (NA).							
#	Asset ID	Location	Asset Year	Age	HI	HI Category	Pole	Crossarms	Guy Assembly	Hardware	Insulators	Conductor	Brace	Grounding	Environment
69	P21682	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
70	P21683	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
71	P21684	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
72	P21685	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
73	P21686	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
74	P21687	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
75	P21688	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
76	P21689	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
77	P21690	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
78	P21691	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
79	P21692	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
80	P21693	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
81	P21694	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
82	P21695	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
83	P21696	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
84	P21697	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
85	P21698	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
86	P21699	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
87	P21700	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
88	P21701	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
89	P21702	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
90	P21703	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
91	P21704	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
92	P21705	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
93	P21706	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
94	P21707	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
95	P21708	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
96	P21709	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
97	P21710	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
98	P21711	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
99	P21712	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA
100	P21713	NT	2012	8	100.0%	Very Good		NA	NA	NA	NA	NA	NA	NA	NA

6.3 Data Assessment

Age was available for both wood and concrete poles. Additionally, overall condition and other basic inspection items, such as pole appearance, hammer tests, and comments about guying and electrical grounding, were available. The DAI are 62% and 39% for wood and concrete poles respectively. However, there are no pole strength tests. Further, inspection records were not granular and minor details could only be found in the inspection comments.

Asset Category	Population	Average DAI
Wood Poles	8147	62%
Concrete Poles	303	39%

The data gaps for this asset category are as follows. While some basic inspection items are available, more granular inspection items are noted below.

Table A 6-7 Poles Data Gaps

Data Gap	Priority	Description	Source
Pole Strength (wood)	H	Pole strength test (e.g. Circumference , PSI)	Test Records
Physical Condition Wood poles: damage, rot, animal damage, leaning Concrete poles: damage, rebar corrosion, spalling, leaning	M	Detailed information on physical appearance of the pole.	Inspection records
Pole Accessories	M	Condition of hardware, insulators, conductors, and brace	Inspection records
Environment	L	In water, soil conditions.	Inspection records

7. Underground Cables

This section summarizes the ACA results for NTPDL's Underground Cables. This section summarizes the ACA results for NTPDL's Underground Cables. There were a total of 413 conductor-km of Non-TRXLPE cables and 279 conductor-km of TRXLPE cables. Approximately 92 conductor-km were of unknown type and age. As such, these cables were not inclulded in the assessment.

7.1 Non-TR XLPE Underground Cables

There were a total of 413 conductor-km of Non-TRXLPE cables. Of these, 390 conductor-km had age and were therfore included in the assessment. The average age is 32 years; the age distribution is as follows.

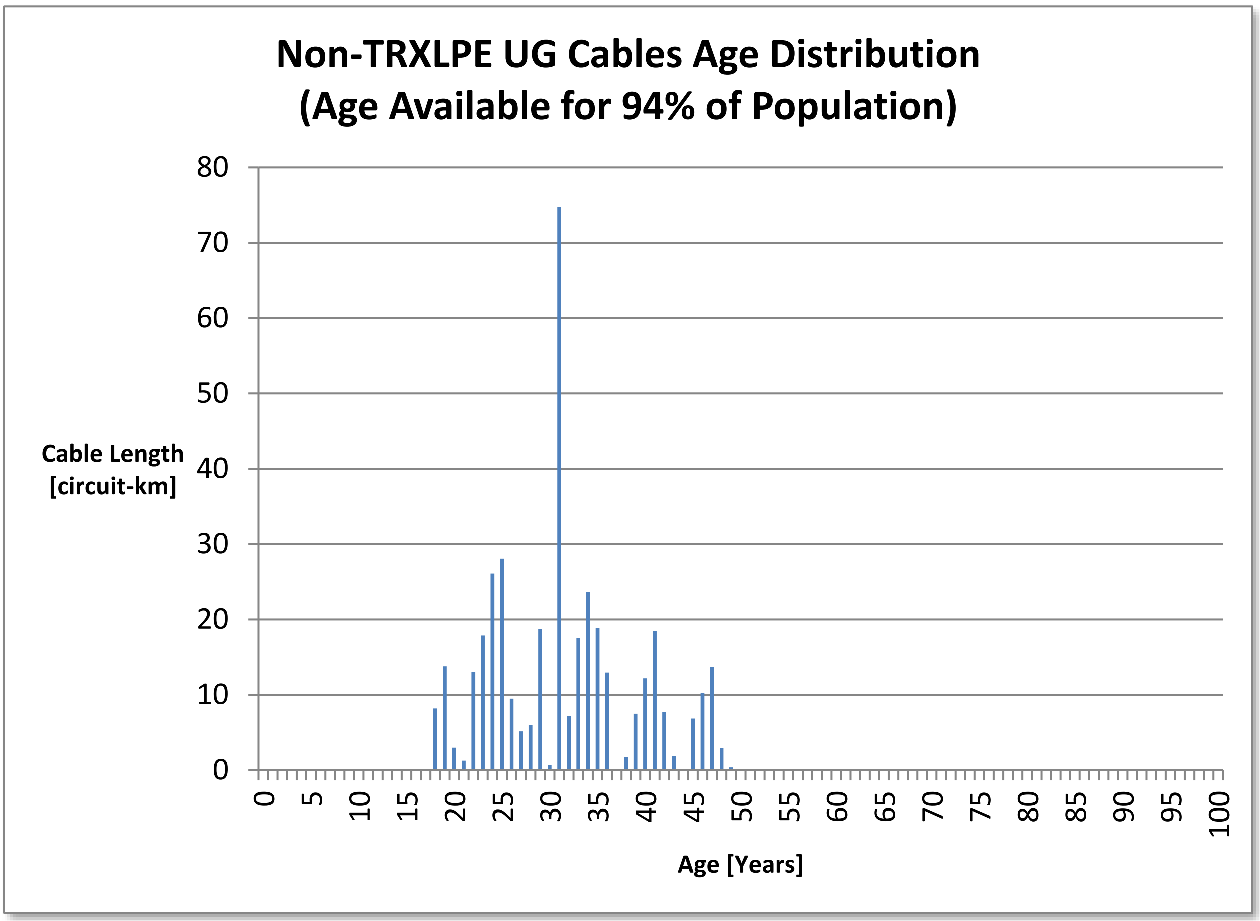

Figure A 7-1 Non-TRXLPE Underground Cables Age Distribution

7.1.1 Health Index Formula

HI is a function of scores and weights of condition and sub-condition parameters and is calculated using Equation 1 and Equation 2 described in Section 2.1. This section defines the condition and sub-condition parameters, as well as criteria.

Table A 7-1 Underground Cables Health Index Formula

Condition Parameter (CP)		Sub-Condition Parameter (SCP)			
Description	**Weight (WCP)**	**Description**	**Source**	**Weight (WSCP)**	**Table**
Cable Condition	0*	Insulation	Tests	0*	NA
		Conductor	Tests	0*	NA
		Neutral Corrosion	Tests	0*	NA
Accessories	0*	Splices	Tests	0*	NA
		Terminations	Tests Visual Inspections	0*	NA
Age Limiter (AL)		Based on typical life curve			Figure A 7-2
HI De-Rating Multiplier (DR)		Fault Rate (segments)			
*where there is no available data for any assets, the weight of the parameter is set to 0 Since no parameters were available, the assessment was age-based (i.e. equivalent to the Age Limiter)					

Age Limiter

The Age Limiter used is equivalent to the survival function of the asset group, as described in Equation 5. It was assumed that the likelihood of removal for non-TRXLPE at 35 years is 20% and that at 45 years the likelihood of removal is 95%. For concrete poles, the assumed 20% and 95% of removal ages are 45 and 55 years respectively. The resultant survival curves (1 – likelihood of removals) are shown below.

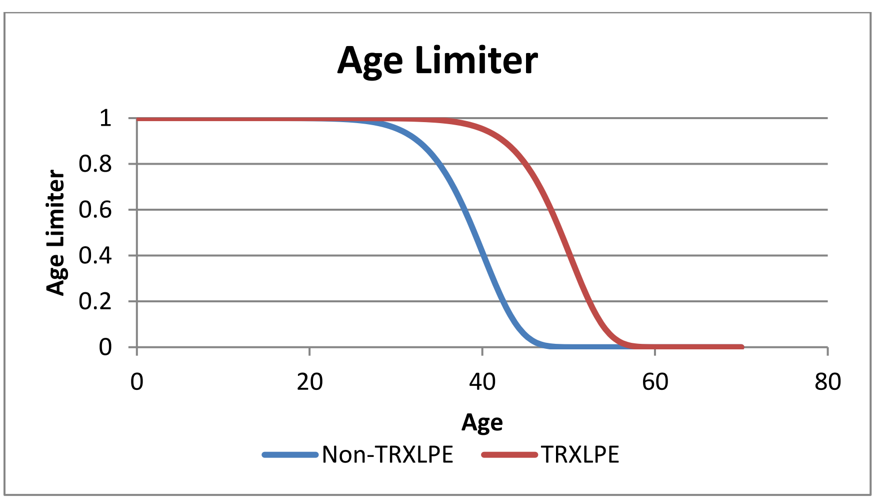

Figure A 7-2 Underground Cables Age Limiter

7.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. Approximately 19% were found to be in poor/very poor condition. The average HI for the asset group was 79.8%.

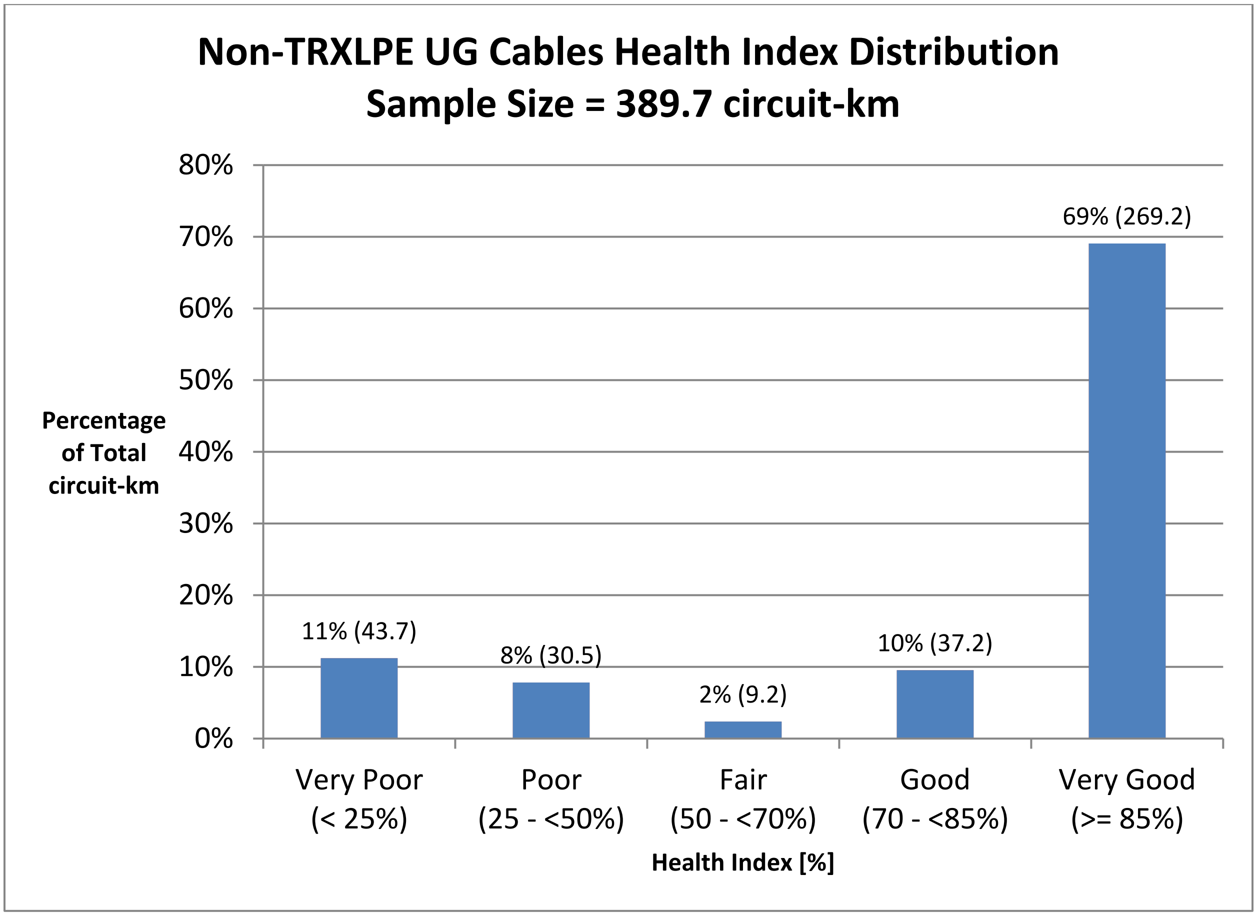

Figure A 7-3 Non-TRXLPE Underground Cables Health Index Distribution

7.1.3 Flagged for Action Plan

The flagged for action plan, which was derived using the life curve method in Section 2.2 shows the expected number of assets to be addressed each year. The plan accounts for the entire asset population, i.e. the results from 'sample size' (assets with HI) were extrapolated to the population. As it may not always be feasible to address assets per this plan, a 'levelized' plan for better pacing of investments is also provided.

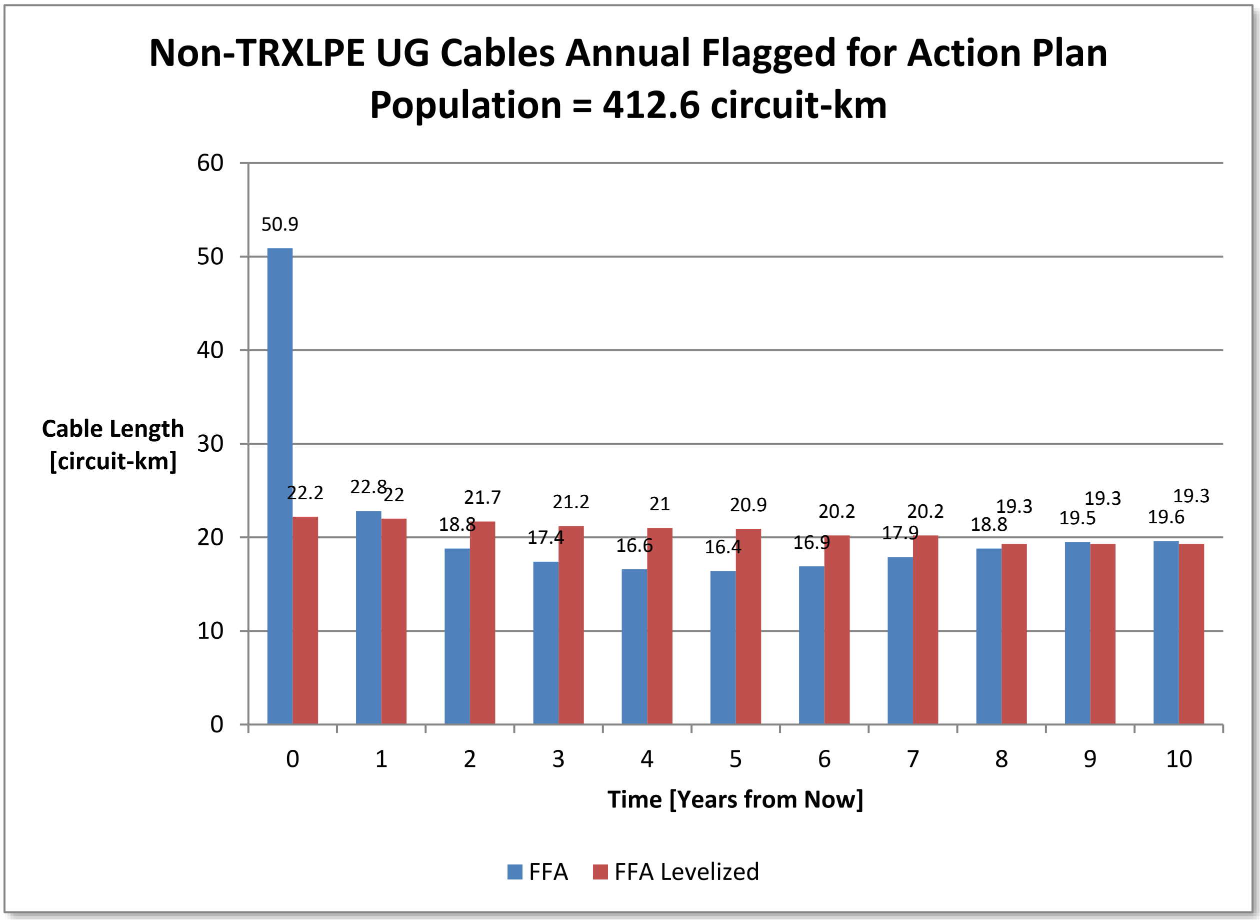

Figure A 7-4 Non-TRXLPE Underground Cables Flagged for Action Plan

7.2 TRXLPE Underground Cables

There were a total of 279 conductor-km of TRXLPE cables. Of these, 229 conductor-km had age and were therfore included in the assessment. The average age is 18 years; the age distribution is as follows.

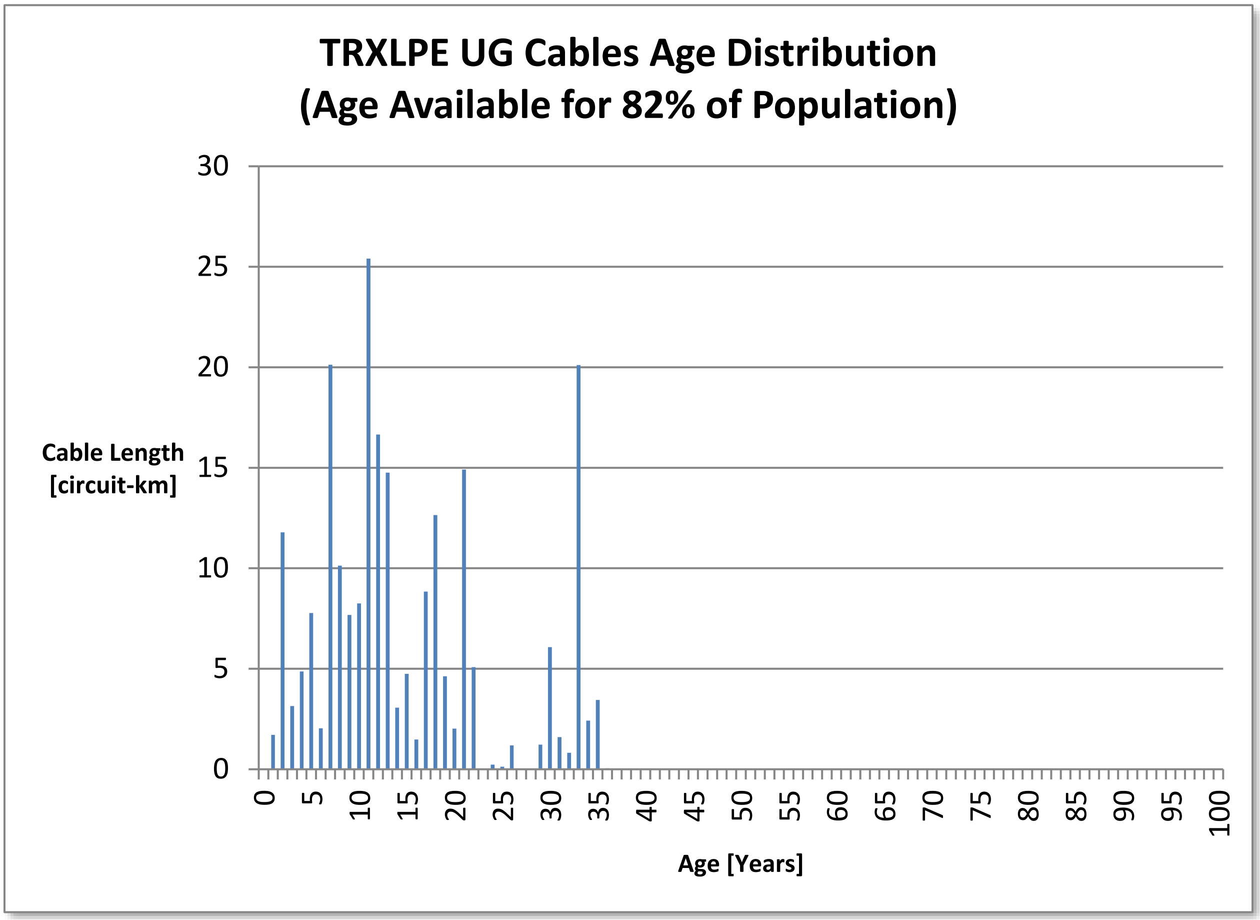

Figure A 7-5 TRXLPE Underground Cables Age Distribution

7.2.1 Health Index

7.2.1.1 Health Index Formula

See Section 7.1.1.

7.2.1.2 Health Index Results

The HI Distribution, in terms of number of units and percentage of units, is shown below. None were found to be in poor/very poor condition. The average HI for the asset group was 99.9%.

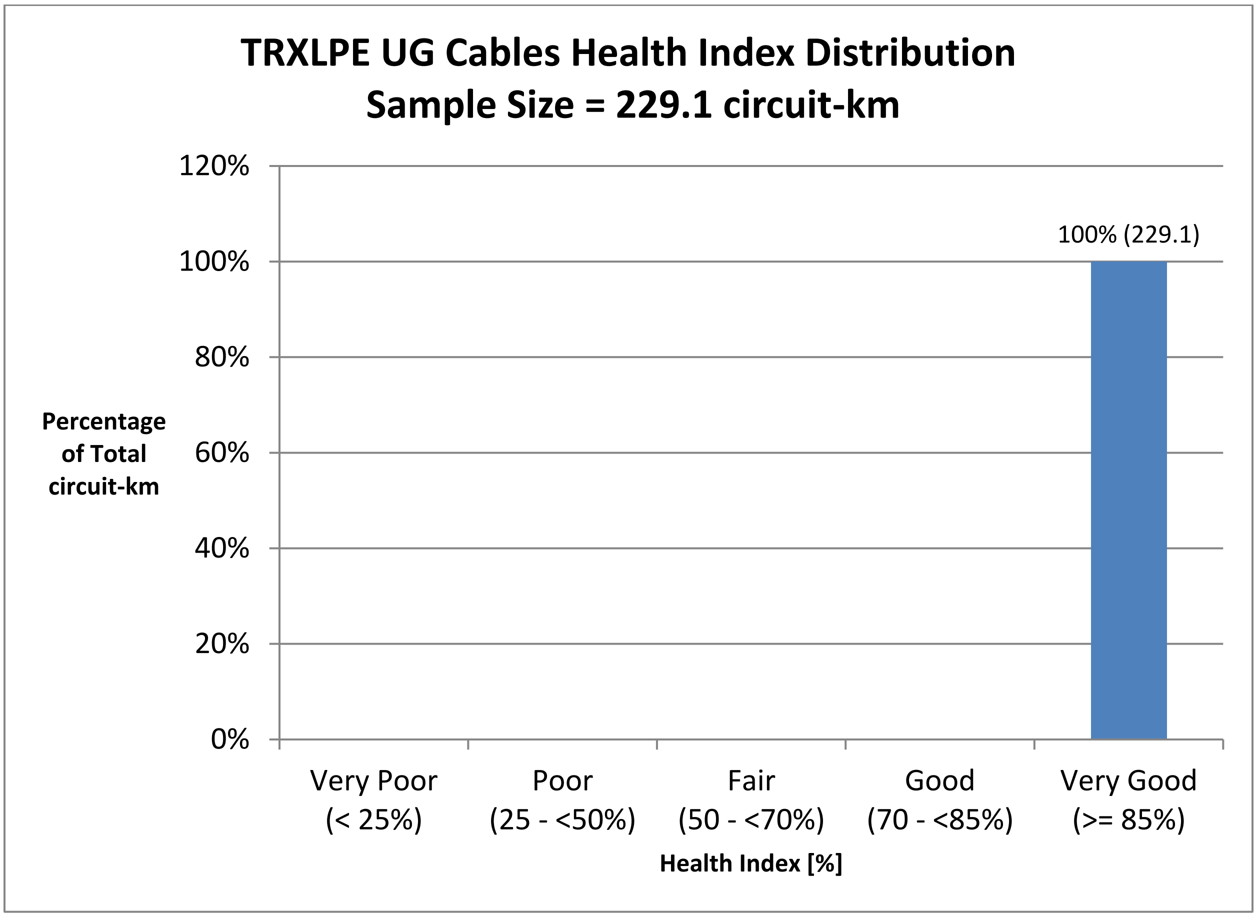

Figure A 7-6 TRXLPE Underground Cables Health Index Distribution

7.2.2 Flagged for Action Plan

The flagged for action plan, which was derived using the life curve method in Section 2.2 shows the expected number of assets to be addressed each year. The plan accounts for the entire asset population, i.e. the results from 'sample size' (assets with HI) were extrapolated to the population. As it may not always be feasible to address assets per this plan, a 'levelized' plan for better pacing of investments is also provided.

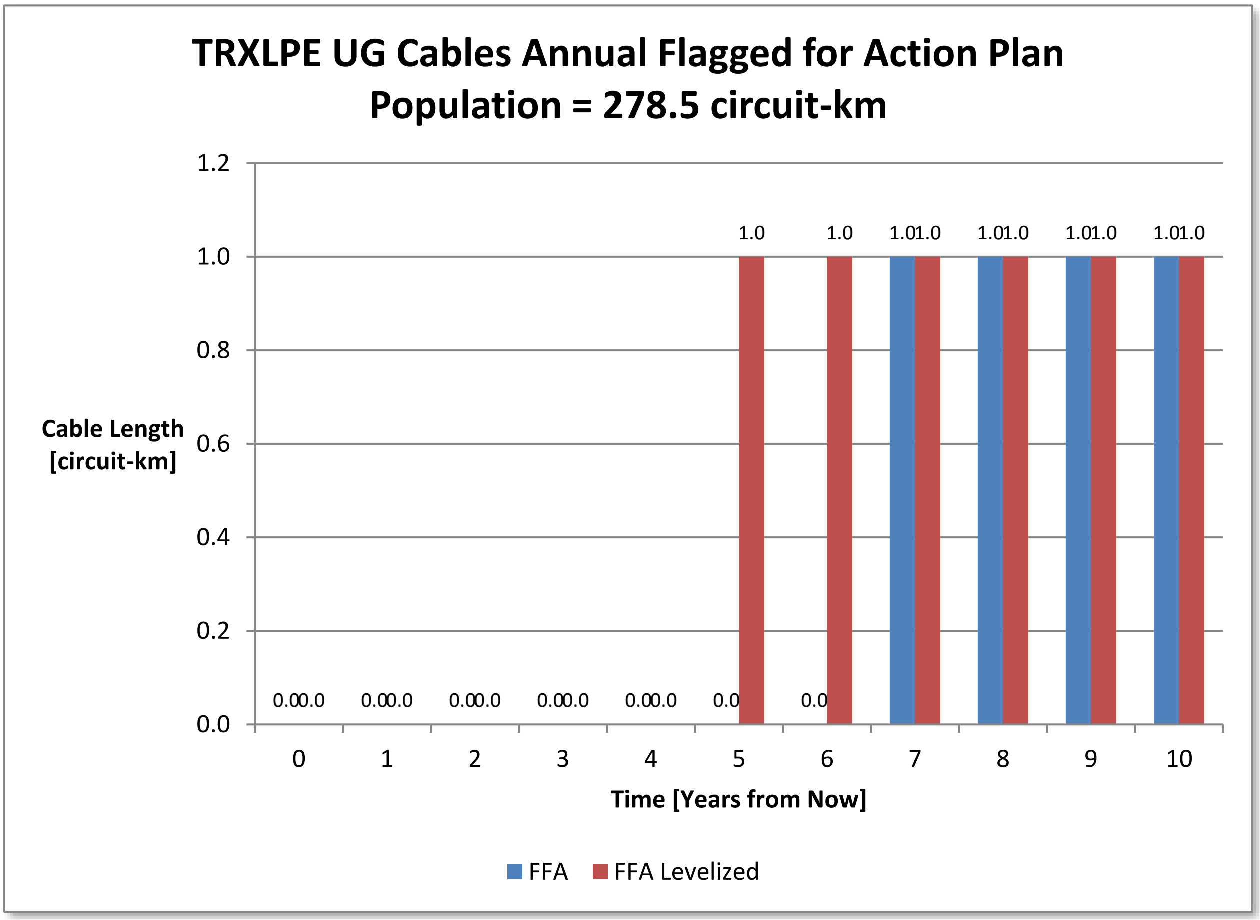

Figure A 7-7 Non-TRXLPE Underground Cables Flagged for Action Plan

7.3 Data Assessment

The assessment for underground cables was age-based.

Asset Category	Population (conductor-km)	Average DAI
Non-TRXLPE Poles	413	Age-based
TRXLPE Poles	279	Age-based

The data gaps for this asset category are as follows:

Table A 7-2 Underground Cables Data Gaps

Data Gap	Priority	Description	Source
Insulation condition	H	Insulation defect (dielectric loss, partial discharge)	Tests
Conductor condition	M	Conductor resistance, damage	Tests
Neutral condition	M	Neutral resistance, damage, corrosion	Tests
Splices	H	Splices	Testing
Terminations	H	Termination defect	Tests, IR scan, Visual inspection
Neutral Corrosion	M	Neutral defect	Testing
Fault Rate (segment level)	M	Failure records that can be associated with specific cable segments.	Historic records