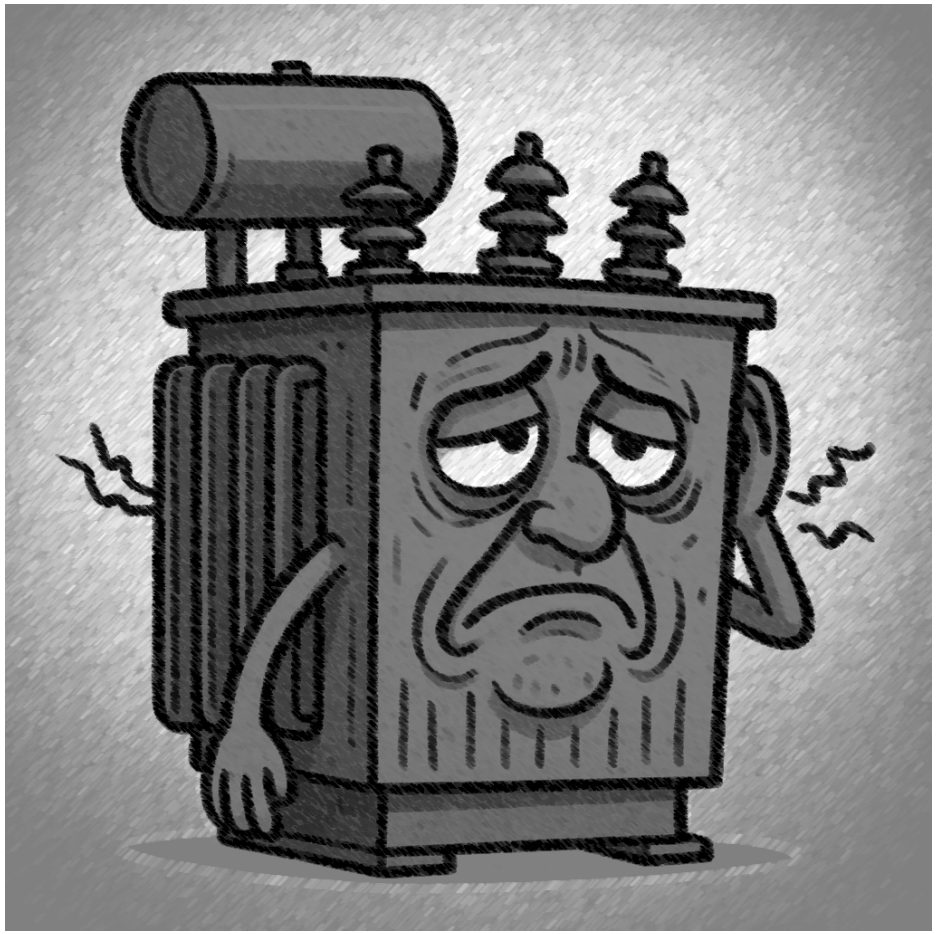
How Old Do Our Transformers Really Feel? Nature vs Nurture

Lydia Kerr – APEX 2025

Electra

Plan

- Importance of condition monitoring in asset management
- Introduction to the Transformer Age Index Model (TAIM)
- Significance of results

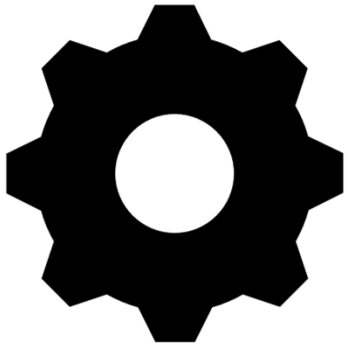


Why is condition monitoring in asset management important?

Condition Monitoring with Power Transformers

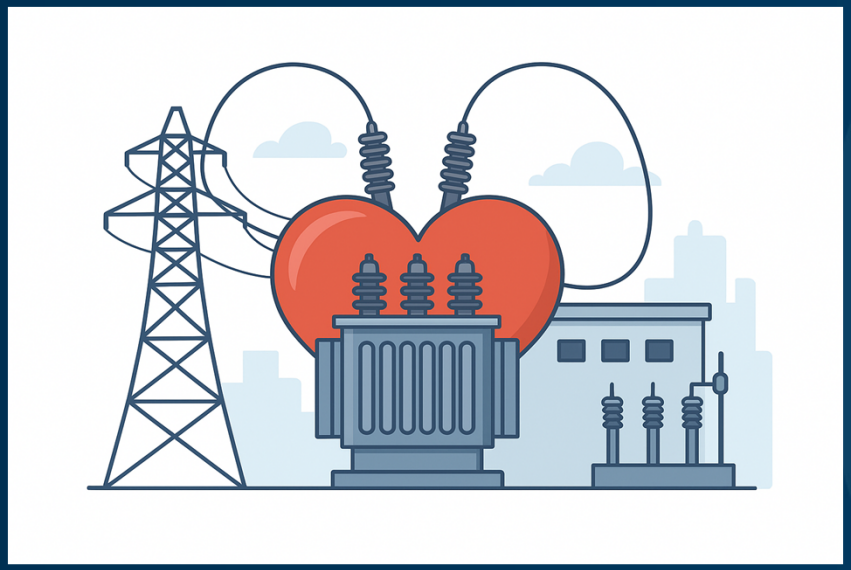
Informed Maintenance Decisions

Integration of multiple data sources



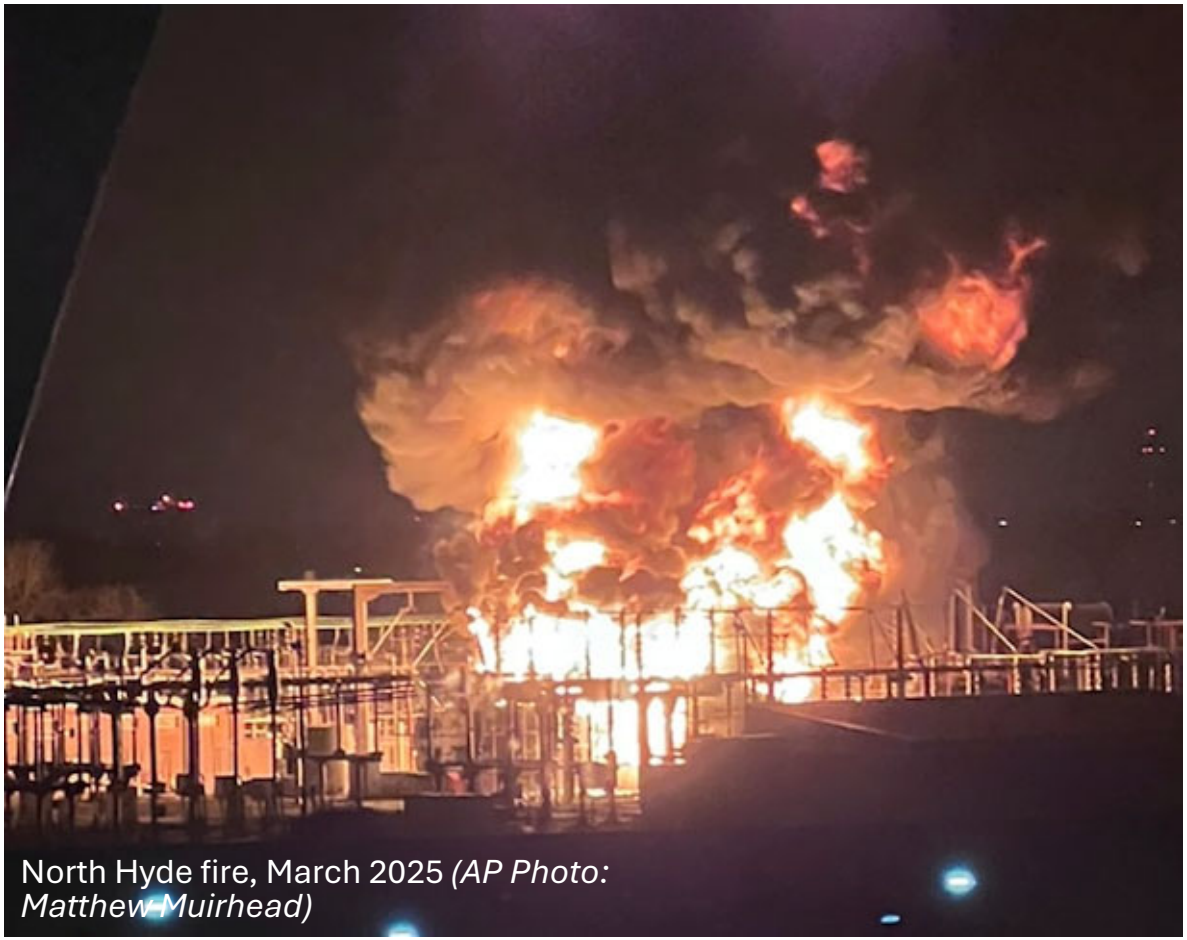
Early Detection of Faults

Better investment and risk decisions



When thinking about power transformers...

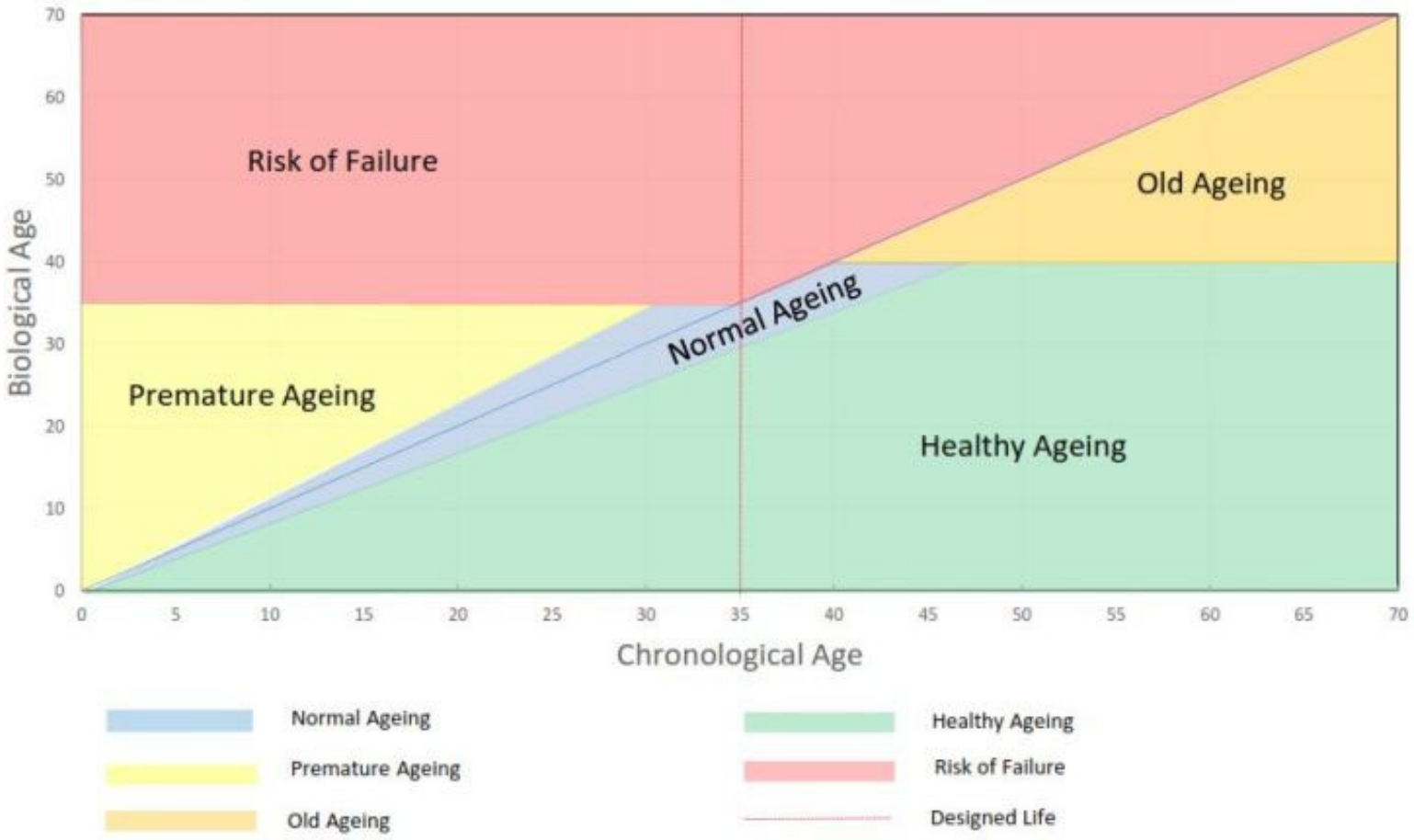
What happens when we don’t listen to the results?



North Hyde fire, March 2025 *(AP Photo: Matthew Muirhead)*

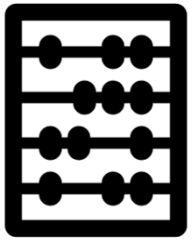
Transformer Age Index Model (TAIM)

TAIM Boundaries



The maths behind it

Biological age = chronological age x ageing factor

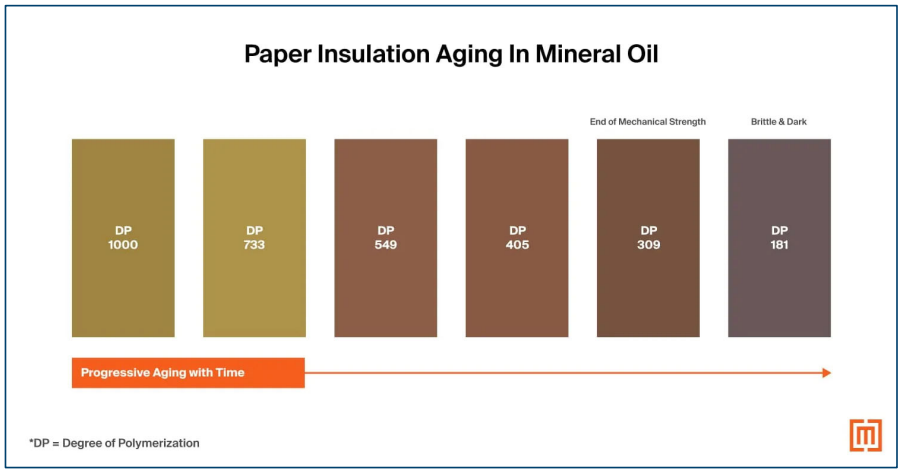


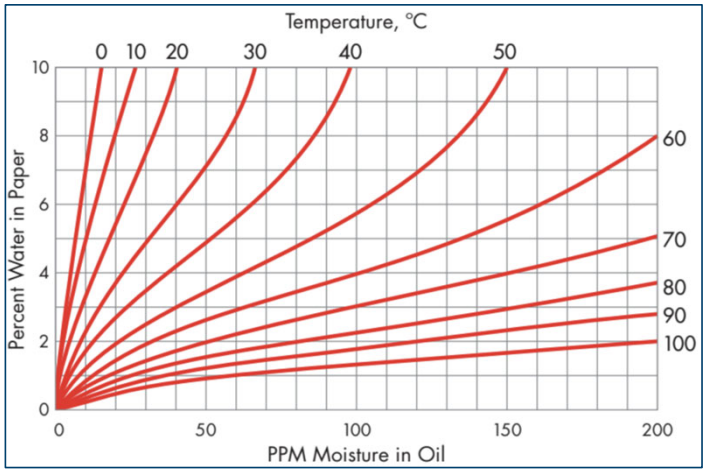
Paper Ageing factor

A_{DP} = 600 / DP	
DP = 600	A_{DP} = 1
DP < 600	A_{DP} > 1
DP > 600	A_{DP} < 1

$$A_{PAPER} = (0.4*A_{DP}) + (0.6*A_{PW})$$

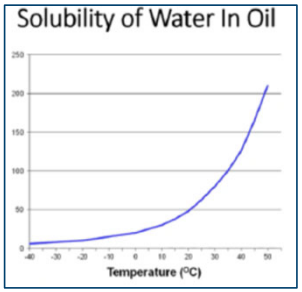
A_{PW} = Water Content (%) / 1.5	
Water Content (%) = 1.5%	A_{PW} = 1
Water Content (%) < 1.5%	A_{PW} < 1
Water Content (%) > 1.5%	A_{PW} > 1

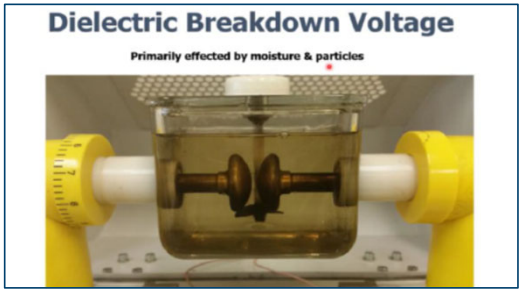


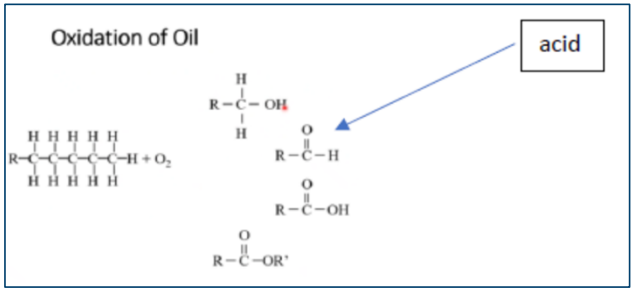


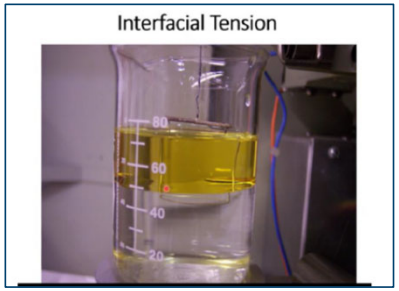
Oil Ageing factor

$$A_{OIL} = (0.4*A_{OW}) + (0.3*A_{DS}) + (0.2*A_{IFT}) + (0.1*A_{ACID})$$









A_{OW} = Water Content (ppm) / 10	
Water Content (ppm) = 10	$A_{OW} = 1$
Water Content (ppm) < 10	$A_{OW} < 1$
Water Content (ppm) > 10	$A_{OW} > 1$

A_{DS} = 50 / Dielectric Strength	
Dielectric Strength = 50	$A_{DS} = 1$
Dielectric Strength < 50	$A_{DS} > 1$
Dielectric Strength > 50	$A_{DS} < 1$

A_{IFT} = 30 / Interfacial Tension	
Interfacial Tension = 30	$A_{IFT} = 1$
Interfacial Tension < 30	$A_{IFT} > 1$
Interfacial Tension > 30	$A_{IFT} < 1$

A_{ACID} = Acidity / 0.07	
Acidity = 0.07	$A_{ACID} = 1$
Acidity < 0.07	$A_{ACID} < 1$
Acidity > 0.07	$A_{ACID} > 1$

Tap Changer Ageing factor

$$A_{TAP} = \max (A_{TOW} , A_{TDS} , A_{TFAULTS})$$

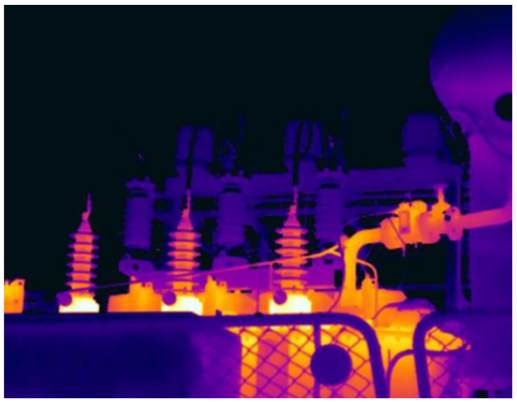
A_{TOW} = Water Content (ppm) / 30	
Water Content (ppm) = 30	$A_{OW} = 1$
Water Content (ppm) < 30	$A_{OW} < 1$
Water Content (ppm) > 30	$A_{OW} > 1$

A_{TDS} = 40 / Dielectric Strength	
Dielectric Strength = 40	$A_{TDS} = 1$
Dielectric Strength < 40	$A_{TDS} > 1$
Dielectric Strength > 40	$A_{TDS} < 1$

A_{TFault} = Stenestam Ratio	
Stenestam Ratio < 0.5	$A_{TFault} < 0.5$
0.5 < Stenestam Ratio < 3	$A_{TFault} = 2$
Stenestam Ration ≥ 3	$A_{TFault} = 3$

Bushing Ageing factor

$$A_{BUSH} = \max(A_{BTAN}, A_{BINSP})$$



Thermal inspection of Electra's Levin East T2, 2023

A_{BTAN} = Tan δ / 0.7	RIP	OIP	RBP
$A_{BTAN} = 1$	Tan δ = 0.7	Tan δ = 0.7	Tan δ = 0.15
$A_{BTAN} > 1$	Tan δ > 0.7	Tan δ > 0.7	Tan δ > 0.15
$A_{BTAN} < 1$	Tan δ < 0.7	Tan δ < 0.7	Tan δ < 0.15

A_{BINSP}	
No Findings	$A_{BINPS} = 1$
Some Contamination	$A_{BINPS} = 1.5$
Cracks/Leaks/Hot Spots	$A_{BINPS} = 3$

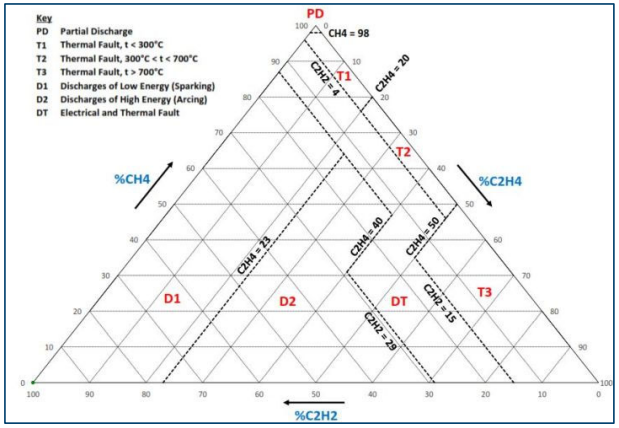
Fault Ageing factor

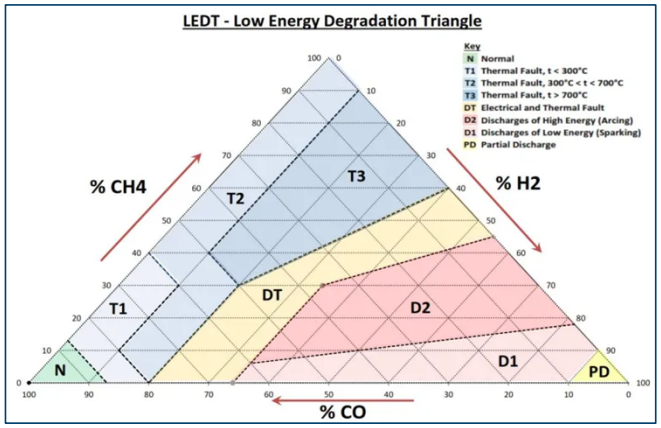
$$A_{FAULT} = (0.2*A_{GL}) + (0.4*A_{DT}) + (0.4*A_{LEDT})$$

A_{Duval} =	Condition	Score
PD	Partial Discharges	1.2
D1	Discharges of Low Energy	1.5
D2	Discharges of High Energy	3
T1	Thermal Fault, T < 300 °C	2
T2	Thermal Fault, 300 °C < T < 700 °C	2.5
T3	Thermal Fault, T > 700 °C	3

A_{LEDT} =	Condition	Score
Normal	Normal Operation	0.5
PD	Partial Discharges	1.2
D1	Discharges of Low Energy	1.5
D2	Discharges of High Energy	3
T1	Thermal Fault, T < 300 °C	2
T2	Thermal Fault, 300 °C < T < 700 °C	2.5
T3	Thermal Fault, T > 700 °C	3

A_{GL} = Max ()	= 1	< 1	> 1
$H2_F$ = H2/50	H2 = 50	H2 < 50	H2 > 50
$CH4_F$ = CH4/40	CH4 = 40	CH4 < 40	CH4 > 40
$C2H6_F$ = C2H6/30	C2H6 = 30	C2H6 < 30	C2H6 > 30
$C2H4_F$ = C2H4/40	C2H4 = 40	C2H4 < 40	C2H4 > 40
$C2H2_F$ = C2H2/2	C2H2 = 2	C2H2 < 2	C2H2 > 2
CO_F = CO/350	CO = 350	CO < 350	CO > 350

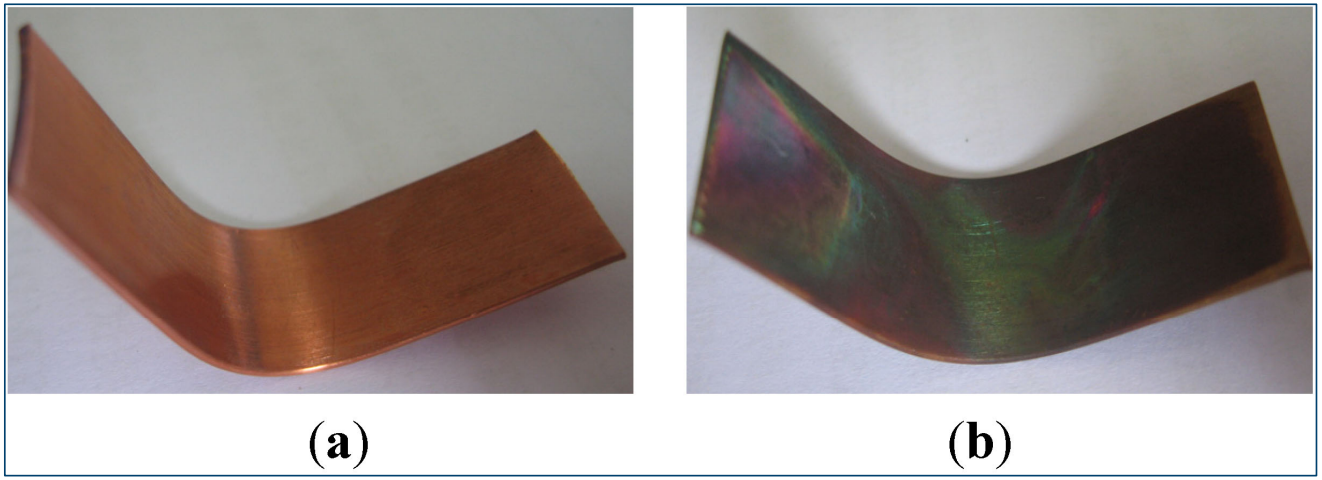




Gas	Limit
Hydrogen	150
Methane	67
Ethane	50
Ethylene	50
Acetylene	1

Disease Ageing factor

$$A_{DIS} = A_{CS}$$



Example of corrosive sulfur on a piece of copper

A_{CS}	
Non Corrosive	$A_{CS} = 1$
Corrosive	$A_{CS} = 2$

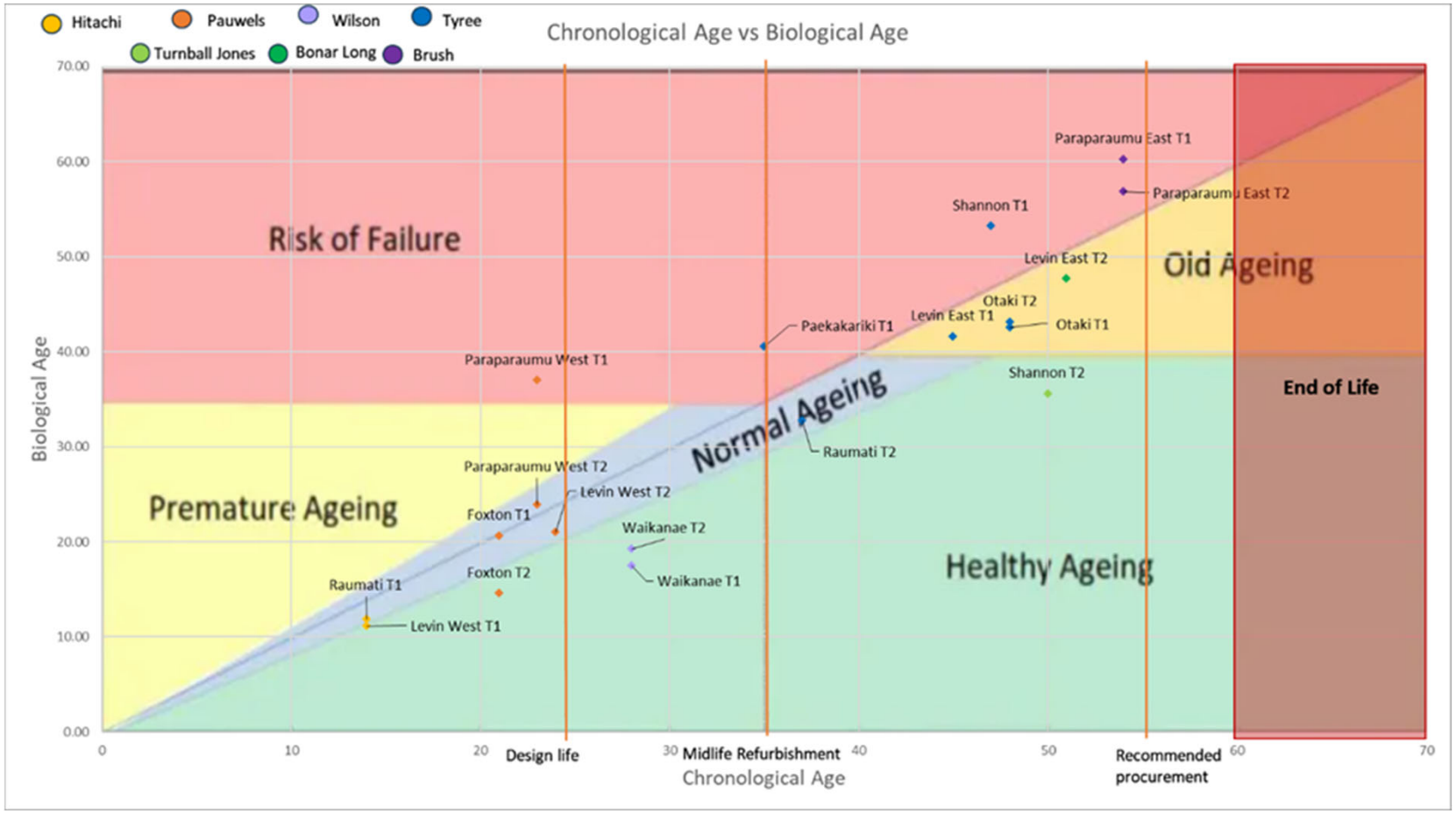
Final equation

Ageing Factor:

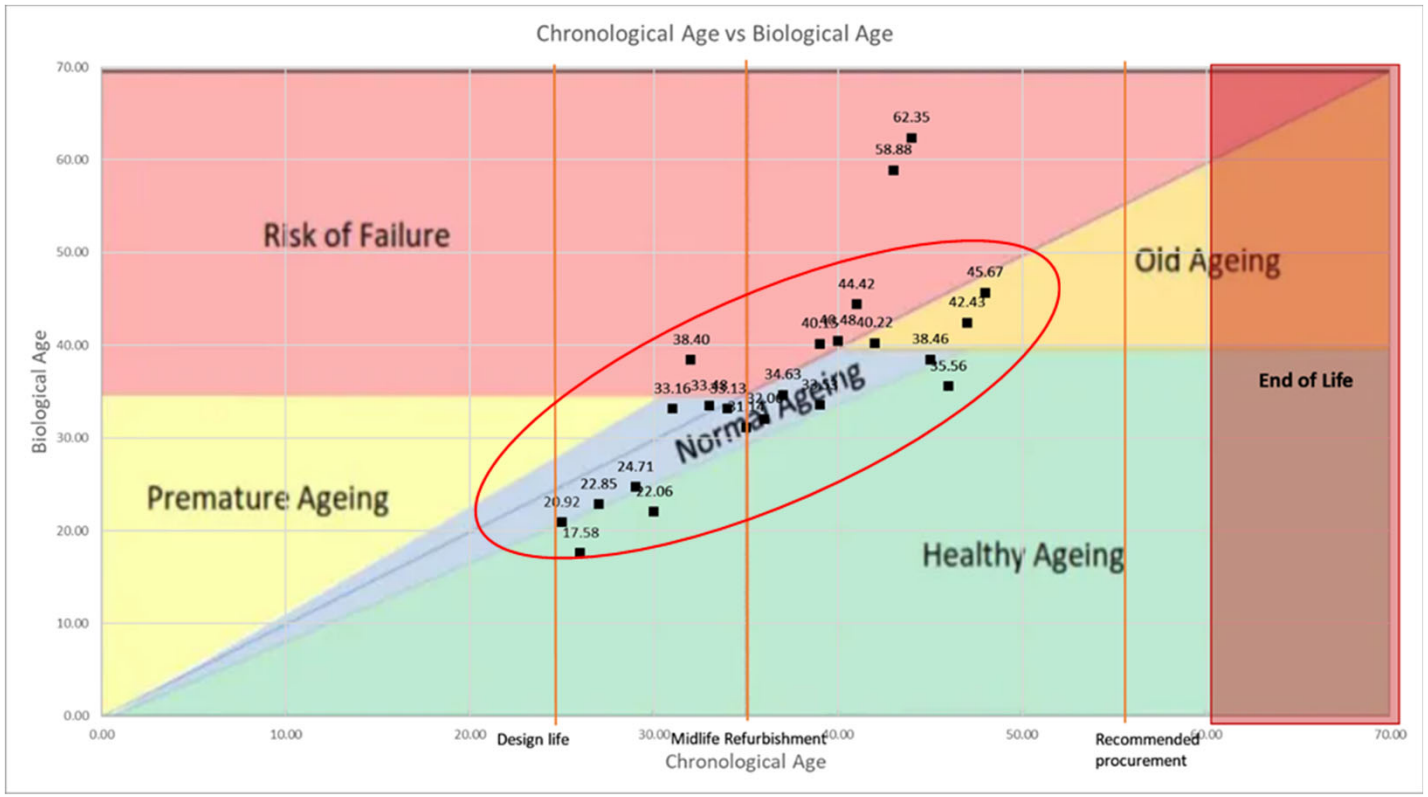
$(A_{FACTOR}) = (A_{PAPER\ x}\ K_{PAPER}) + (A_{OIL\ x}\ K_{OIL}) + (A_{TAP\ x}\ K_{TAP}) + (A_{BUSH\ x}\ K_{BUSH}) + (A_{FAULT\ x}\ K_{FAULT}) + (A_{DIS\ x}\ K_{DIS})$

$(A_{FACTOR}) = (A_{PAPER}\ X\ 0.1) + (\ A_{OIL}\ X\ 0.1) + (A_{TAP}\ X\ 0.2) + (0.42\ X\ 0.2) + (A_{FAULT}\ X\ 0.35) + (\mathbf{1}\ x\ 0.05)$

Electra Power Transformer Fleet



Ōtaki T1 profile



So what is the outcome for using TAIM?

Outcomes

Visual representation

Data driven planning

Combines health and age

Prioritisation for maintenance

Thank you!