

Asset Management of MV Cables using Data Driven Health Indices for Water Treeing

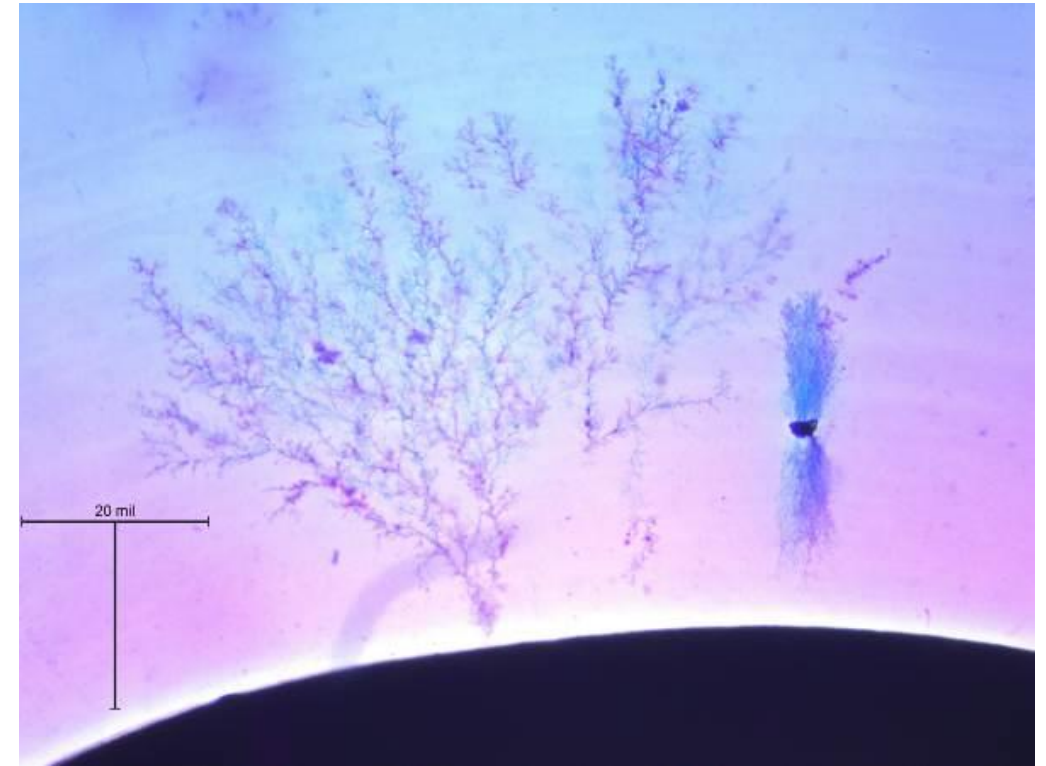
Nigel Hampton, Josh Perkel, Dean Williams



10th International Conference on Insulated Power Cables

Background

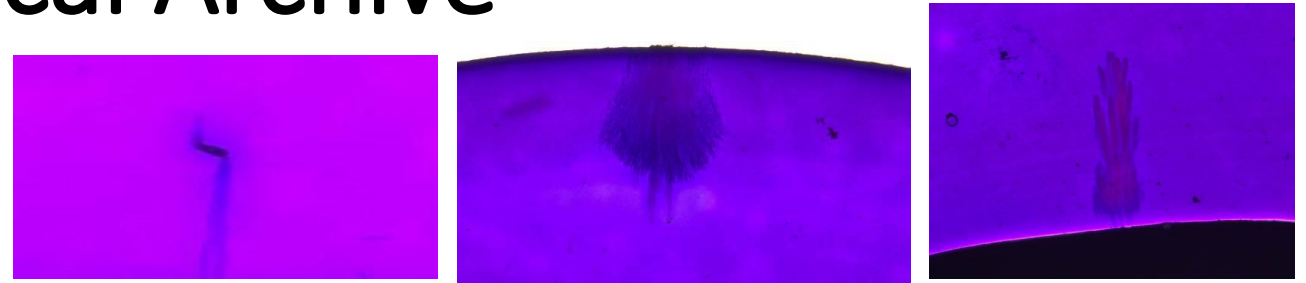
- (MV) XLPE insulated cables were first installed in the early 1960's.
- Expected to perform reliably for ≈ 30 yrs.
- Not aware that moisture, voltage stress, imperfections would combine to grow water trees.
- Many cables failed after few years.



- This impacted operating costs that electric utilities are still dealing with today.

Prior Work to Historical Archive

- >450 different examinations
- >40 Utilities
- Individual Reports -> Database
- >1500 large Vented Trees
- >3200 large Bowtie Trees
- Meta Data
 - Generation
 - Material
 - Neutral Condition
 - Prior Failures
- **21,000 data entries**



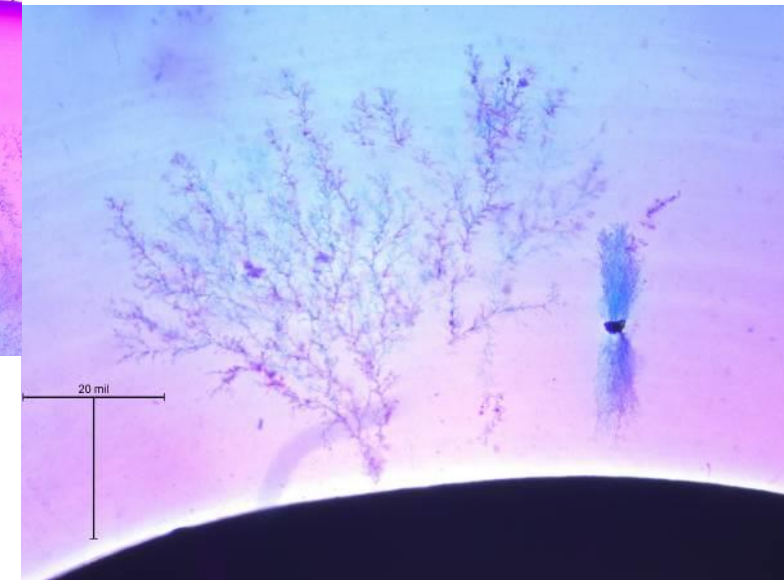
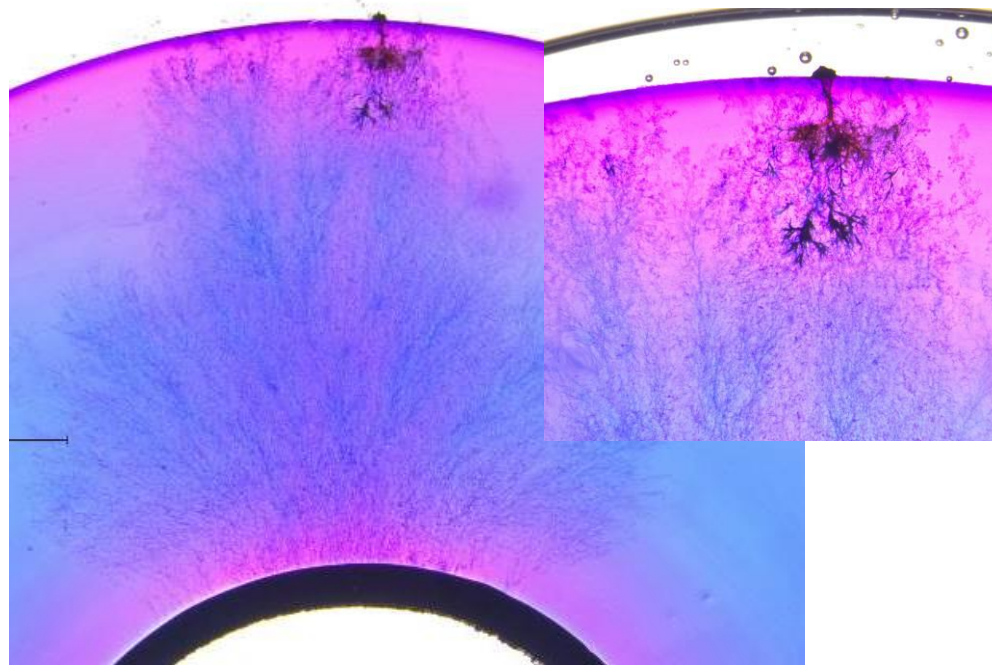
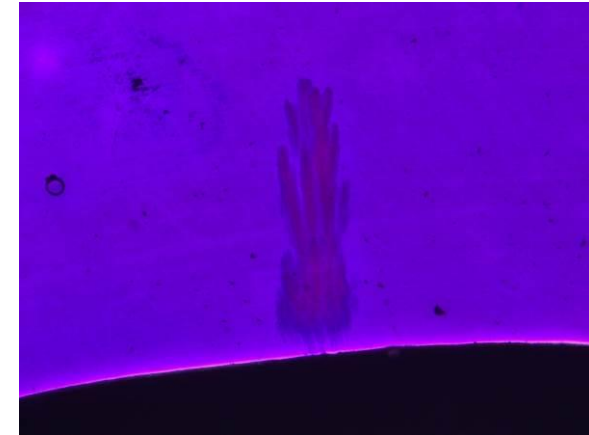
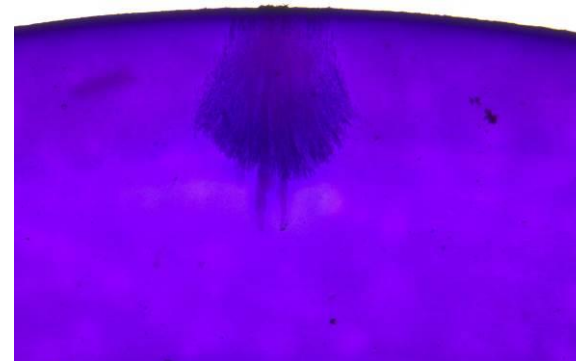
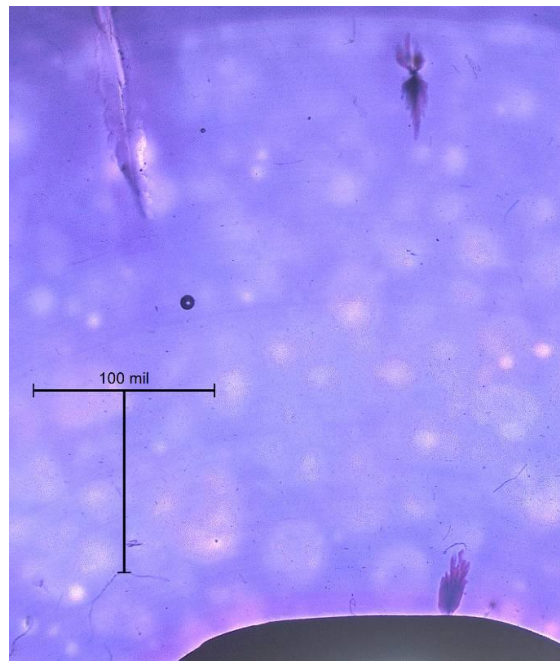
Summary of Largest Water Trees Sites Identified (Wafer or Hot Oil)

Tree Type	Tree Length (mils)	% Growth through Wall	Initiation Point
Example 1			
BT	100	38	5 mil Void
BT	67	26	9 mil Contaminant
ISAT	88	34	Unknown
BT	35	13	11 mil Contaminant
CSAT	80	31	Unknown
Example 2			
BT	27	10	Small Particle
Example 3			
ISAT	254	Full	Unknown
BT	30	12	Small Particle

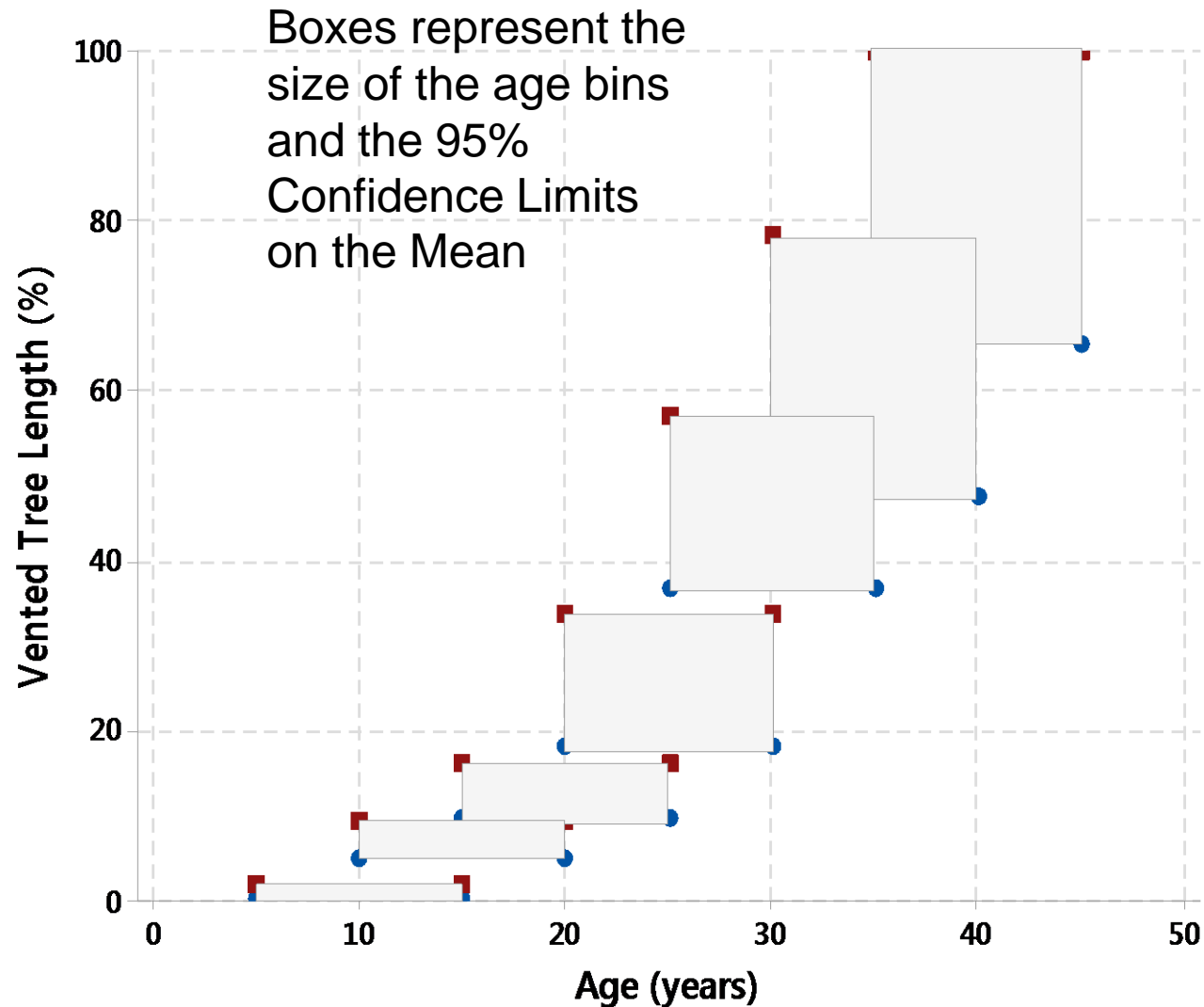
Basic Assessments

Cables are extracted from the field

- Failed
- Siblings of Failures
- Concerning

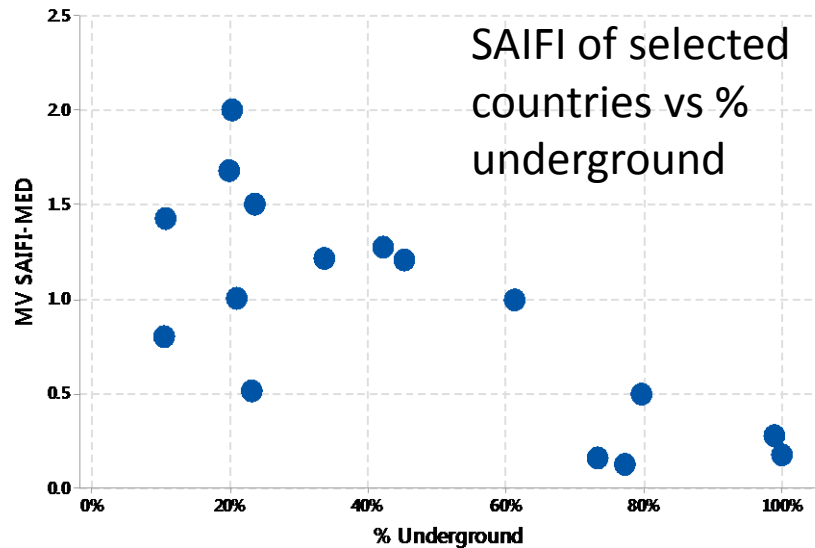


Evolution of Tree Length – Measured Data



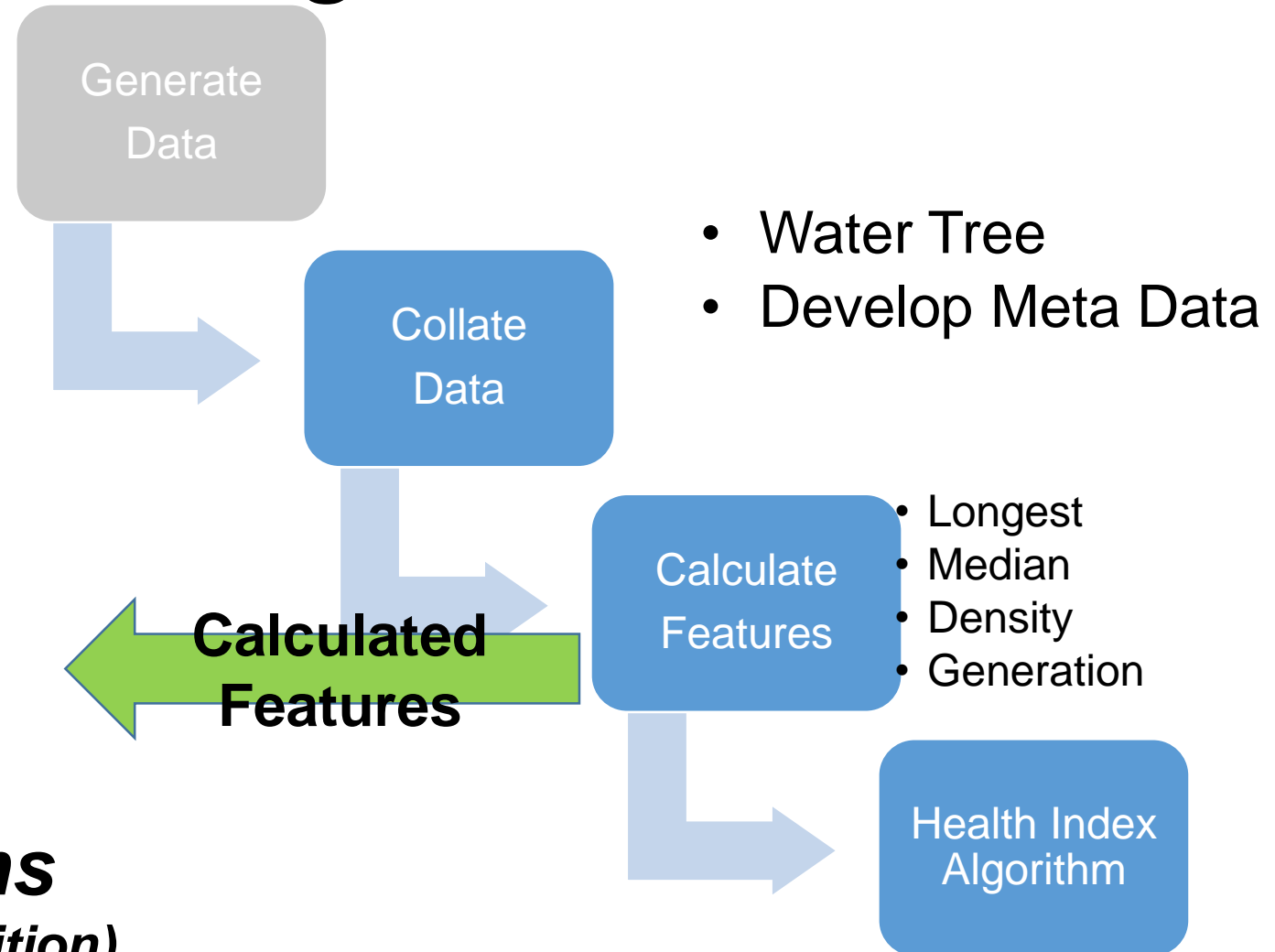
- Age data are generally available
- These are grouped to determine the distribution of lengths of trees in “Age Bins” – Mean Lengths
- These estimates use all available tree lengths

Diagnostic Process to Manage the Asset



Rules of Thumb
(Heuristics)

Classification Algorithms
(Machine Learning, Pattern Recognition)

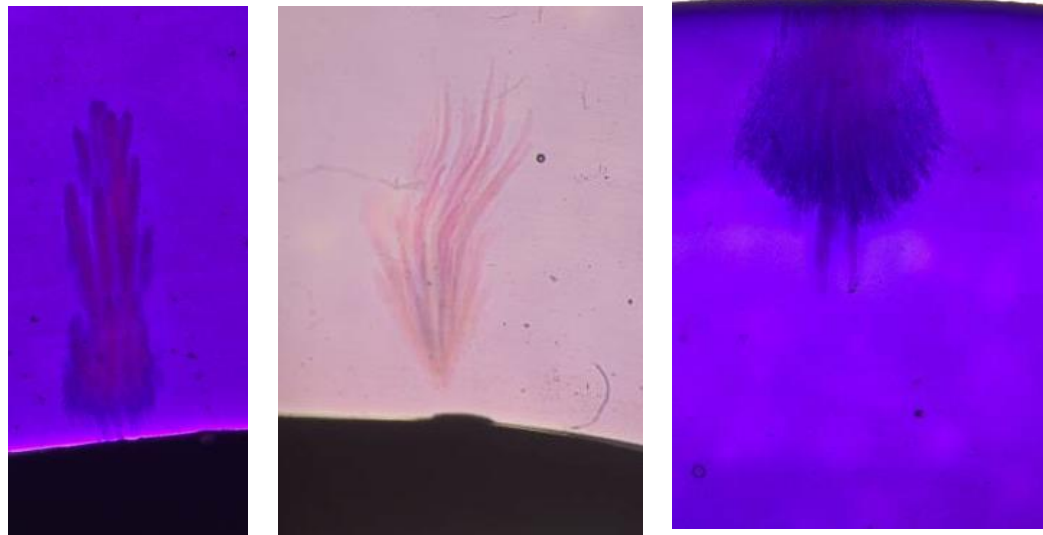


Measured Tree Diagnostic - Heuristic

**Heuristic
Engineering Expertise**

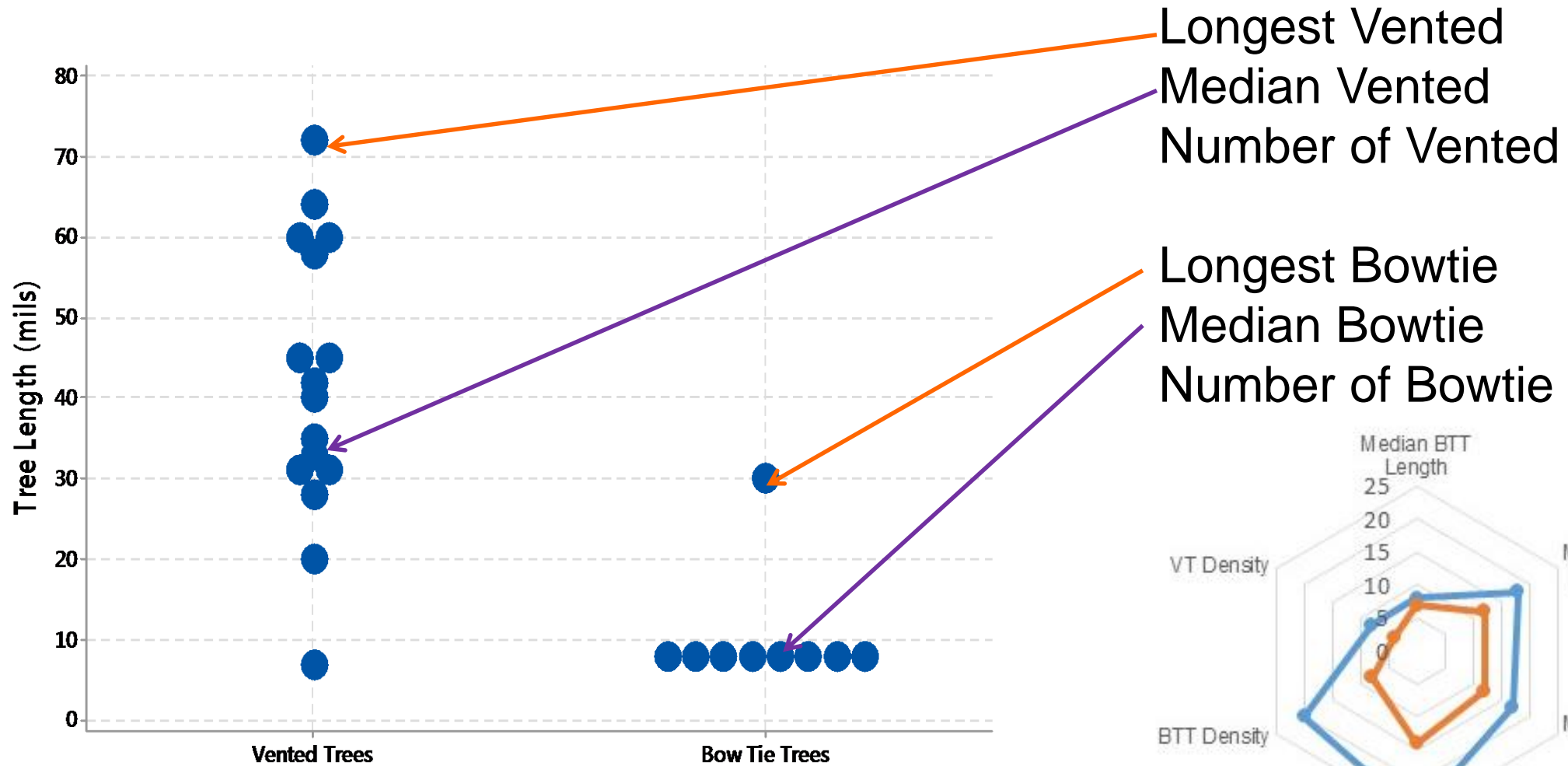
*Trees > 50% of insulation
correlate with Failure in Service*

	Trees <50%	Trees >50%
Survived in Service	80	32
Failed in Service	76	24



Overall → 49%
Expert Driven
Heuristics not effective

Use More Information ?



Health Indices for Asset Management

- Health Indices summarise many inputs (Treeing, Age, History, Generation, etc)
- Most are simple “Rules of Thumb” developed based on expert opinion

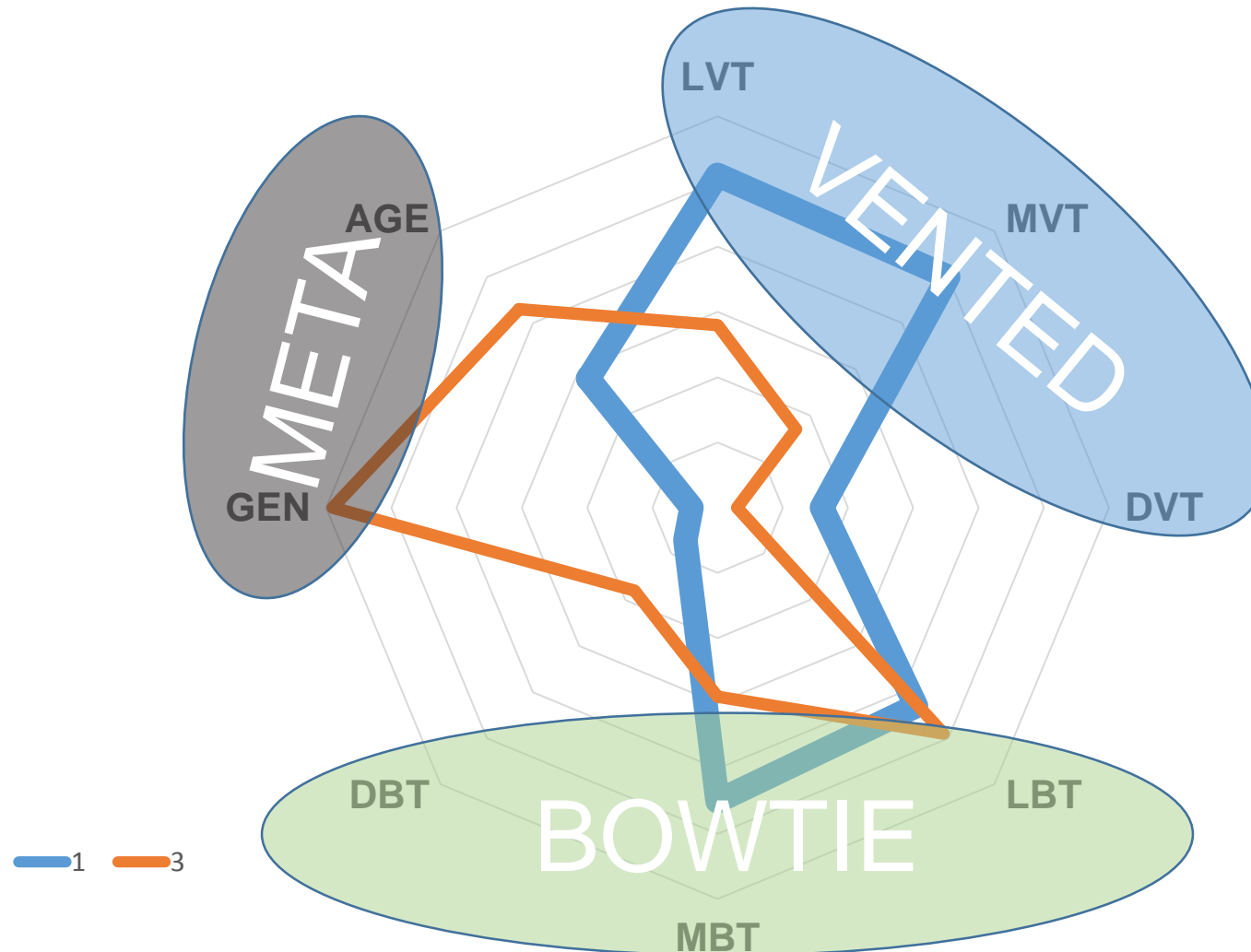
$$HI = \alpha \textit{Length} + \beta \textit{Density} + \gamma \textit{Generation} + \dots + \dots + \dots + \dots$$

- **In this work** large datasets are available hence the most appropriate way forward is to use a “Machine Learning / Algorithmic” approach
- Determine the Weights ($\alpha, \beta, \chi, \dots, \dots, \dots$)
- For
 - Length – Bowtie & Vented, Longest & Median
 - Density - Bowtie & Vented
 - Meta Data – Generation, Age

Evolving Cable Design Solutions

Generation	Insulation	Semicons	Jacket	Barrier
0	Paper Tape	Carbon Tape	Jacket	Extruded Lead
1	Thermoplastic HMPWE	Graphite / Carbon Tape	None	None
2		Extruded Thermoplastic		
3	XLPE or EPR	Graphite / Carbon Tape		
4		Extruded Thermoplastic		
5				
6			Jacket	Conductor Blocking Blocking / Metal Barrier
7	WTR XLPE or EPR	Extruded Thermoset (crosslinked)		
8				
9				
10	?	?	?	?

Weightings for Water Tree Factors



— 1 — 3

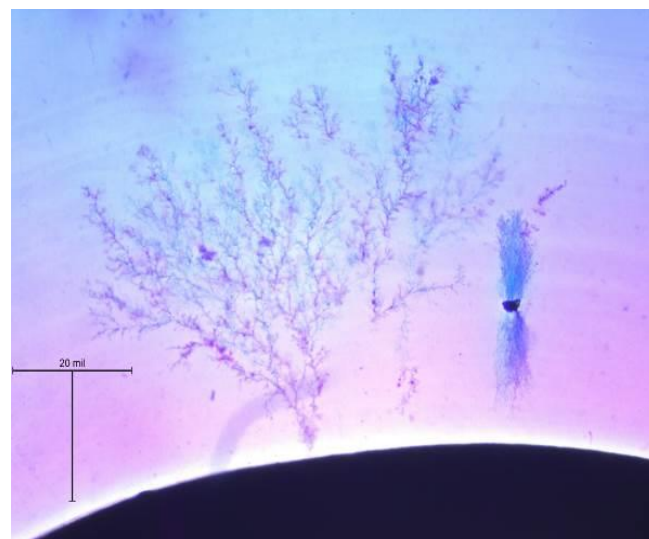
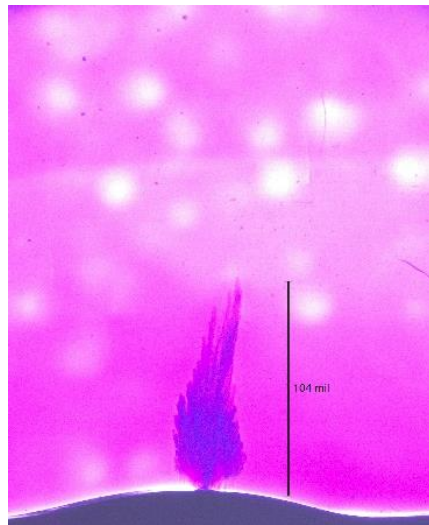
Health Index – Algorithm & Machine Learning



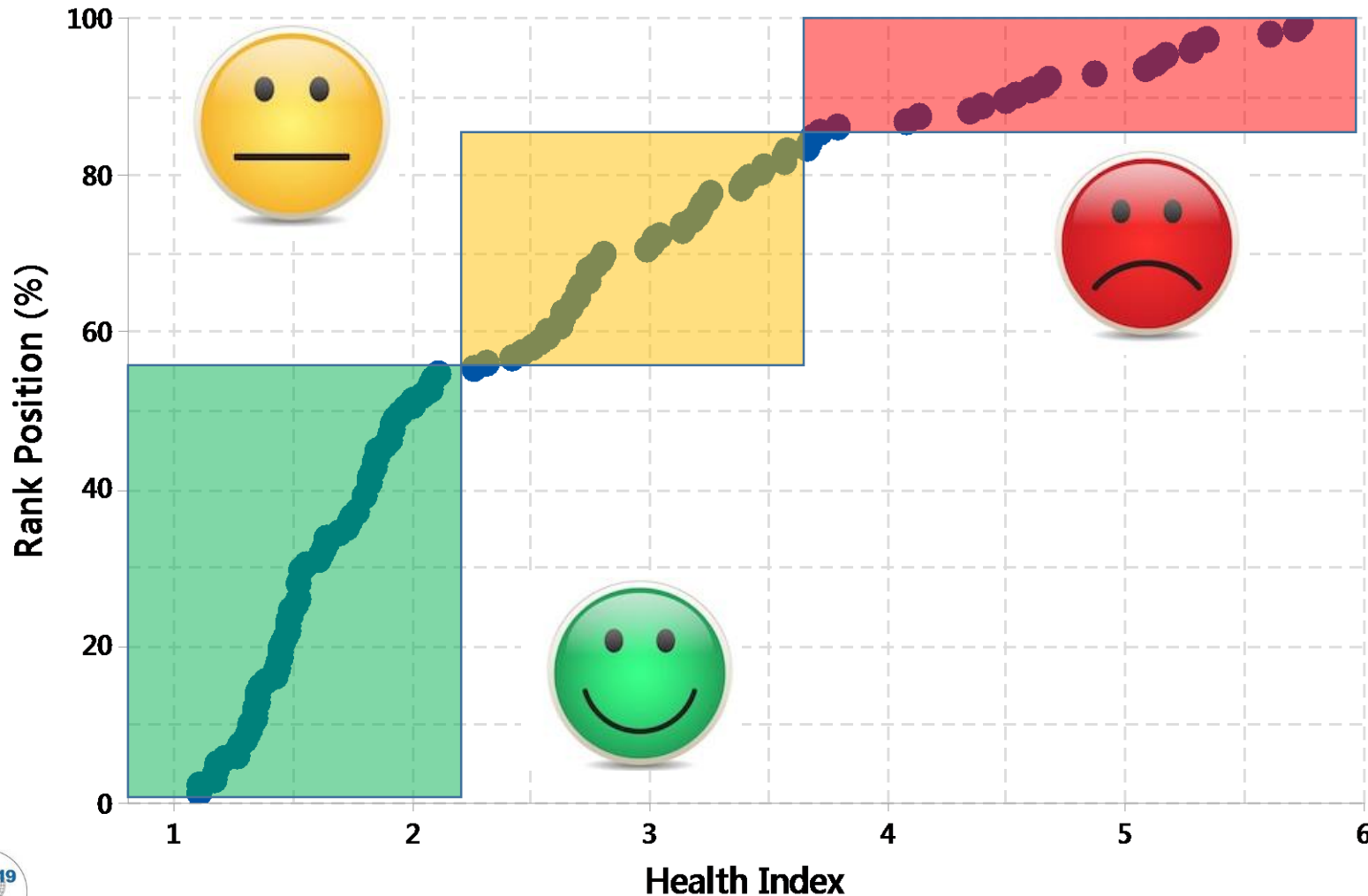
	Predict	
	Survive	Fail
Survived in Service	74	24
Failed in Service	35	65

Overall → 70%

**Current
Optimum**



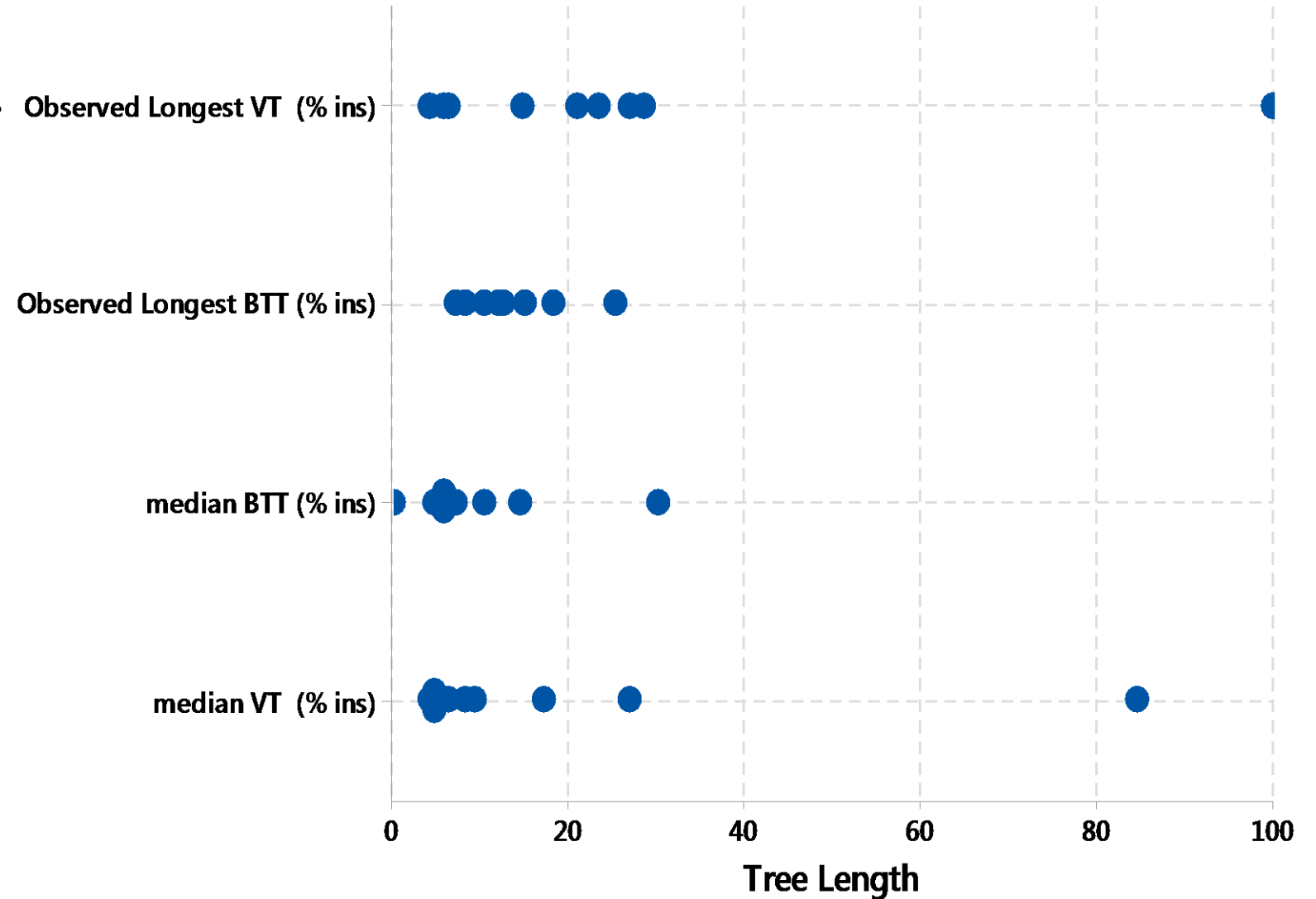
Generating Context



- Individual Health Index (HI)
- HI's have meaning – large values = more / big trees = poorer performance
- Provide a context for future measurements
- Auto update with new data
- Provides a “relative prioritization”

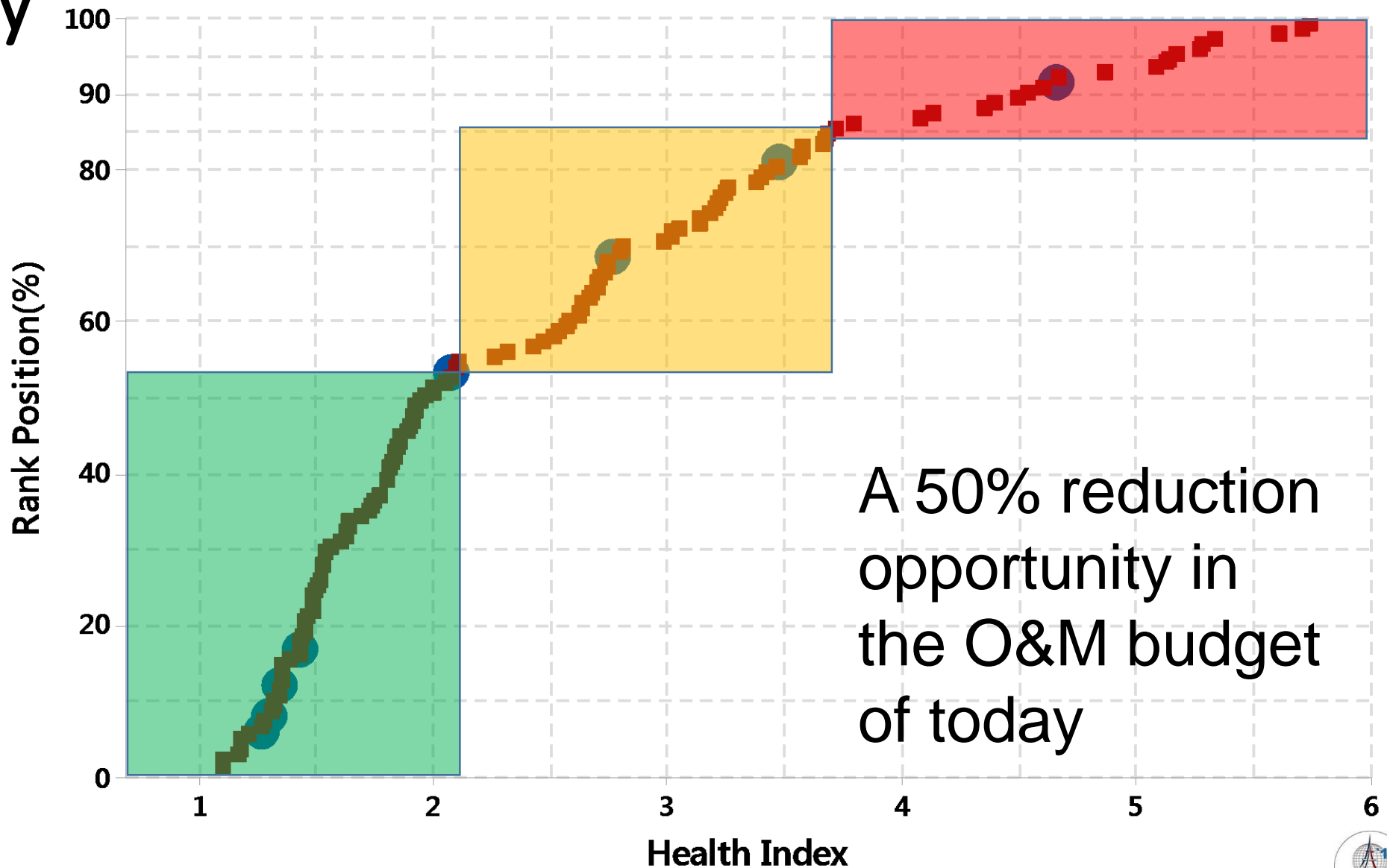
Case Study

- 8 cable investigations for 1979 vintage cables
- None of these cables have experienced a failure in service
- Interested in relative health and what actions are suggested by experience



Case Study

- 8 cable investigations for 1979 vintage cables
- 4 - 5 in “No Immediate Action Required”
- 2 - 3 in “Watch”
- 1 in “Action Required”



A 50% reduction opportunity in the O&M budget of today

Conclusions

- Collated data is the basis for analyses – datamining is worth the effort
 - Brings insights
 - Enables testing of “Heuristics / Tribal Knowledge”
- Data and Expertise derived Health Indices
 - Outperform simple Heuristics
 - Capture valuable knowledge
- Health Indices provide
 - Context
 - Transparent decision making
- There is a way to make use of the information that come from forensic cable analyses