Data Analytics for Transformer Dissolved Gas Analysis to Aid Asset Management

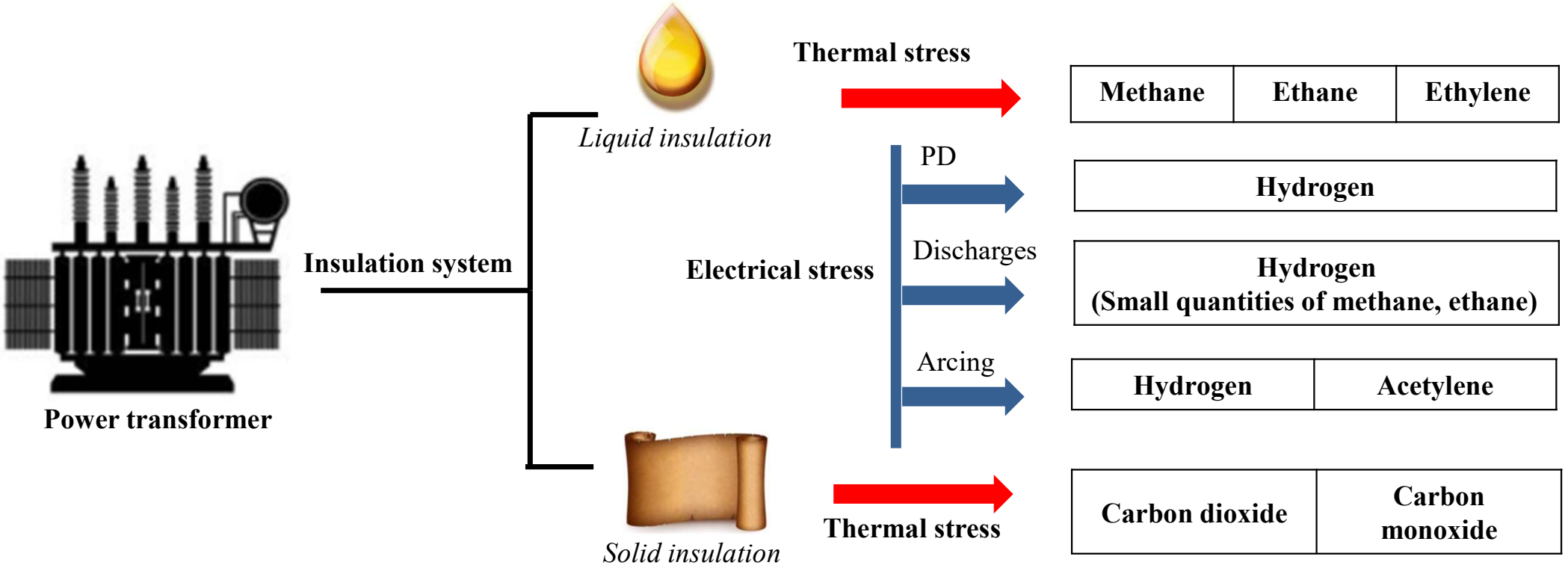
Presenter: Prof Zhongdong Wang
The University of Manchester

Content

- Introduction
- Database
- Exploratory Data Analysis (EDA)
- Trend Detection
- Summary

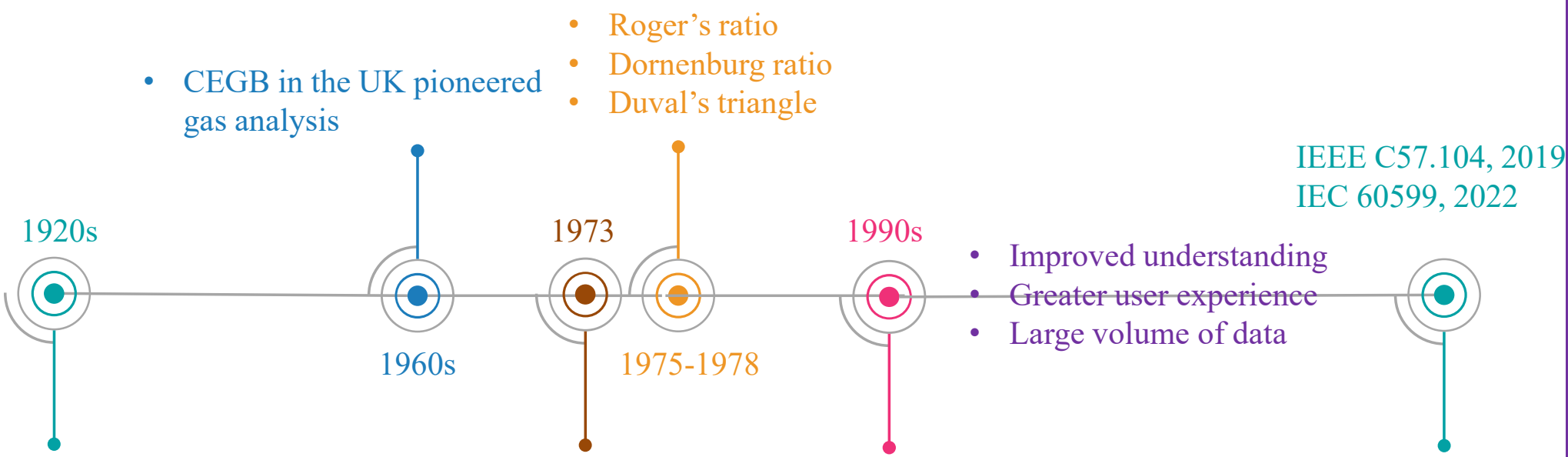
Dissolved Gas Analysis (DGA)

- The deterioration of the transformer insulation system results in the formation of gases



- Periodical sampling of transformer oil for DGA helps utilities diagnose and monitor the insulation condition

DGA Milestones

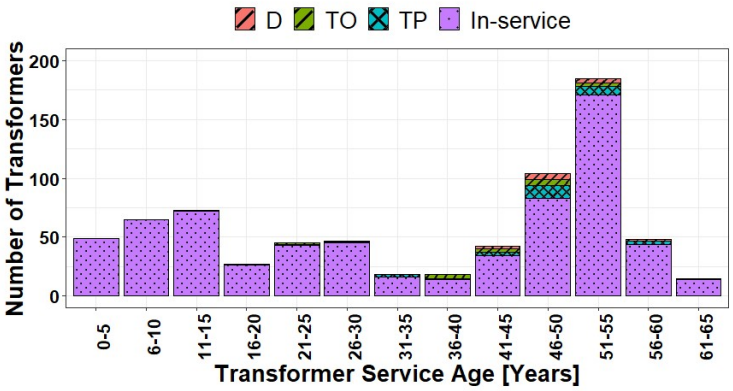


Database

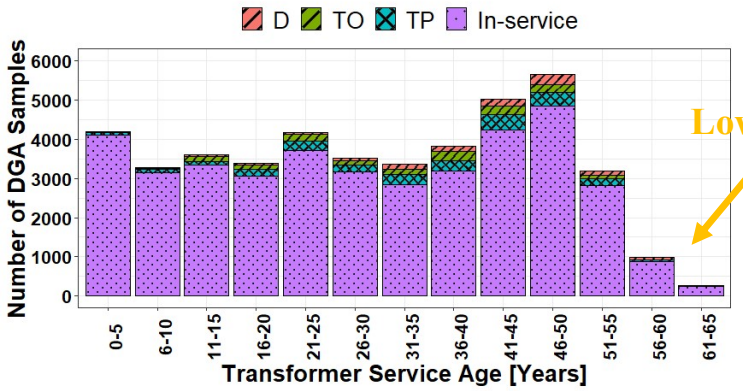
- Main tank DGA data of free-breathing and mineral oil-filled transmission transformers

Transformer Group		Transformers	DGA Samples
In-service		676	39,612
Scrapped	Dielectric (D)	12	1,076
	Paper ageing (TP)	30	2,332
	Oil ageing (TO)	18	1,416
	Total	60	4,824

- In-service TX are highly outnumbered
- A limited number of scrapped units



Composition of transformers over service age



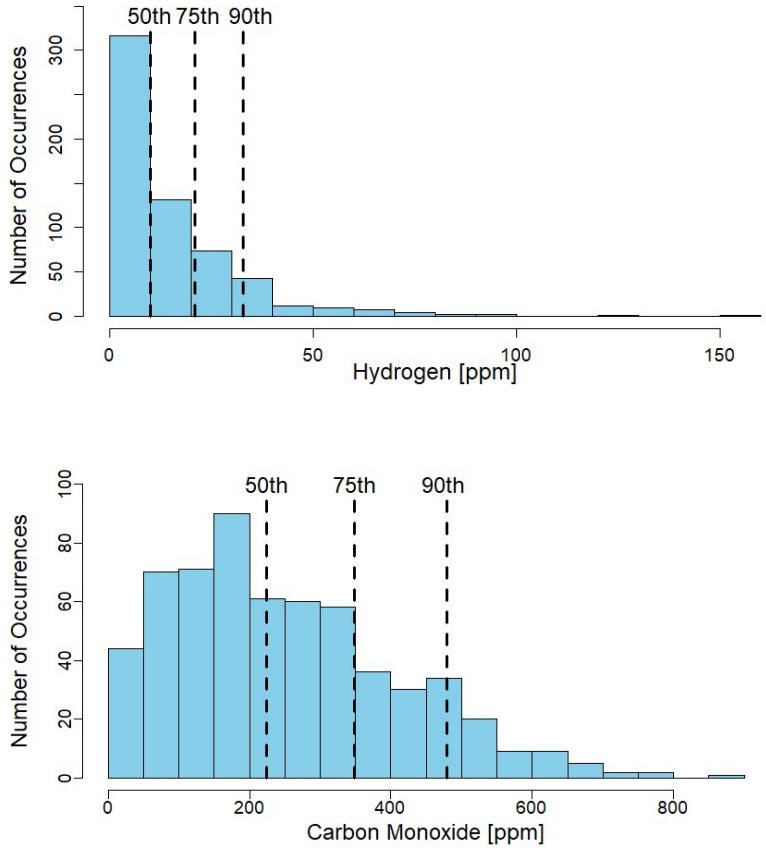
Low sample size (>55 years)

Composition of DGA samples over service age

Data Exploration by Percentiles

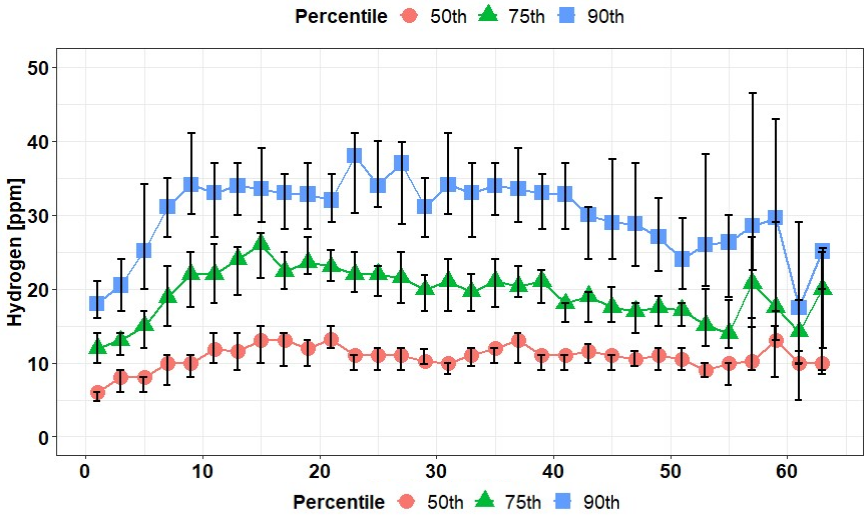
- The gases showed a right skewed gas level distribution for each service age.
  - Hydrogen and hydrocarbon gases are generally concentrated to the lower end.
  - Carbon oxide values are concentrated to the middle.

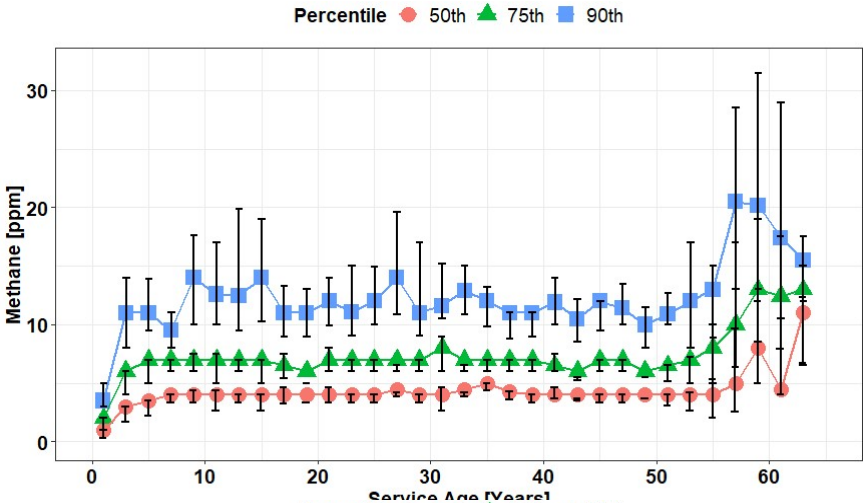
- Three percentiles were selected to represent the generic trend nature.
  - **50th** represents where the data are concentrated.
  - **90th** represents the maximum level of gas with reduced possible rare events.
  - **75th** incorporates the data variation between the 50th and 90th percentile.

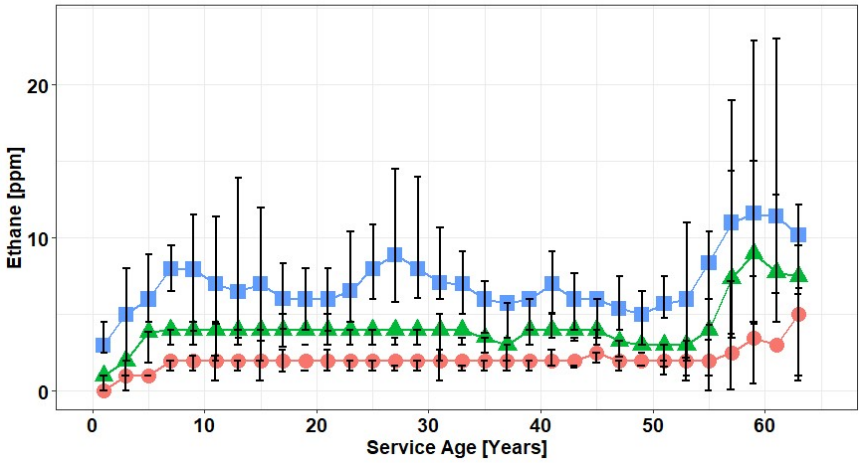


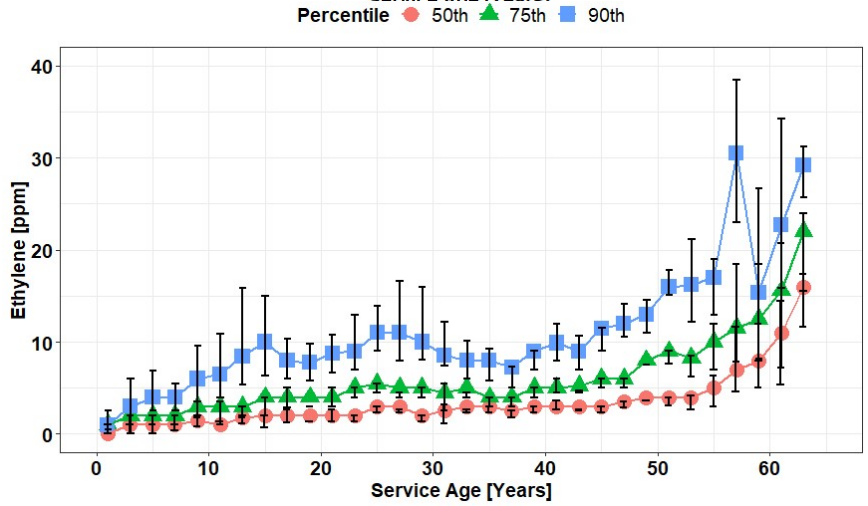
Example of data distribution and percentiles

Hydrogen and Hydrocarbon Gases

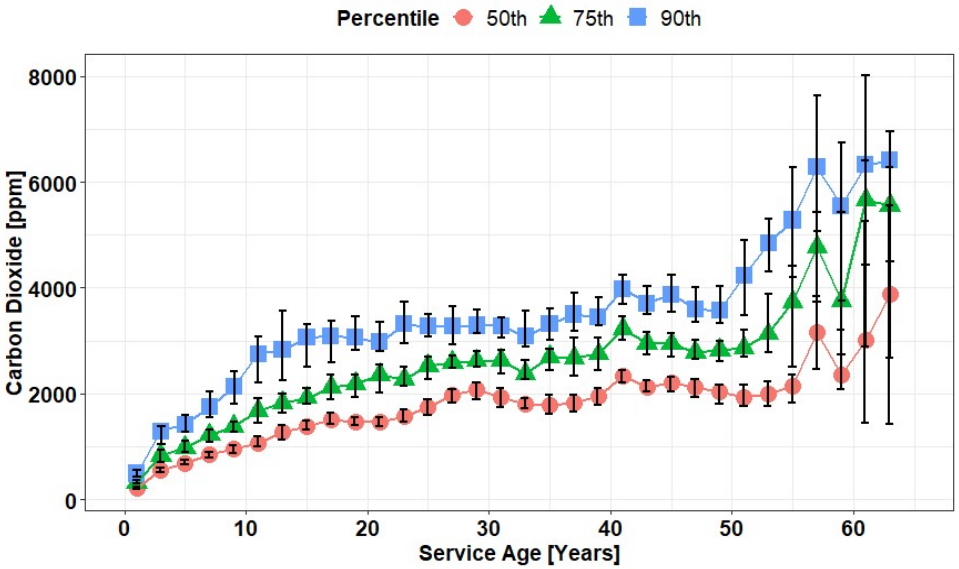


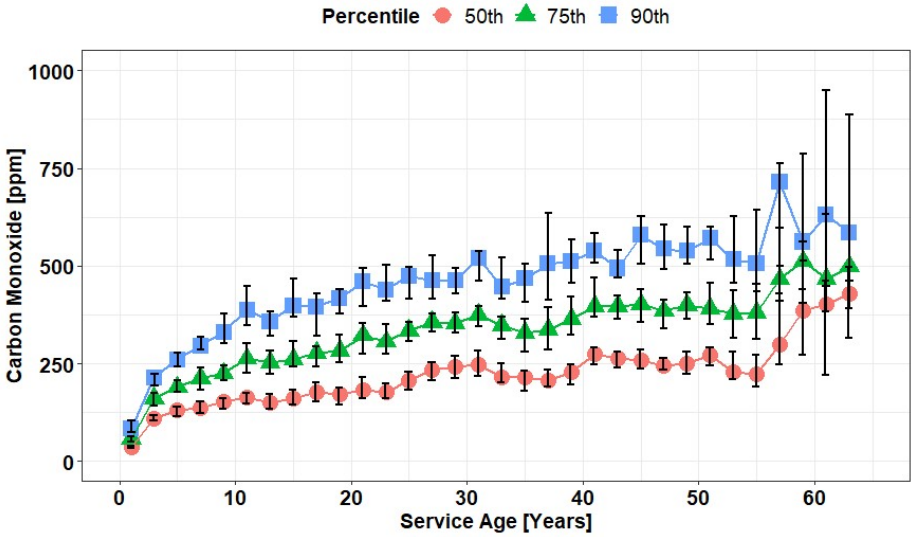






Carbon Oxides





Observations of EDA

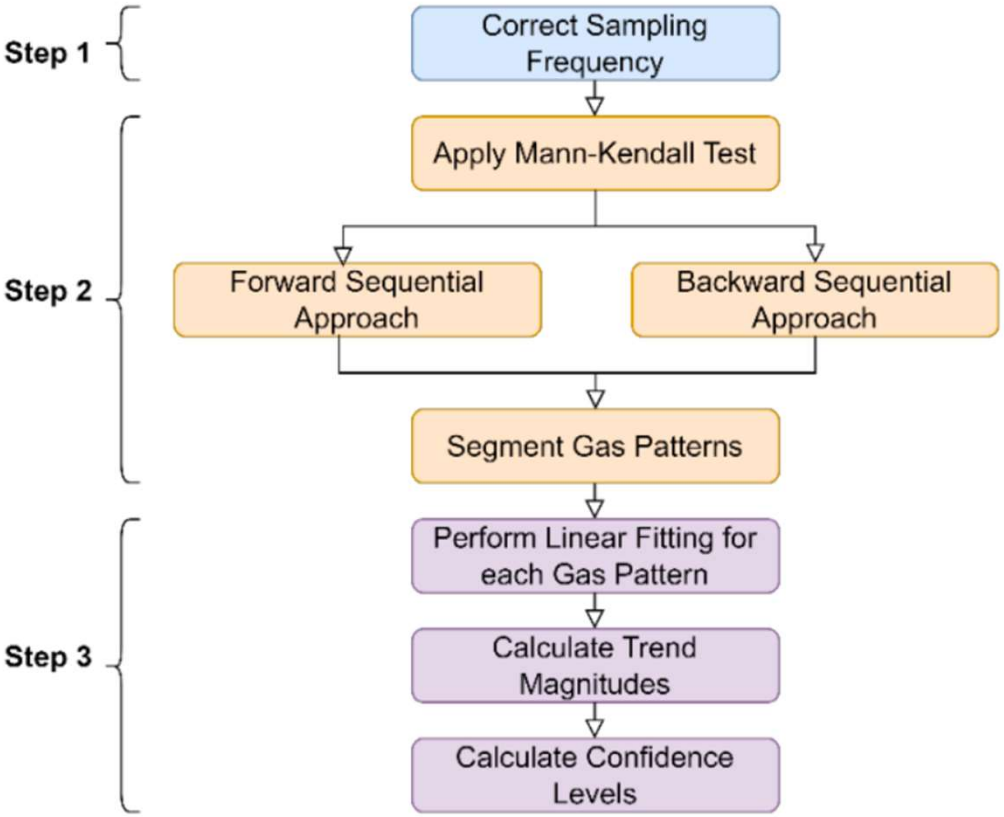
- Graphical and statistical analyses were performed through percentile curves for long-term gas patterns
- The following table summarises observed gassing patterns with transformer service age

Gas	Generic pattern	Remarks
Hydrogen	No influence on service age	Higher levels in hydro-treated uninhibited oil
Methane	No influence on service age	
Ethane	No influence on service age	Higher levels in hydro-treated uninhibited oil
Ethylene	No influence on service age	Some TX families show incremental nature towards late service ages (>50 years)
Acetylene	Mostly zero	
Carbon dioxide	Increasing pattern with a decremental rate	Higher levels in old TX families (before1970s)
Carbon monoxide	Increasing pattern with a decremental rate	Higher levels in old TX families (before 1970s)

Development of Trend Detection Method

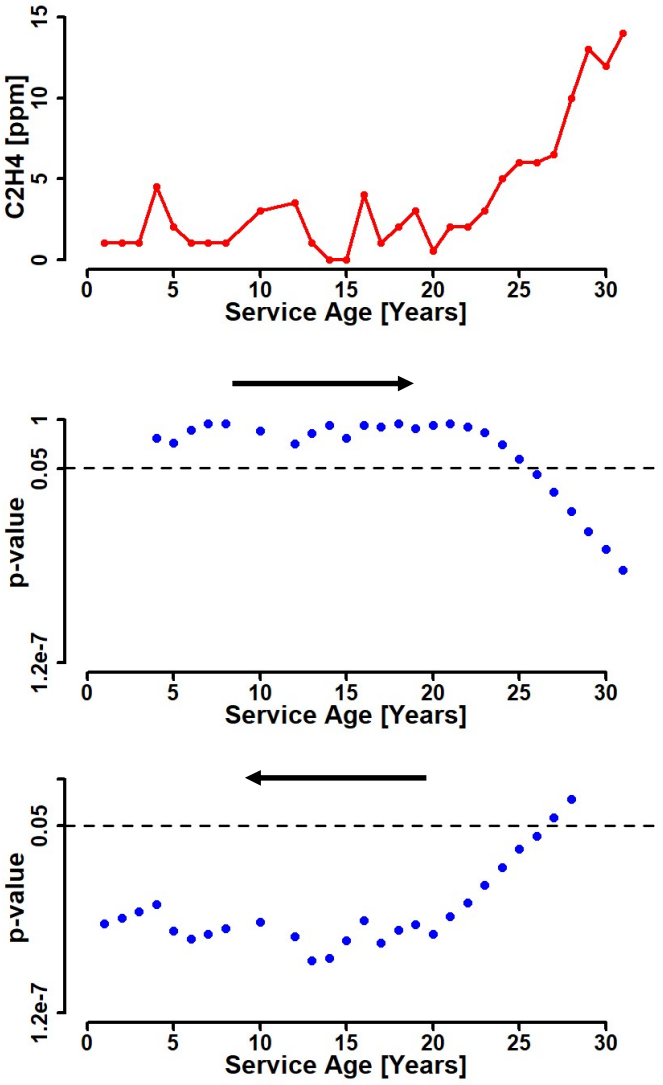
- The methodology consists three main stages

1. Correction of sampling frequency
   - 6-month median
2. Segmentation by Mann-Kendall trend detection test
   - A minimum of 4 samples
   - Widely used in hydrological data
3. Determine trend magnitudes (ppm/year) by linear fitting
   - Supress the effect of data fluctuation



Bi-directional Observation of Mann-Kendall Test

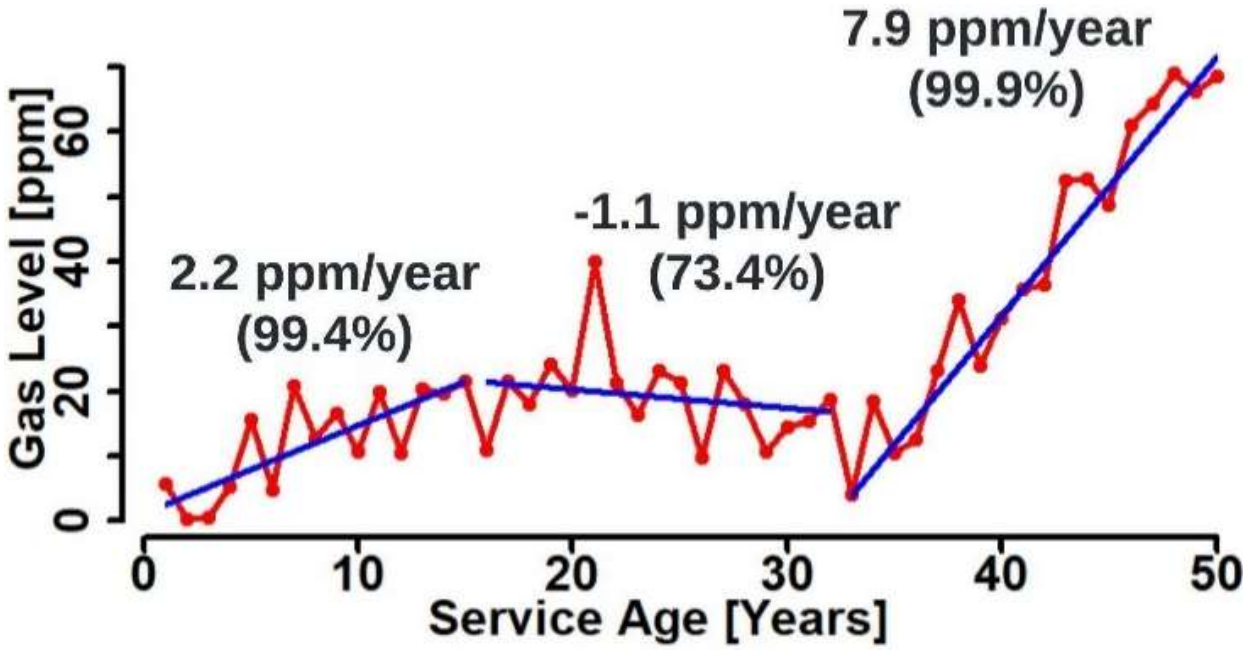
- Opposite directional observation of p-value variation helps to identify the starting point of linear trends [1,2]
- From the forward directional observation, the endpoint of the segment is the last point
- From the backward directional observation, the p-value tends to be constant beyond 20 years
- Selecting the first local minima point that p-value < 0.05 is a better approach to finding the other end of the trend [1]
- Discreate second derivative is one option to find the local minima points (x_n) [2]
  - $x_n; x_n < x_{n+1}$



[1] Gersterngarbe F., Werner P. C., 'Estimation of the beginning and end of recurrent events within a climate regime', Climate Research, Vol. 11, pp. 97-107, 1999

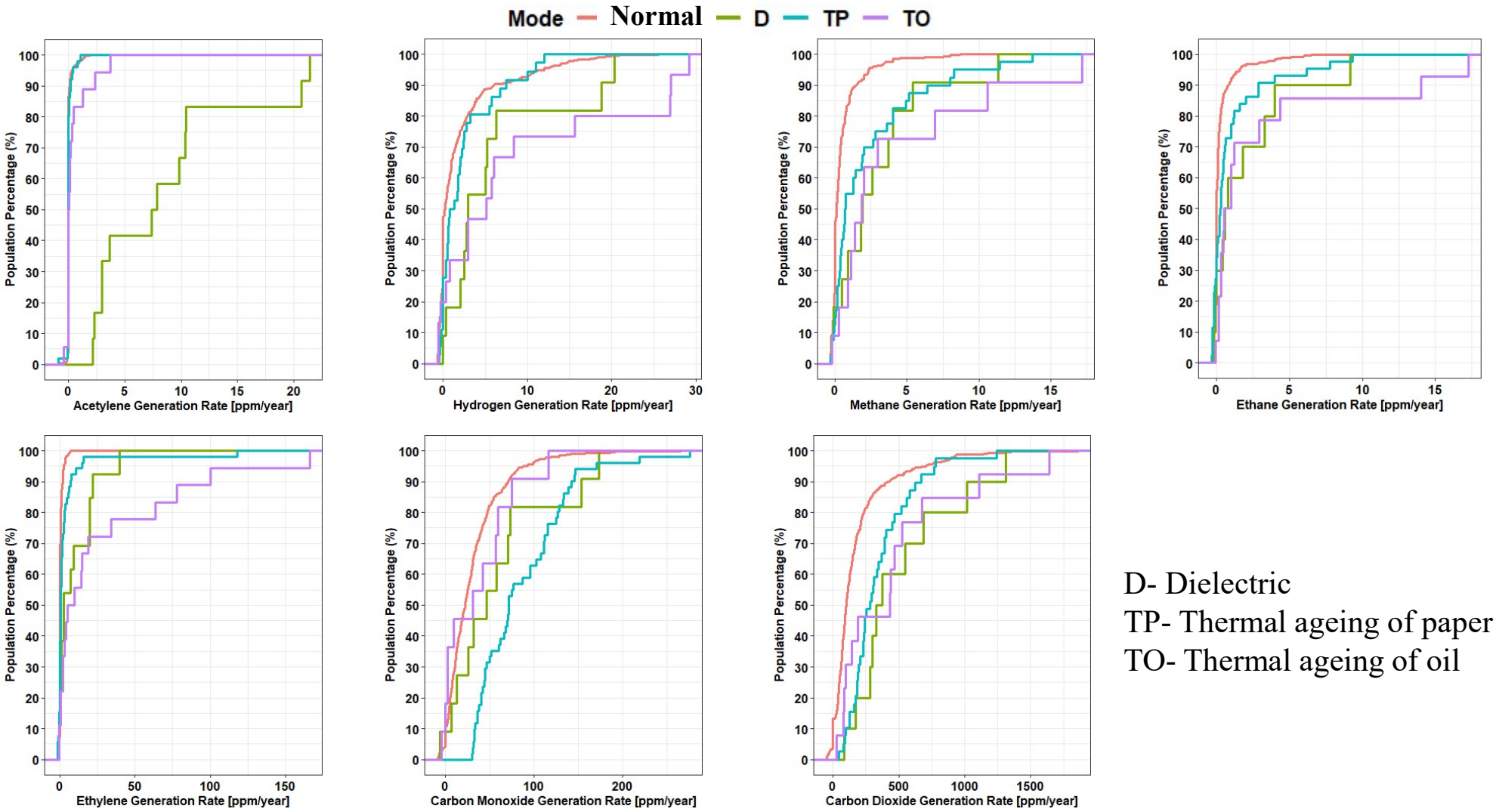
[2] Z. J. Wang and P. Willett, "Joint segmentation and classification of time series using class-specific features," in IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics), vol. 34, no. 2, pp. 1056-1067, April 2004

Example of Trend Detection Output



Demonstration of trend detection using the developed method

Gas Generation Rates of Transformer Population



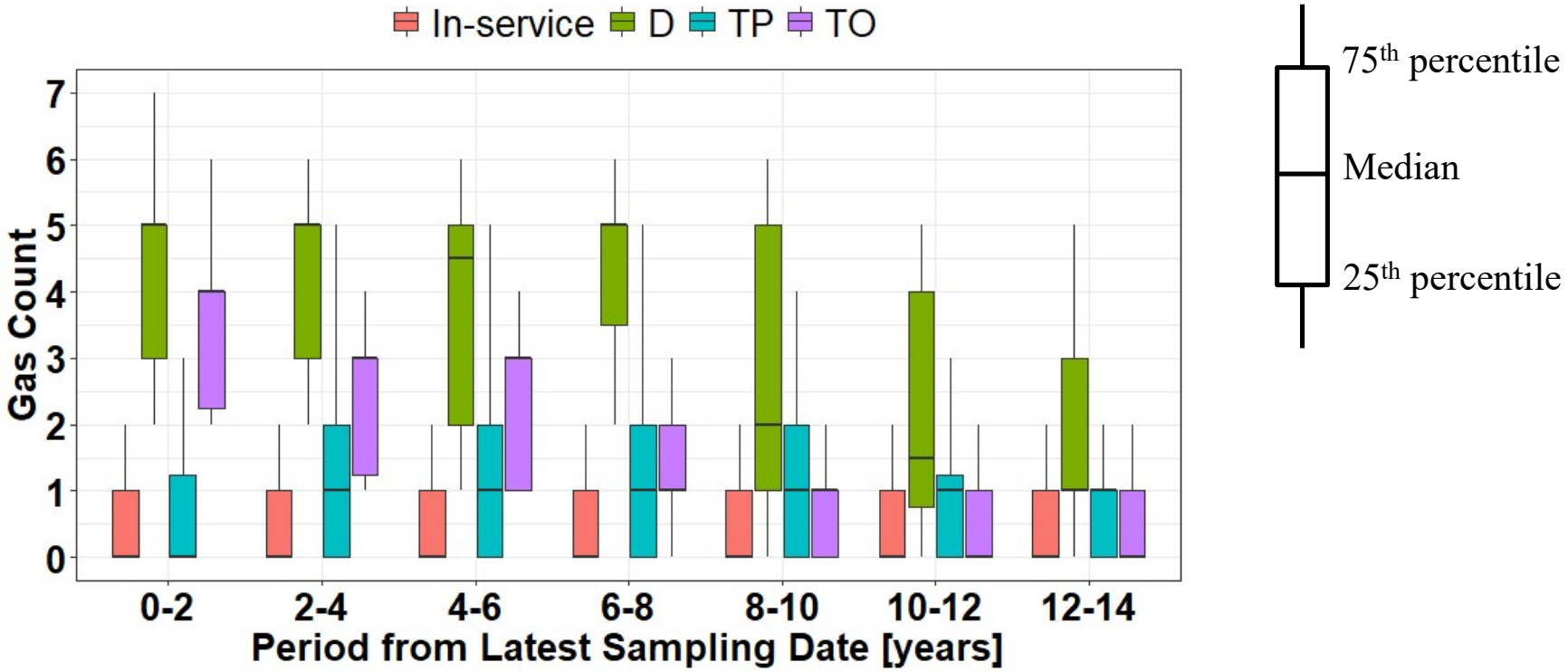
D- Dielectric
TP- Thermal ageing of paper
TO- Thermal ageing of oil

Observations from Trend Profiles

- The observations of gas generation rates reflect the theoretical and practical experiences of fault interpretation of gases

Gas	Observation with reference to normal TX	Primary indication [IEEE, IEC]	Secondary indication [IEEE, IEC]
Hydrogen	Higher in D and TO	Corona, PD	Arcing, Overheating of oil
Methane	Slightly higher in D, TO and TP		Corona, Arcing, Overheating of oil
Ethane	Slightly higher in D and TO		
Ethylene	Higher in TO	Overheating of oil	Corona, Arcing
Acetylene	Higher in D and slightly higher in TO	Arcing	Severe overheating of oil
Carbon dioxide			Overheating and arcing in cellulose
Carbon monoxide	Higher in TP	Overheating of cellulose	Arcing in cellulose

Number of Gases Counts



- A clear difference in the number of gases generated from normal and scrapped transformers (D and TO) is observed
- Dielectric faults (D) show gas generations up to around 10 years early from the scrapped date
- Thermal heating of oil (TO) shows gas generations up to around 6 years early from the scrapped date

Summary

- This research analysed DGA databases of in-service and scrapped transformers and developed the following data management methodologies to aid asset management.
- Long-term DGA patterns were revealed through graphical and statistical analyses to incorporate service age in DGA interpretations
- An automated trend detection tool was developed to support DGA interpretation and manage large amounts of DGA data.

For more details:
[1] T. Herath, Z.D. Wang, Q. Liu, G. Wilson, R. Hooton and T. Raymond, "Development of Trend Detection Technique for Dissolved Gas Analysis of Transmission Power Transformers," IEEE Transactions on Power Delivery. (Accepted)
[2] T. Herath, Z.D. Wang, Q. Liu, G. Wilson, R. Hooton, D. Walker, T. Raymond, and L. Van-der-Zel "Data Analytics for Transformer Dissolved Gas Analysis to Aid Asset Management," CIGRE 2024 Paris Session, A2-10403.
[3] T. Herath, Q. Liu, G. Wilson, S. Tee, and Z. Wang, "Observations of abnormal gassing rise after metal passivation in transformers," in 8th International Conference on Condition Monitoring and Diagnosis (CMD), Phuket, Thailand, 2020, pp. 246-249.
[4] T. Herath, Z. Wang, Q. Liu, G. Wilson, R. Hooton, and S. Tee, "Long-term DGA trend evaluation of transmission power transformers," in 22nd International Symposium on High Voltage Engineering (ISH), Xi'an, China, Nov. 2021, pp. 509-514.
[5] T. Herath, Z. Wang, Q. Liu, G. Wilson, R. Hooton, T. Raymond, and S. Tee, "Observations of abnormal gassing rise after metal passivation in transformers," in 9th International Conference on Condition Monitoring and Diagnosis (CMD), Kitakyushu, Japan, 2022, pp. 221-224.