Risk Associated with Transformer Degradation

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Outlines

- ***Motivations and Objectives***
- ***Methodology with the use of ANN***
- ***Preliminary results and some issues***
- ***Data simulation***
- ***Conclusions***

Motivations

RISK

Failure probability

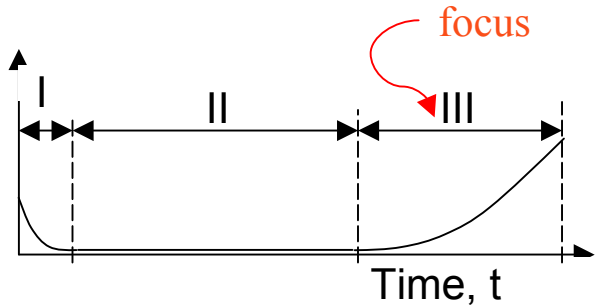
The industry experienced more loss due to ageing (degradation), retirement of engineers, e.t.c

Consequence

1. The average loss: $9000 per MVA
2. The largest loss: $86M

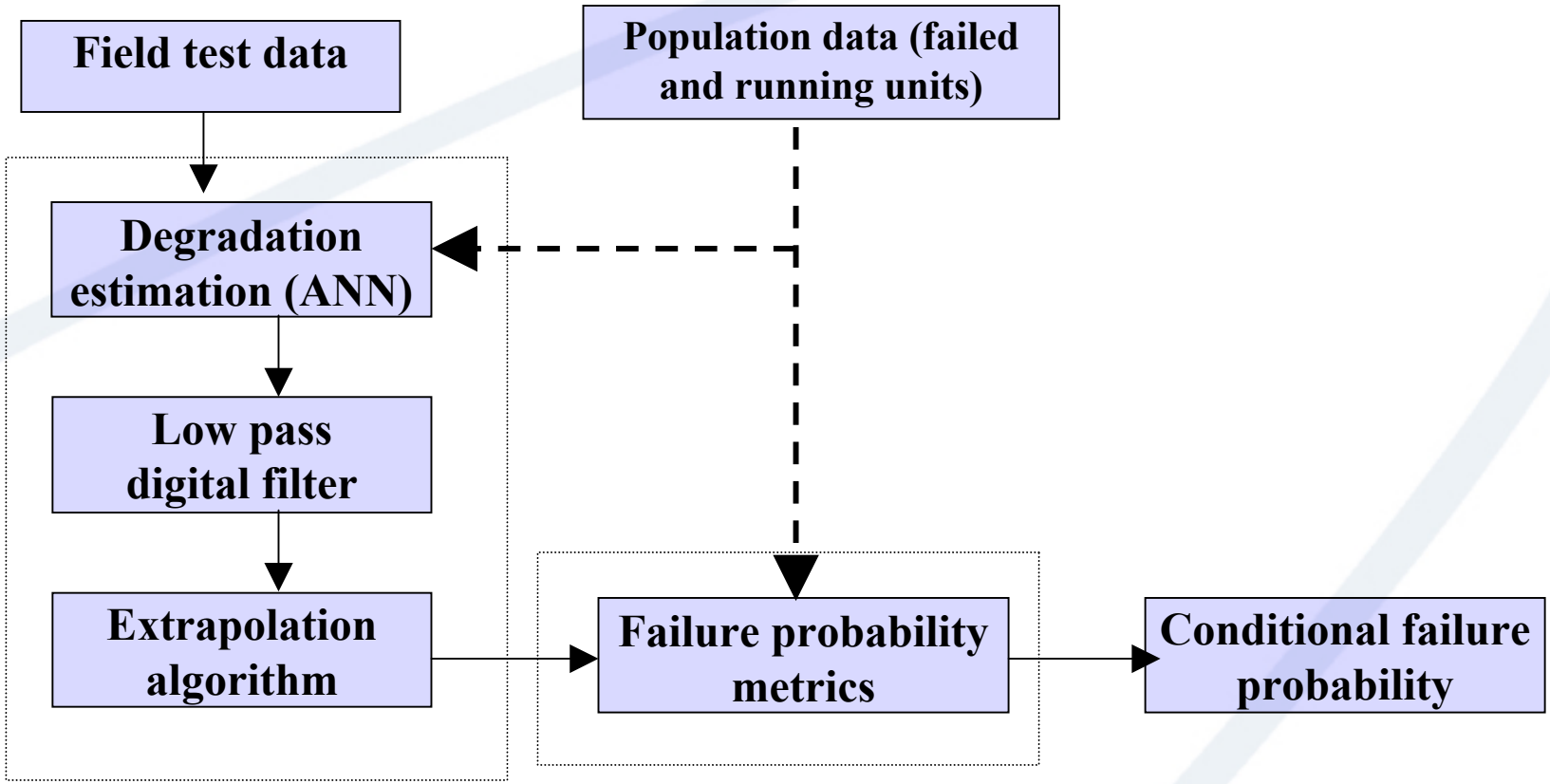
Objectives

- ***Failure probability assessment***
  - Early failures.
  - "Over-stress" failures.
  - "Under-strength" failures.

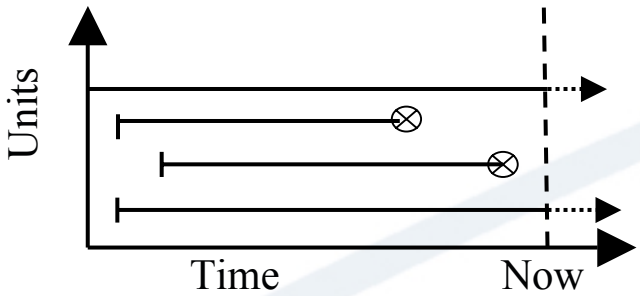


- ***Degradation assessment***
  - Degradation causes: operation history, maintenance, environment, design effects etc.
  - Difficulties: no single element available to measure the degradation level although many relevant tests are adopted in the industry.

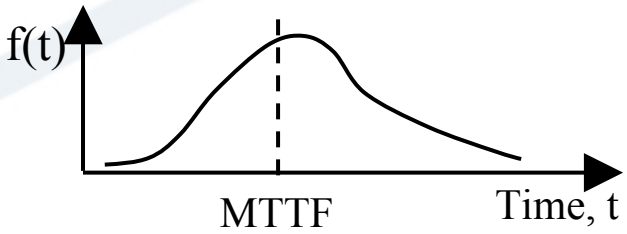
Methodology Overview



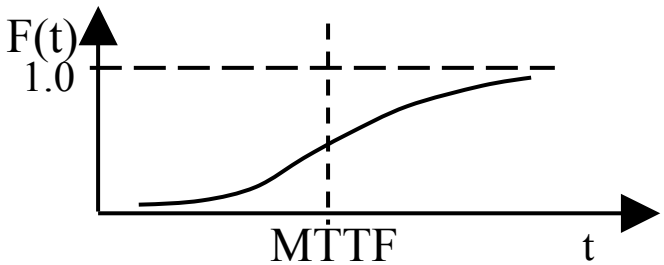
Methodology –failure probability metric



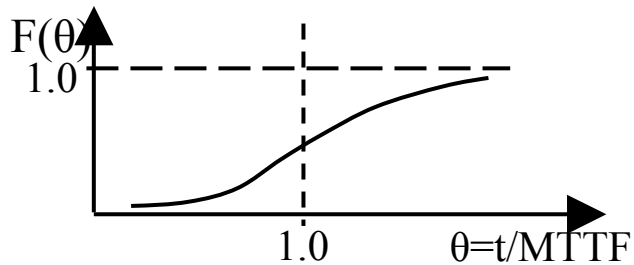
Step 1: unit survey to collect life information



Step 2: estimate the PDF and calculate MTTF



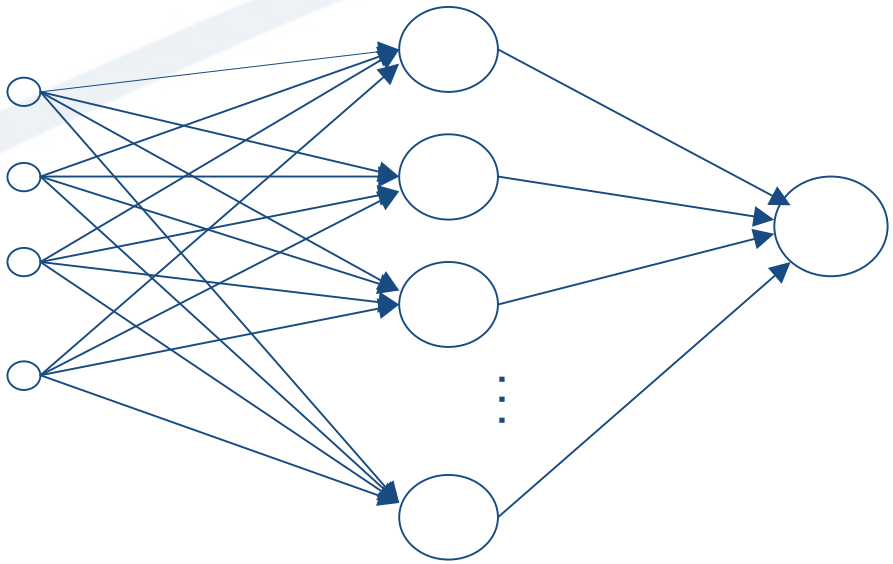
Step 3: estimate the CDF



Step 4: introduce degradation variable θ and the failure probability metric related to θ

Methodology –degradation estimation using ANN

$$\begin{Bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{Bmatrix} = X$$

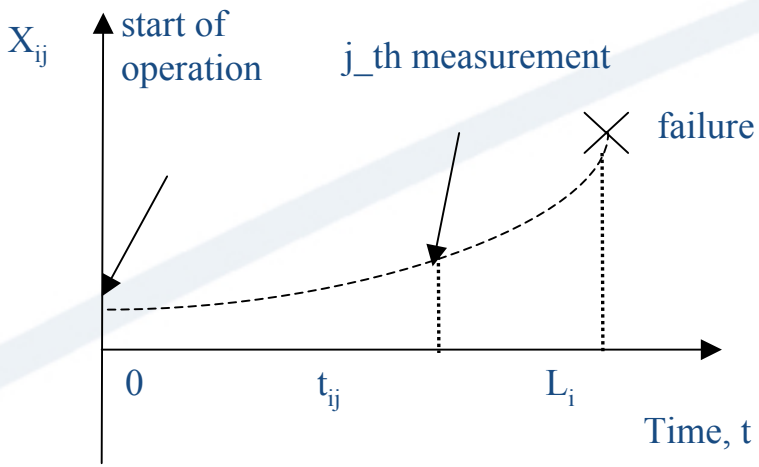


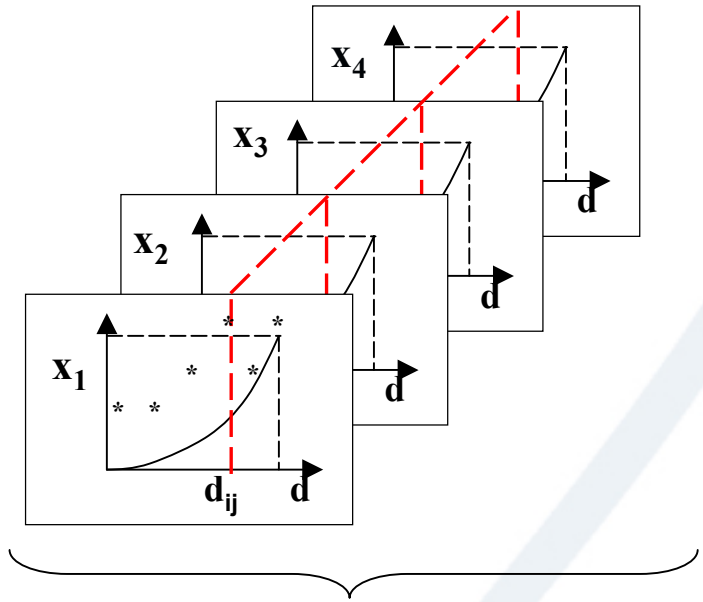
$\sigma = t/L_i$

$\sigma = f(X)$

Two important steps: Training and validation

Methodology- training data gathering





Equipment history

- t_{ij} – j^{th} test time of i^{th} failed unit
- L_i – life to failure of i^{th} unit
- d_{ij} – degradation at T_{ij} ($d_{ij} = t_{ij}/L_i$)
- $\underline{x}_{ij}$ – vector of variables measured at t_{ij}

Training case: ($\underline{x}_{ij}$, d_{ij})

Methodology- ANN training and validation estimates

Training

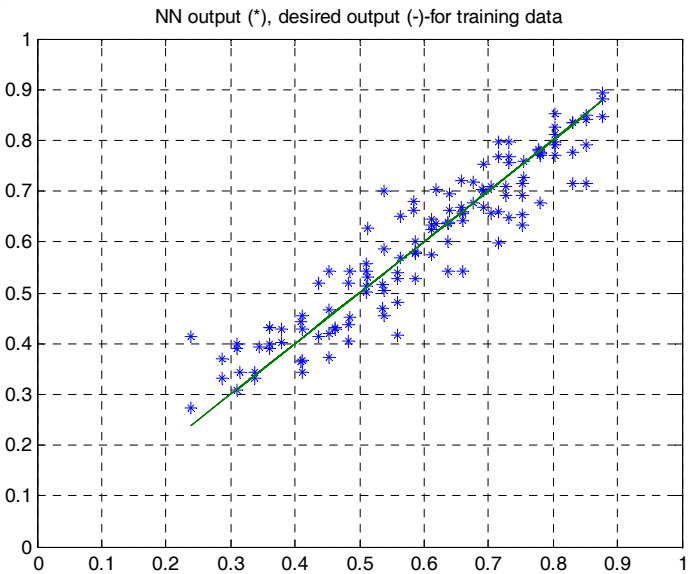
Mean(err) = -5.73 E-04

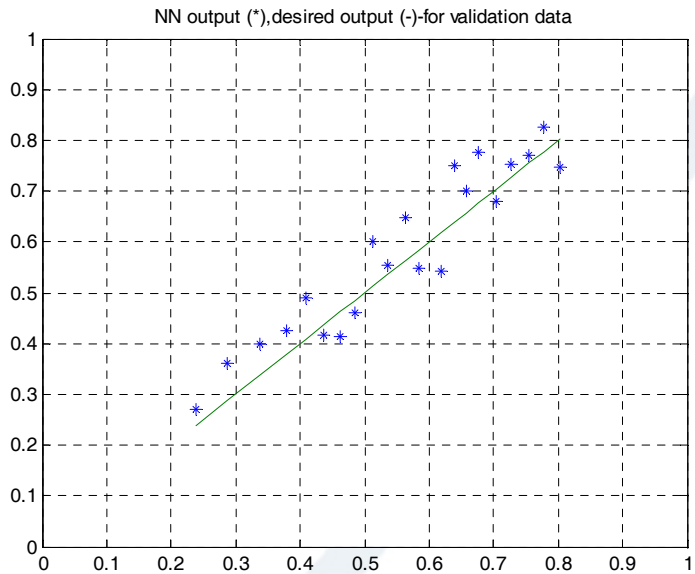
Var(err) = 2.81 E-03

Validation

Mean(err) = -1.79 E-03

Var(err) = 1.49 E-03

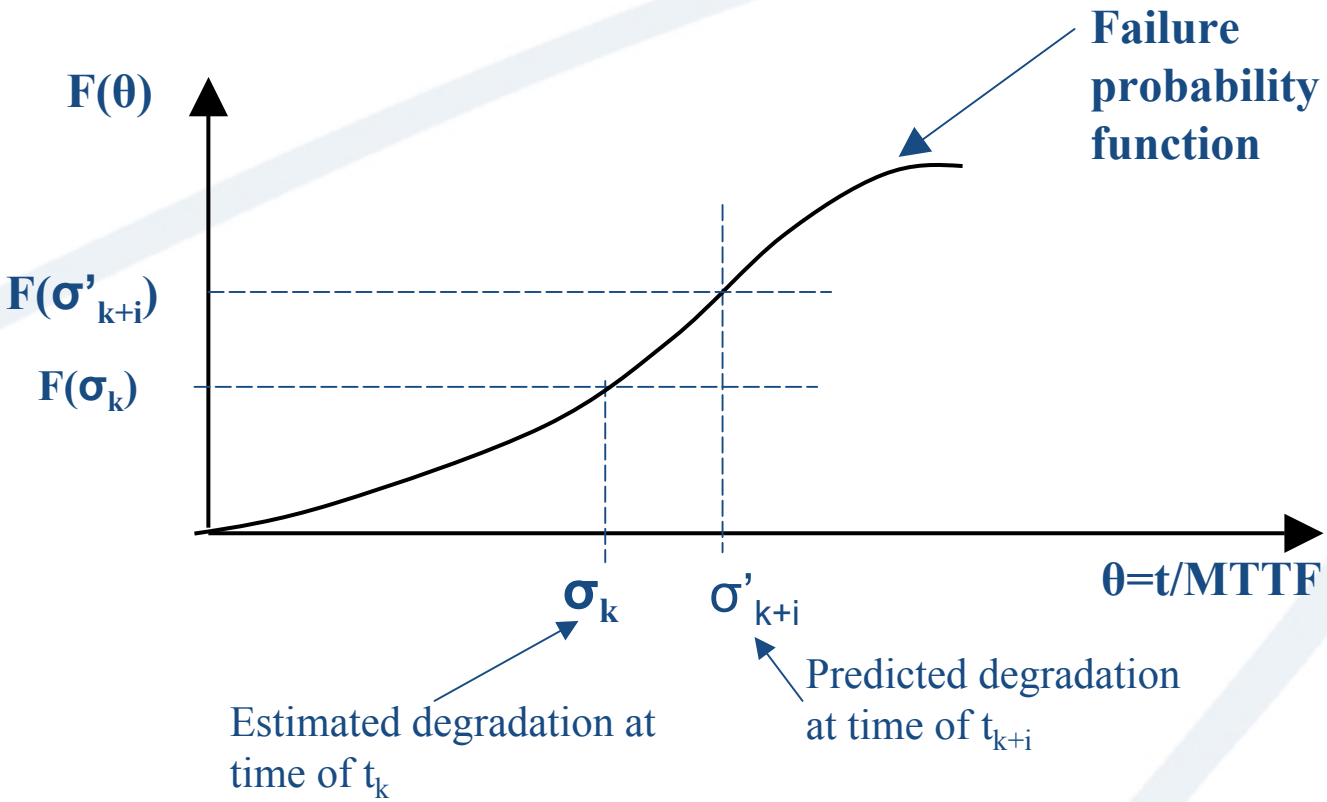




ANN estimates of degradation, σ

Actual degradation, d

Methodology- failure probability calculation

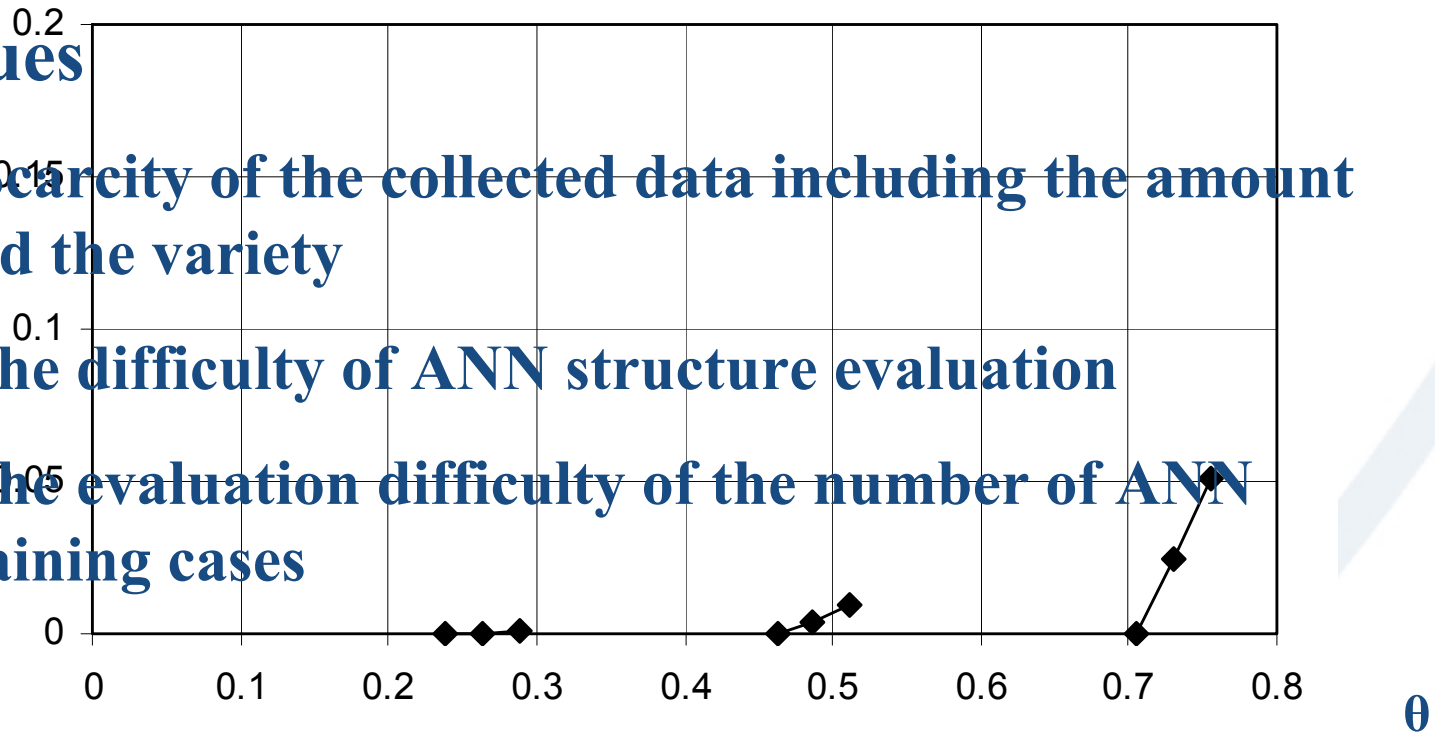


$$\varphi\left(t_{k+i} \mid t_k\right) = \frac{F\left(\sigma'_{k+i}\right) - F\left(\sigma_k\right)}{1 - F\left(\sigma_k\right)}$$

Preliminary results and issues

➢ Issues

- Scarcity of the collected data including the amount and the variety
- The difficulty of ANN structure evaluation
- The evaluation difficulty of the number of ANN training cases



An example of the failure probability prediction for a field unit caused by degradation

(one and two years ahead)

Data simulation

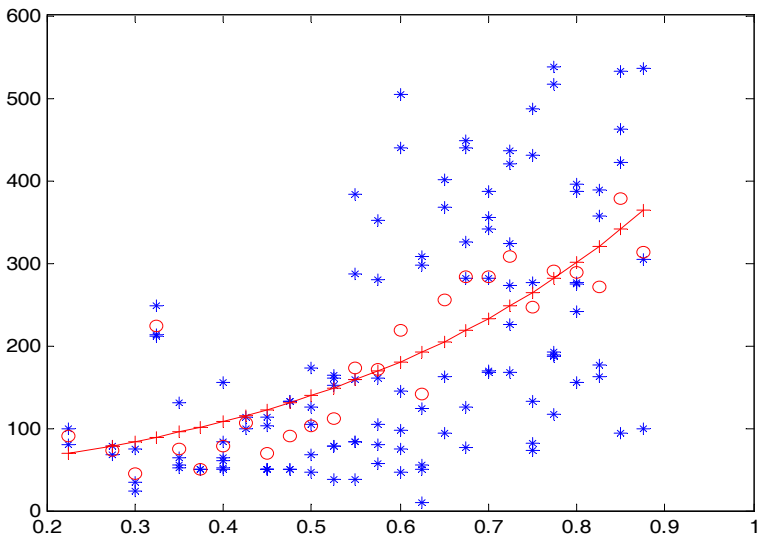
➢**Procedure:**

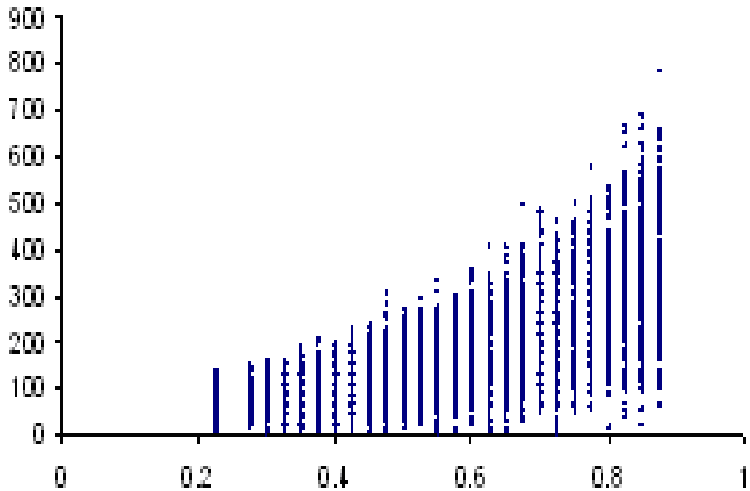
Step 1: Calculate the means (M_{ij}) and the Std.s (D_{ij}) at different stages of degradation based on real collected test data.

Step 2: Force the mean increase monotonously by using curve fitting (μ_{ij}).

Step3: Recalculate the Std.s S_{ij} of the test data at different stages. $S_{ij} = K \cdot \rho_i \cdot \mu_{ij}$

Step 4: Use the curved means and the recalculated Std.s to simulate the test data at different stages.





*: original test data; ○: calculated mean value; +: curve fitted mean value

ANN structure evaluation

Performance criteria

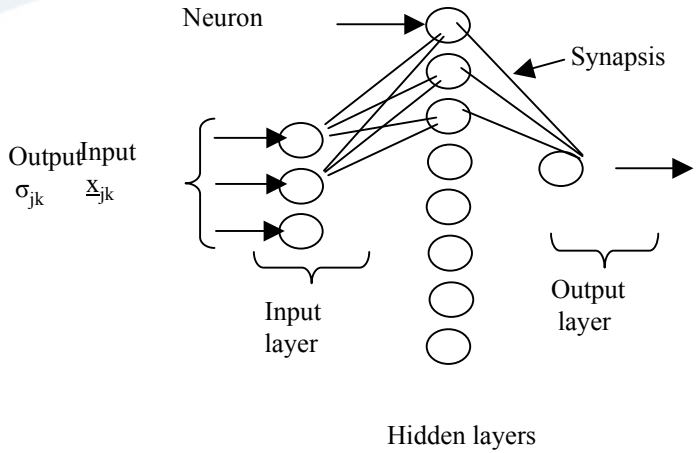
$$\varepsilon = \frac{1}{m}\sum_{j=1}^{m}\sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(\sigma_{jk} - \tau_{jk}\right)^2}$$

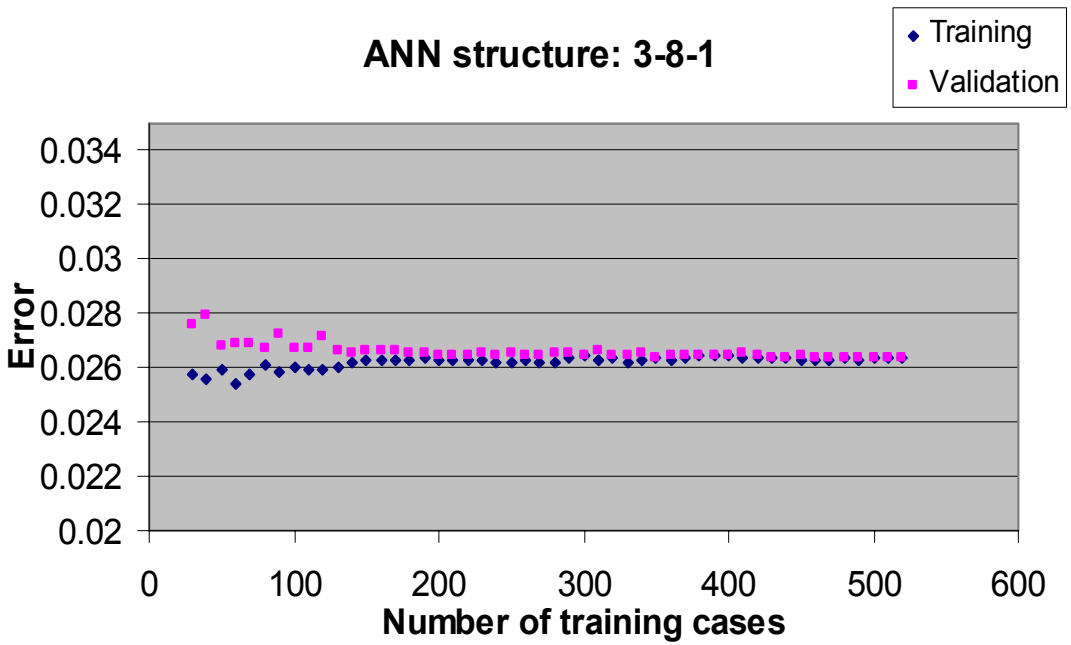
ε: Error of ANN estimates
m: number of training cases
n: number of measurements during the lifetime of the transformer
σ_{jk}: Estimated degradation parameter
d_{jk}: Actual degradation parameter

ANN structure evaluation

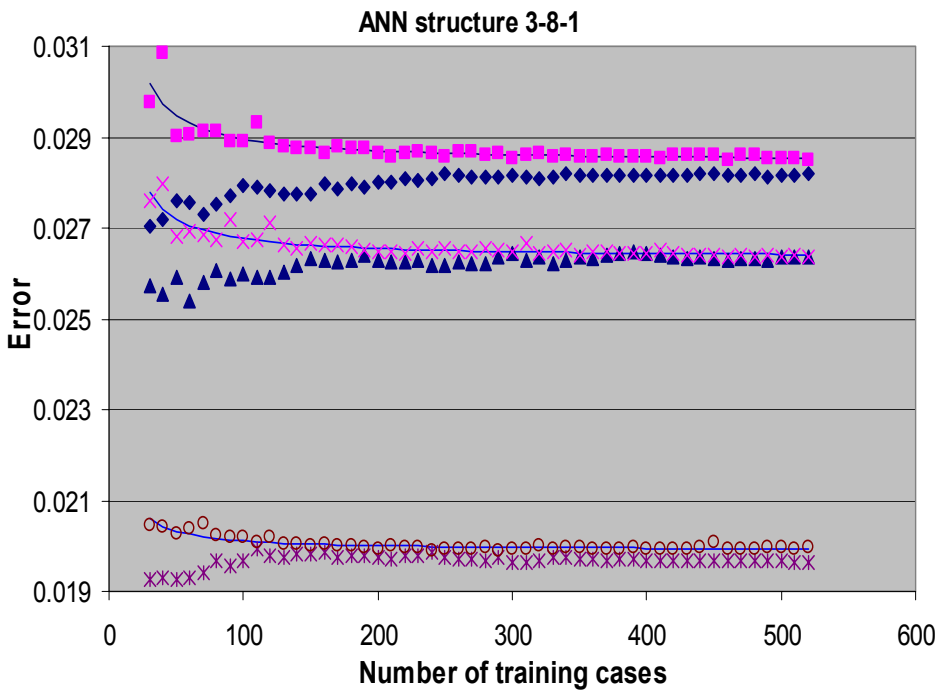
Evaluated Four structures:

3-4-1, 3-8-1,3-4-4-1, 3-8-8-1





ANN training cases evaluation



Results for K=0.5, 1.0, and 1.5
■-V(K=1.5); ♦-T(K=1.5);×-V(K=1);▲- T(K=1);
○-V(K=0.5) ; *-T(K=0.5)

Variance factor	K=0.5	K=1	K=1.5
Asympotic training value	0.0197	0.0263	0.0282
Asympotic validation value	0.0199	0.0264	0.0285
Number of training cases	90	130	140

$$S_{ij} = K \cdot \rho_i \cdot \mu_{ij}$$

Conclusions

- The proposed method to estimate the failure probability of transformers due to degradation by utilizing an ANN shows promising results.

- The approach to generate abundant data statistically equivalent to real data allows the evaluation of the ANN structure and the minimum number of cases required to achieve a certain degree of confidence in the results.

- Further work is currently proceeding to acquire more data and provide better estimates.

Thanks for your attention