BUAA

Beijing University of Aeronautics and Astronautics

Reliability Prediction Based on Degradation Measure Distribution and Wavelet Neural Network

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Content

- Life test VS degradation test
- Reliability prediction
- Wavelet Neural Network Prediction Model
- Application Example

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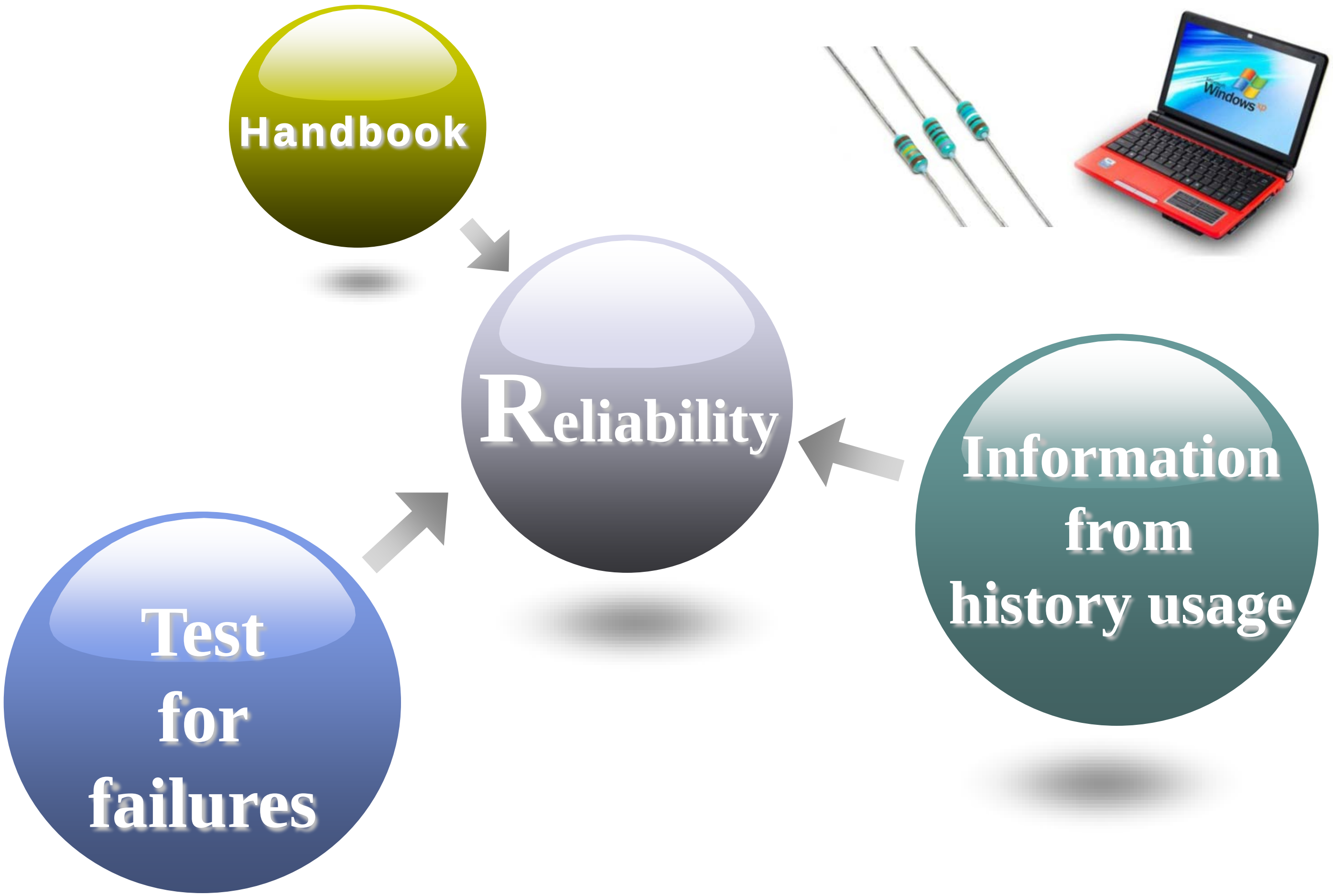
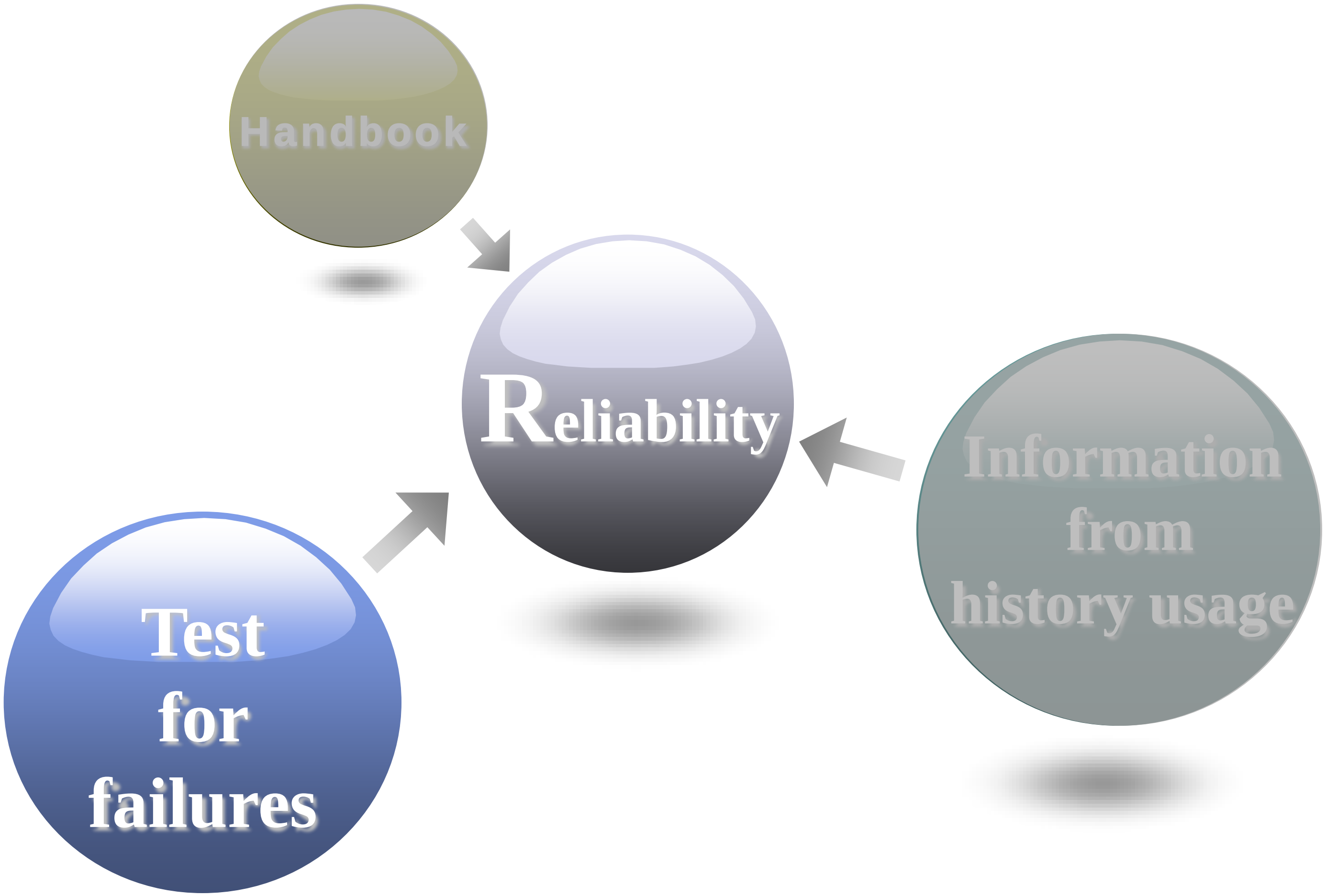
Life test VS degradation test

How to get reliability information of a product?

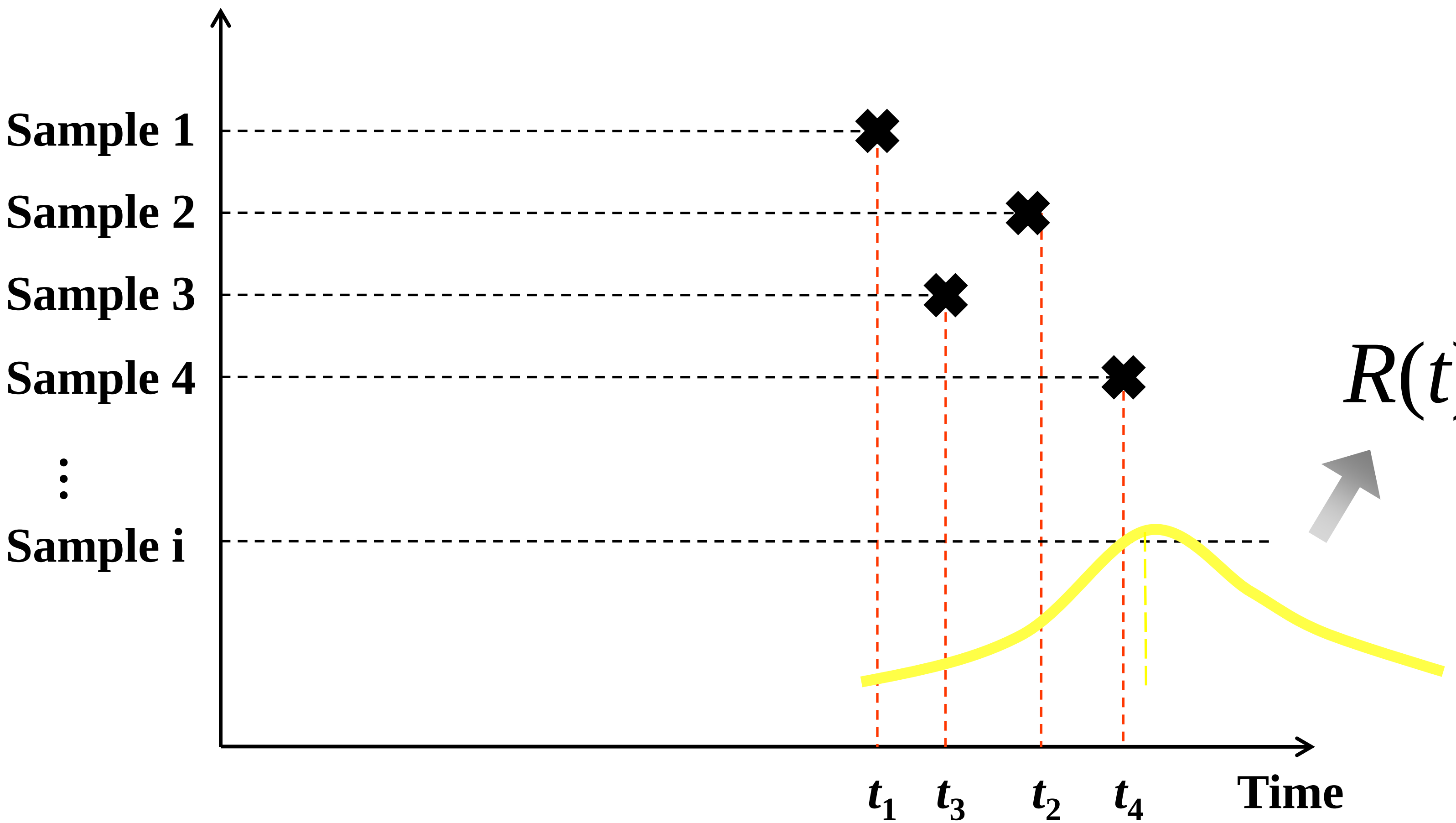


Life test VS degradation test

How to get reliability information of a new product?



Life test VS degradation test



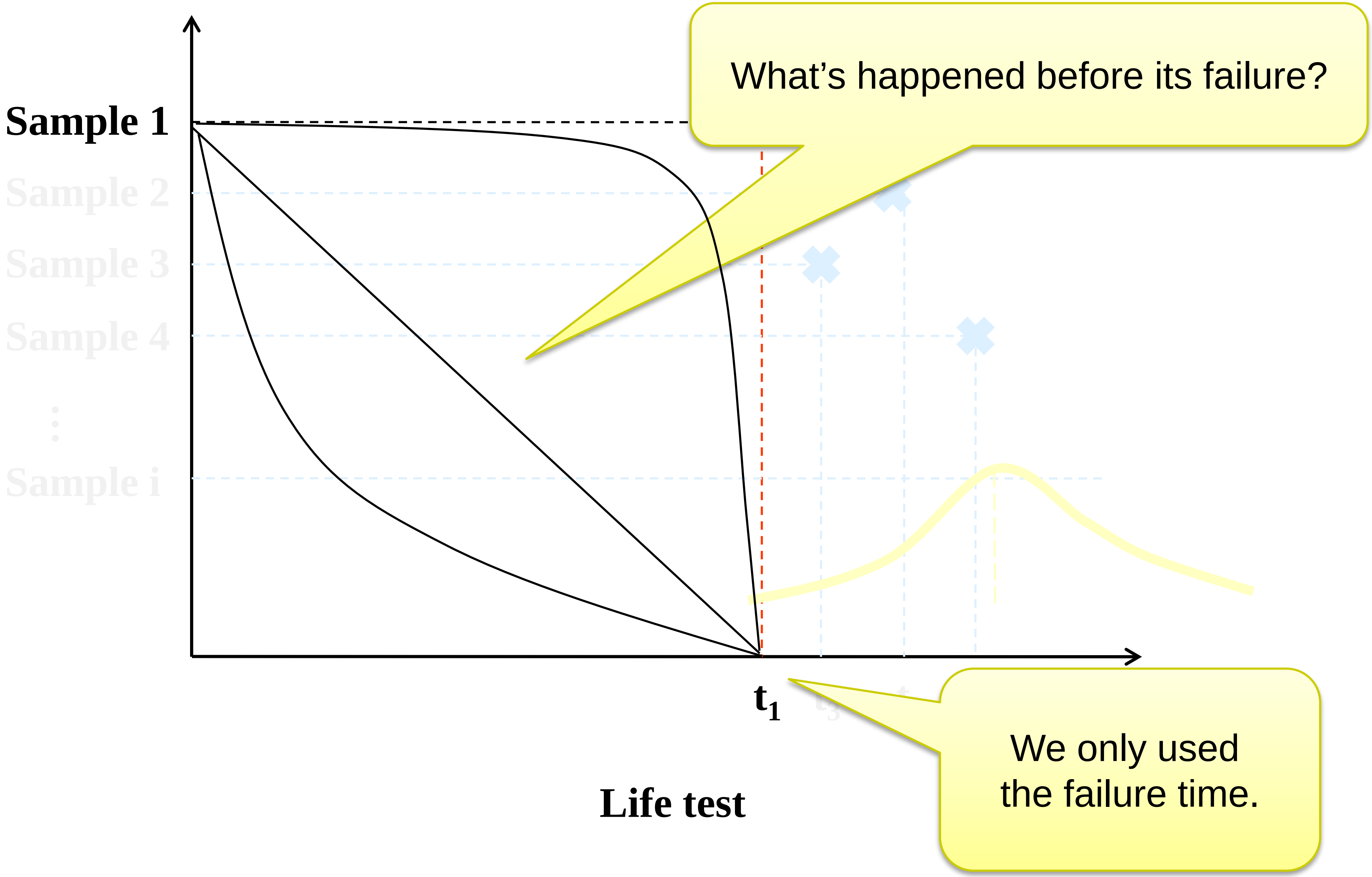
Life test

Life test VS degradation test

- Limitations of life test

  To predict reliability, life tests (no matter censored or not) need to be implemented until enough failures occurred. However, it's always difficult to get failure data in life tests for high reliability and long life products. The time and cost consumed may not be affordable in engineering. Especially when the product need to be released swift for market competitions.

Life test VS degradation test



Life test

Life test VS degradation test

- Merits of degradation test

  Degradation test (continuous monitoring or periodic inspection) can often acquire performance degradation data, which contain lots of reliability information;

  For products whose failure is mainly caused by degradation, it is possible to predict reliability by analyzing the degradation data. Therefore, failures in test are dispensable.

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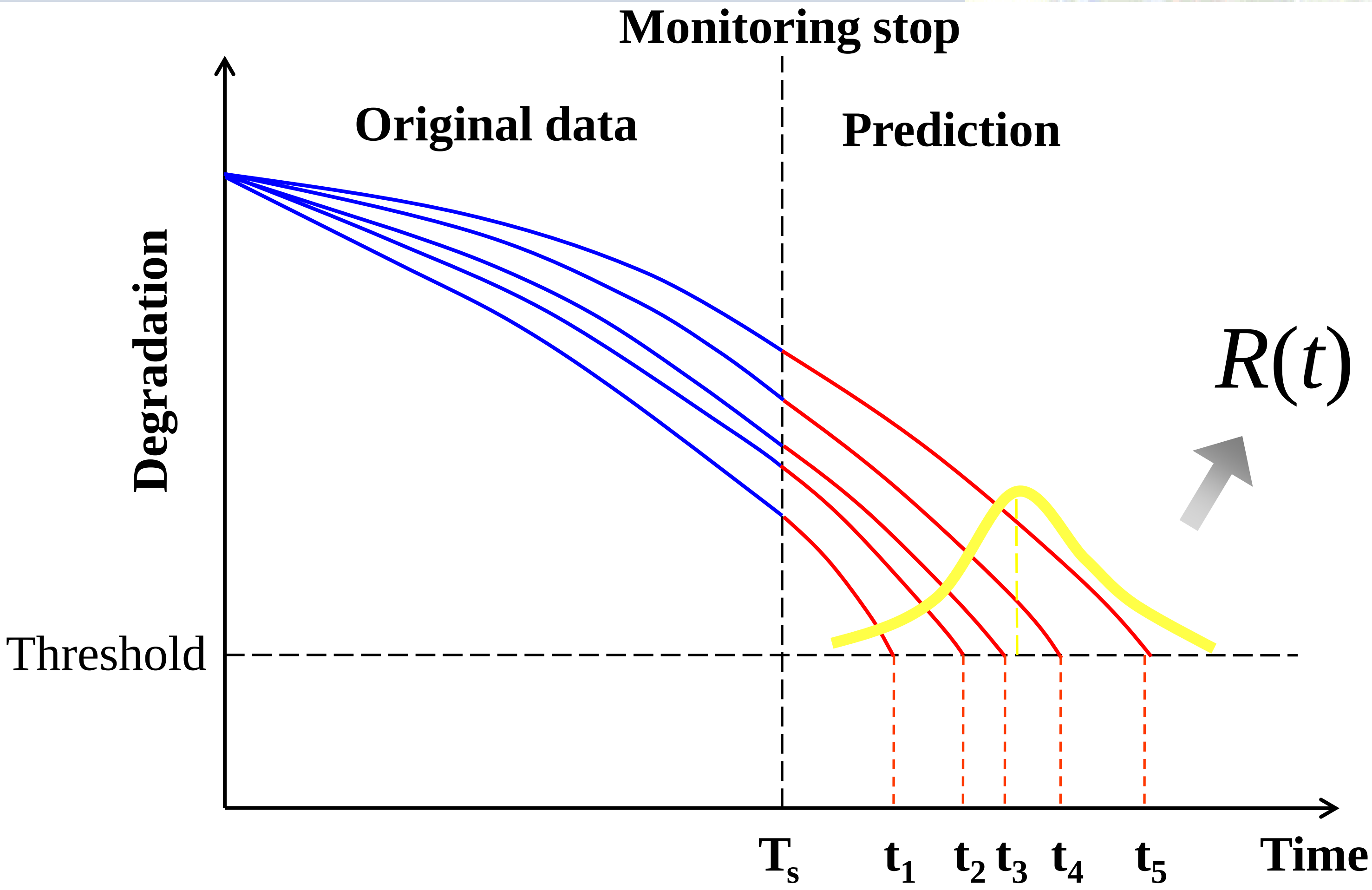
Reliability prediction

- Reliability prediction utilizing degradation data

Method 1 is based on degradation path;

Method 2 is based on degradation measure distribution.



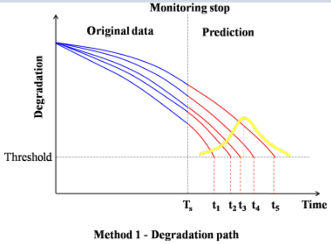
Method 1 - Degradation path

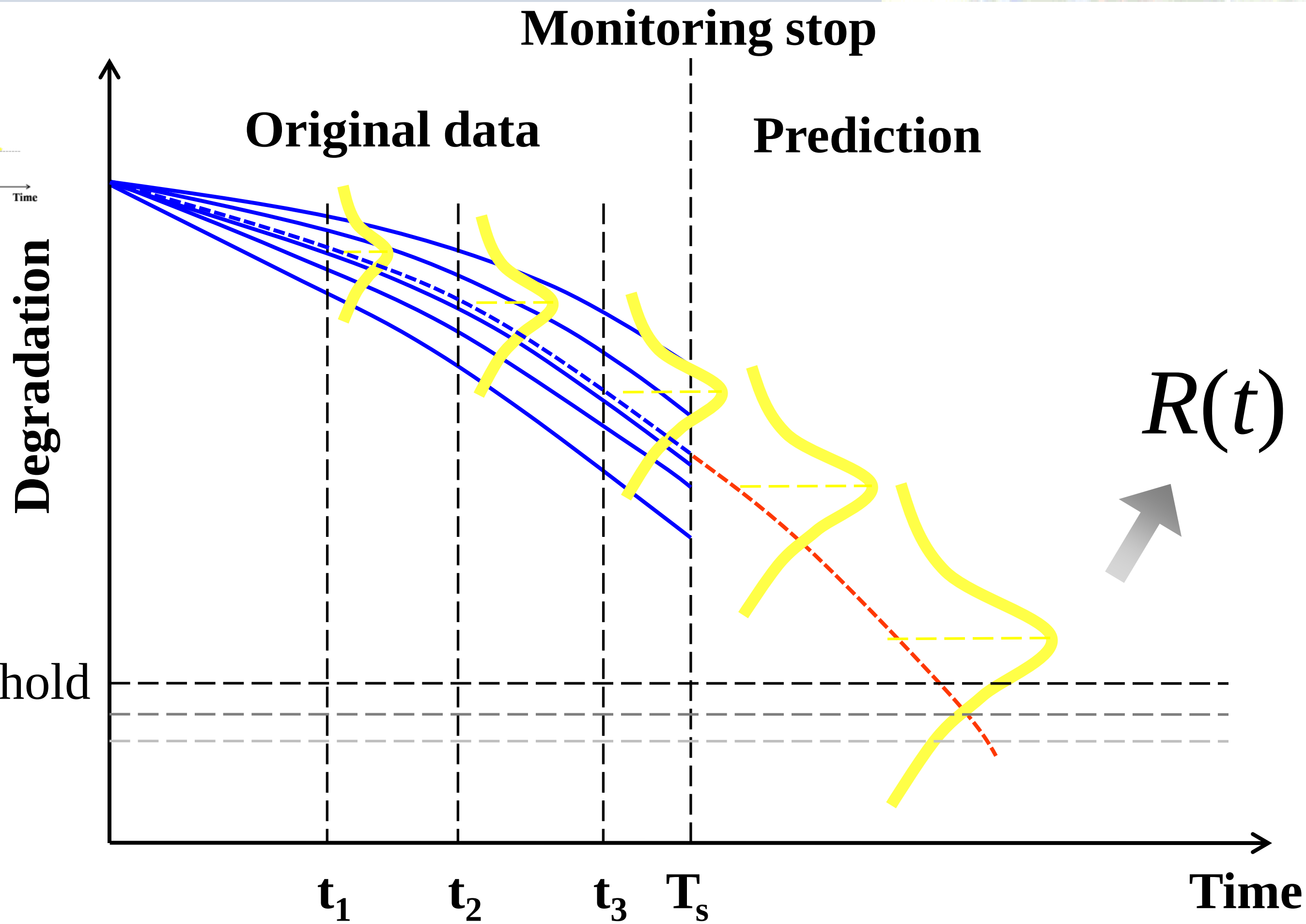
Reliability prediction

- Limitations of method 1

  The model mis-specification for degradation path may have a serious effect on the life prediction, which will remarkably influence reliability precision as sample's number increases.

  Similar to life test, this method only use failure time either.





Method 2 – Degradation measure distribution

Reliability prediction

- Basic Assumptions

  There are two basic assumptions for degradation data:

1. The samplings instant of all products are the same.
2. The degradation measures at each sampling instant follow a same distribution family, and only distribution parameters change with time.

Reliability prediction

- Distribution Parameters Estimation

Estimation of location and scale parameter of distribution is obtained by maximum-likelihood estimation (MLE). The degradation amount of i^{th} product at time t is denoted as y_{ti} and number of products is n. So maximum likelihood function has the following format:

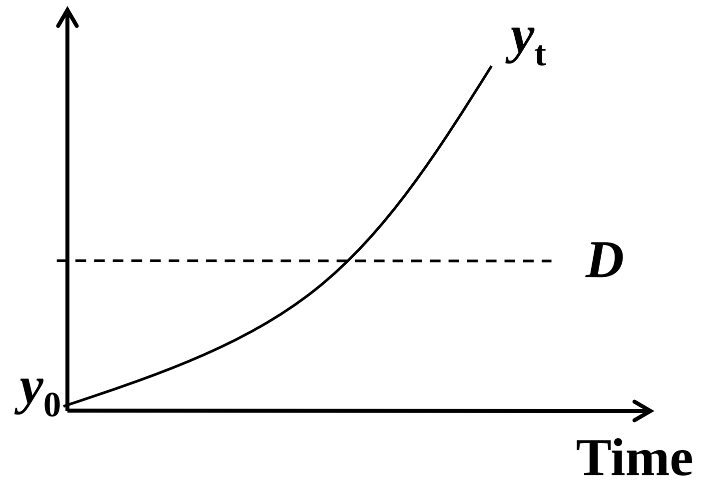
$$L(\beta_t) = \prod_{i=1}^{n} f(y_{ti}, \beta_t)$$

Where $\beta_t=(\mu_t, \sigma_t)^T$, μ_t and σ_t are location and scale parameters at time t. Solving MLE equation at each time, the location and scale parameters series $\{\hat{\mu}_t\}$ and $\{\hat{\sigma}_t\}$ can be obtained.

Reliability prediction

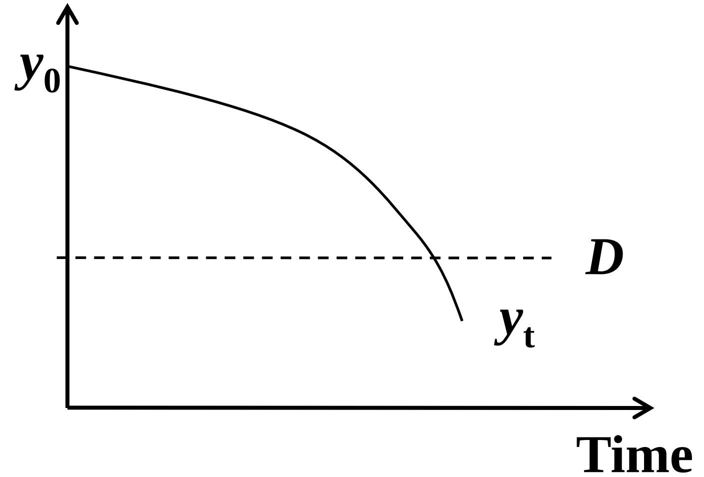
If degradation value y_t increases with time, failure threshold D is not less than degradation initial value y_0, the reliability can be calculated as

$$R_t = 1 - P\{y_t \geq D\}$$



If degradation value y_t decreases with time, failure threshold D is not more than degradation initial value y_0, the reliability can be calculated as

$$R_t = 1 - P\{y_t \leq D\}$$



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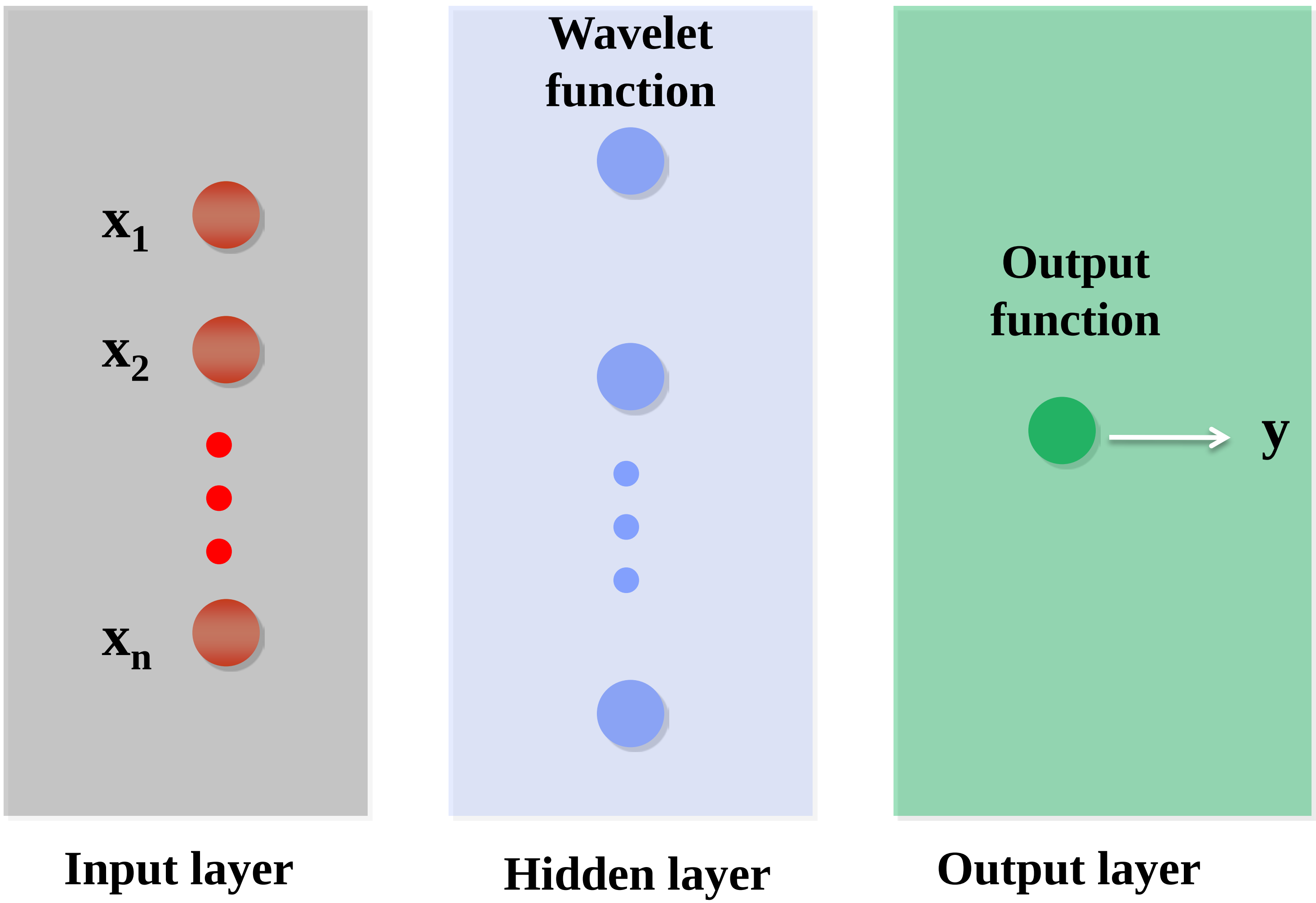
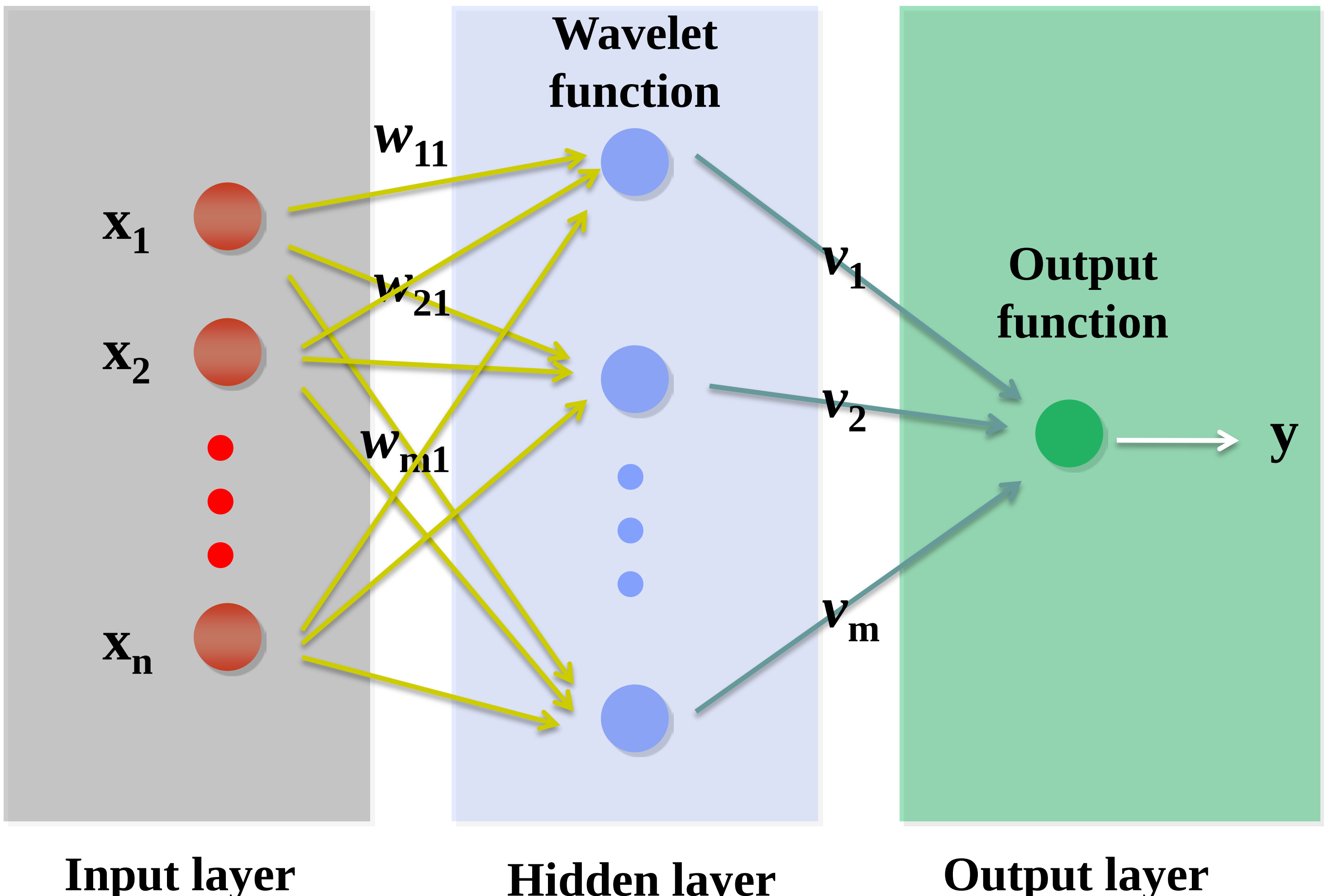
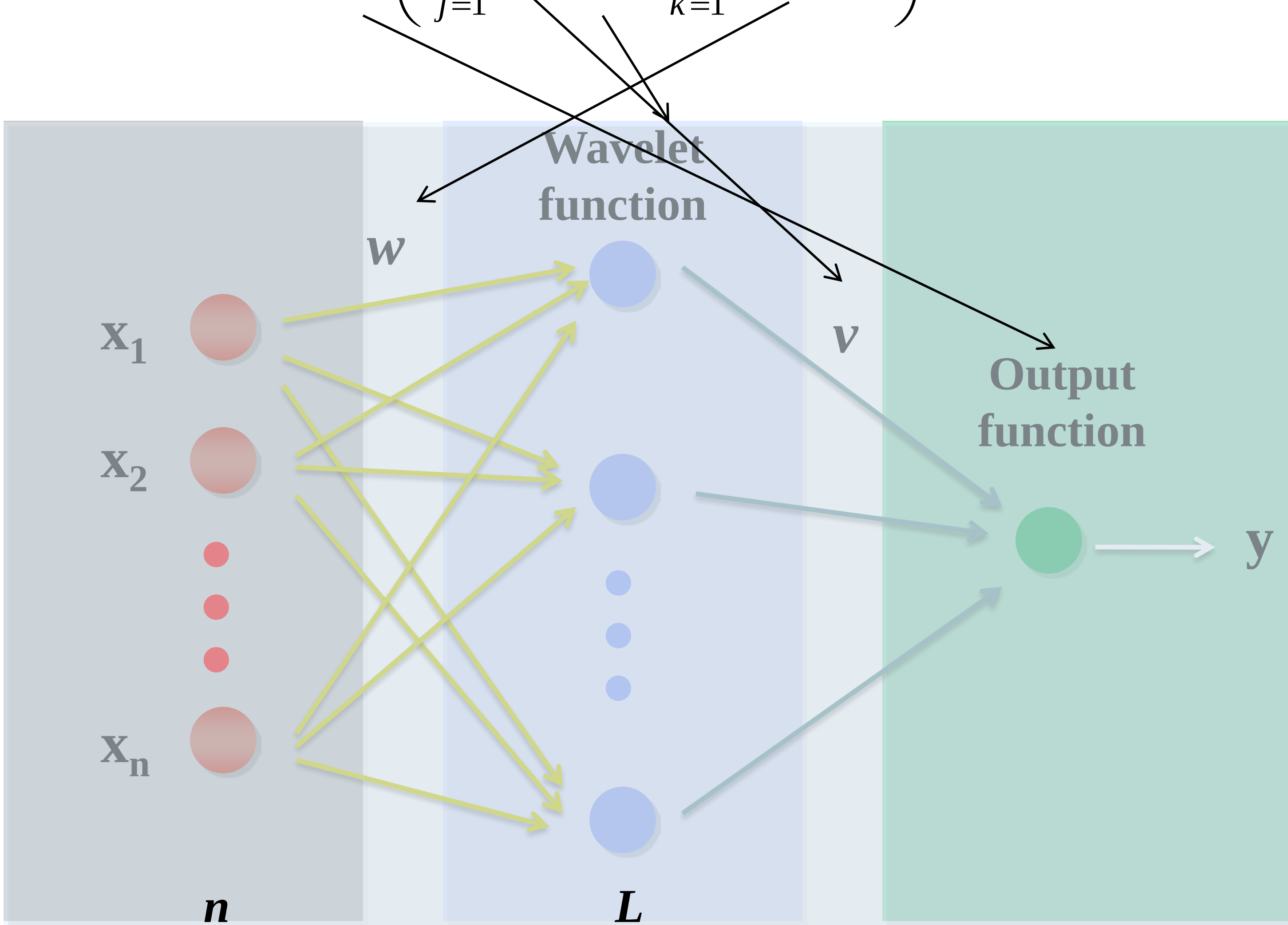
There layers' Wavelet Neural Network



There layers' Wavelet Neural Network



$$y = \sigma\left(\sum_{j=1}^{L} v_j \psi_{a,b}\left(\sum_{k=1}^{n} w_{jk} x_k\right)\right)$$



$$y = \sigma\left(\sum_{j=1}^{L} v_j \psi_{a,b}\left(\sum_{k=1}^{n} w_{jk} x_k\right)\right)$$

How to get *v* and *w*?

Learning

A child

1+1=2
2+1=3
…
9+1=10

10+1=11

WNN

input	output
X_1	Y_1
X_2	Y_2
…	…
X_9	Y_9

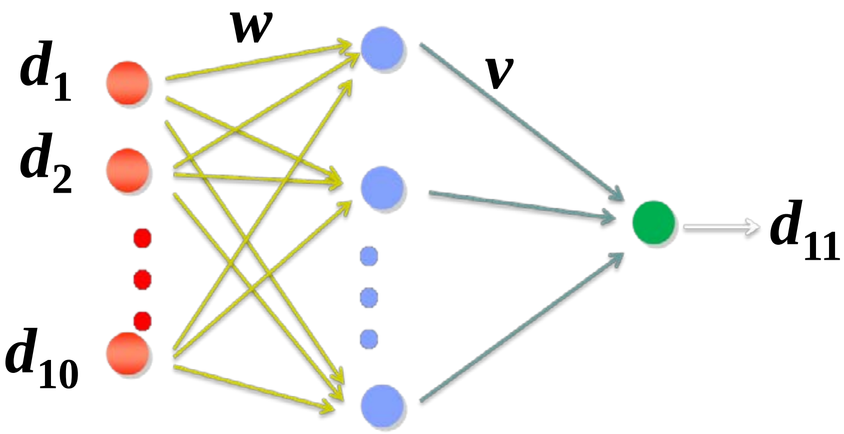
get *v*, *w*

input X_{10}, output Y_{10}

For example: $d_1, d_2 \ldots d_{100}$ ➡ $d_{101}, d_{102} \ldots d_{110}$

Learning from $d_1, d_2 \ldots d_{90}$

	input		output
X_1	$d_1, d_2 \ldots d_{10}$	Y_1	d_{11}
X_2	$d_2, d_3 \ldots d_{11}$	Y_2	d_{12}
.	.	.	.
.	.	.	.
.	.	.	.
X_{80}	$d_{80}, d_{82} \ldots d_{89}$	Y_{80}	d_{90}



Prediction from $d_{91}, d_{92} \ldots d_{100}$

	input		prediction
X_{91}	$d_{91}, d_{92} \ldots d_{100}$	Y_{101}	d_{101}
X_{92}	$d_{92}, d_{93} \ldots d_{101}$	Y_{102}	d_{102}
.		.	
.		.	
.		.	
X_{100}	$d_{100}, d_{101} \ldots d_{109}$	Y_{110}	d_{110}

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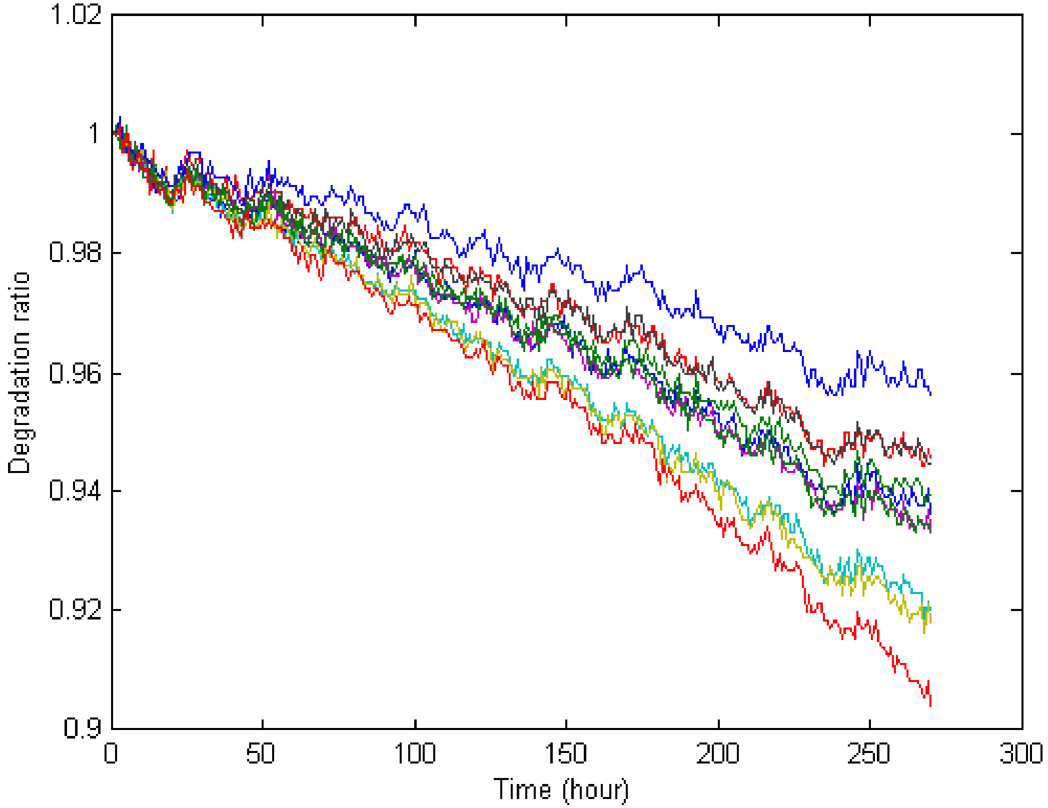
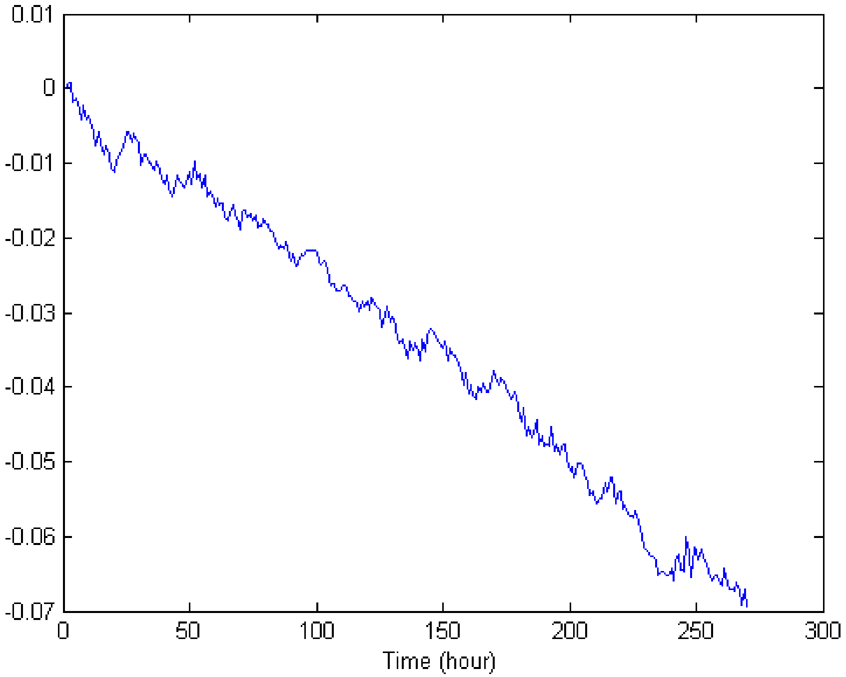
Application Example

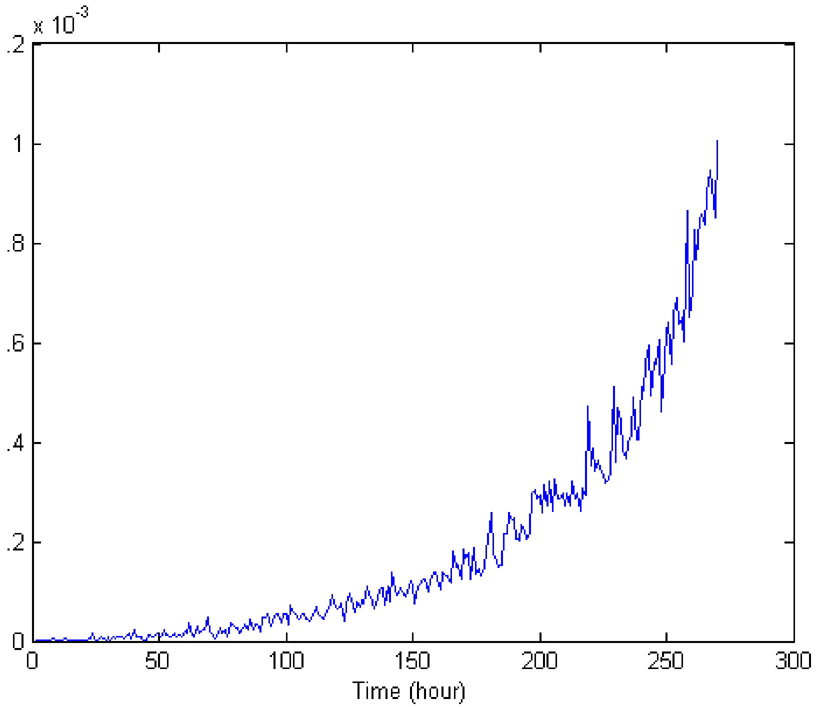
Degradation data of a product are utilized for the application of reliability prediction method. There are 10 products with 270 hours long degradation paths. The original data are translated into the ratio of initial value when $t = 0$.



Application Example

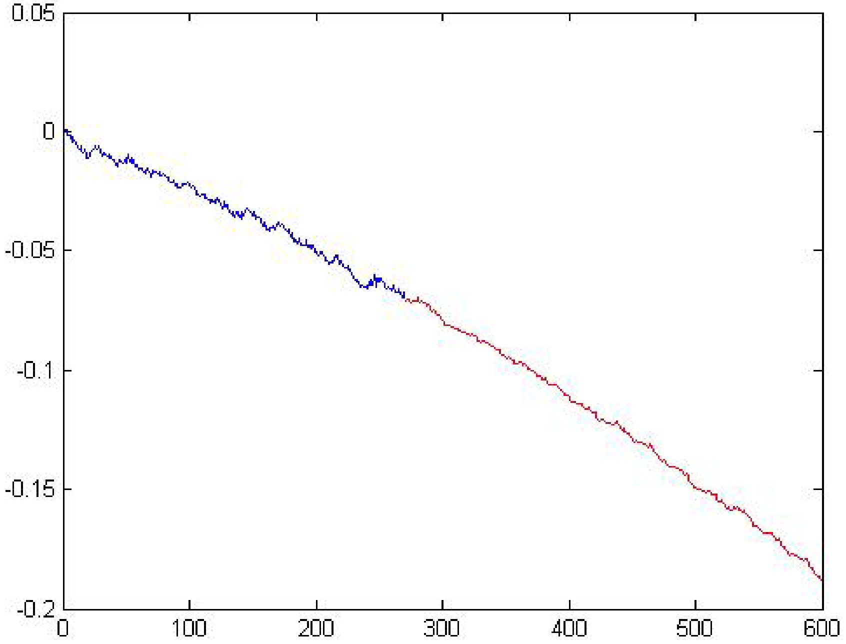
Kolmogorov-Smirnov test proved that the location-scale distribution for the degradation ratio data is lognormal distribution. The mean value and variance are calculated by MLE. The results are shown as

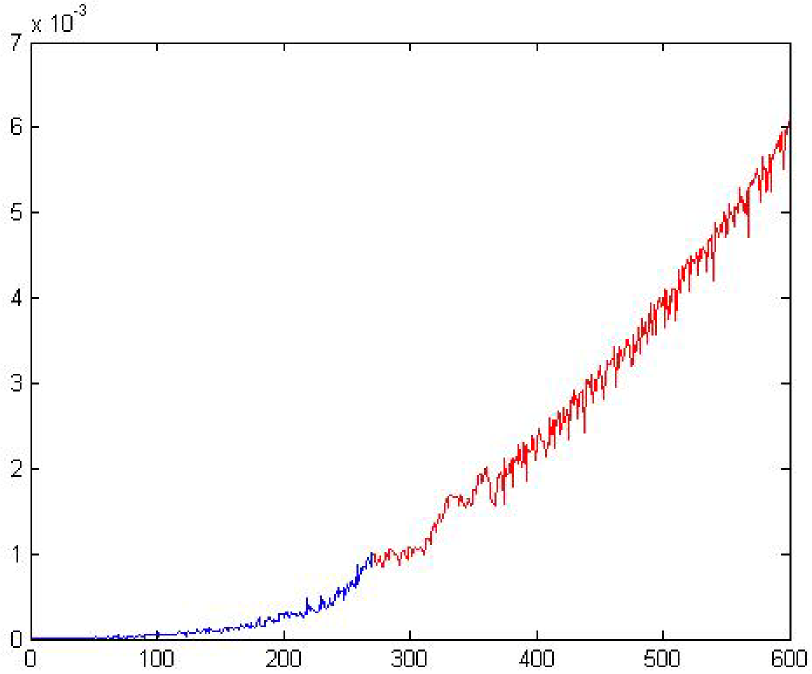




Application Example

The distribution parameters can be respectively predicted by wavelet neural network models. The prediction results are





Application Example

- Entire degradation data

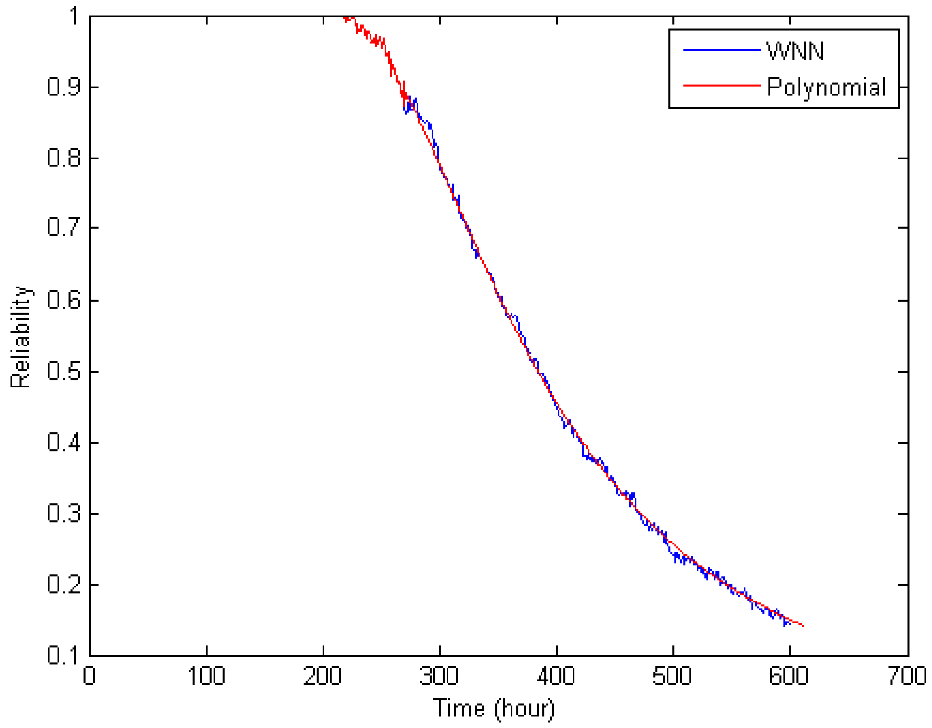
According to failure history of this product, the failure threshold D is selected as 90% of the initial value. Considering that logarithm of degradation follows normal distribution, the reliability can be calculated as

$$
\begin{aligned}
R_t &= 1 - P\{y_t \le D\} \\
&= 1 - P\{\ln y_t \le \ln D\} \\
&= 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\ln D} \exp\left(-\frac{(\ln D - \mu)^2}{2\sigma^2}\right) d(\ln D)
\end{aligned}
$$

Application Example

- Entire degradation data

The reliability curve from 0 to 600 hour is predicted as



Comparing with the result of polynomial regression, WNN offers an effective prediction for reliability, and moreover, it reflects reliability oscillation with the effect of environment factors.

Merci pour votre attention!