Life Data Analysis for Maintenance Optimization & Reliability Improvement

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Agenda

1. Evidence-based Maintenance Decision Models
2. Characterizing the Risk of Failure
3. Life Data Analysis
4. Statistical Tools for Reliability Improvement

1. Evidence-based Maintenance Decision Models

Typical Maintenance Decisions

When (how frequent) to:

- Do preventive replacement
- Inspect the item

What action to take after knowing the results of an inspection?

What level of resources should be provided to support maintenance work?

Optimizing Maintenance Decisions

We Want

Evidence-based arguments

(data driven decisions)

NOT

Intuition-based pronouncements

(strength of personalities, # of mechanics' complaints)

Maintenance Policies

Run to Failure

- The unscheduled actions taken, as a result of failure, to restore a system to a specified level of performance

Preventive Replacement

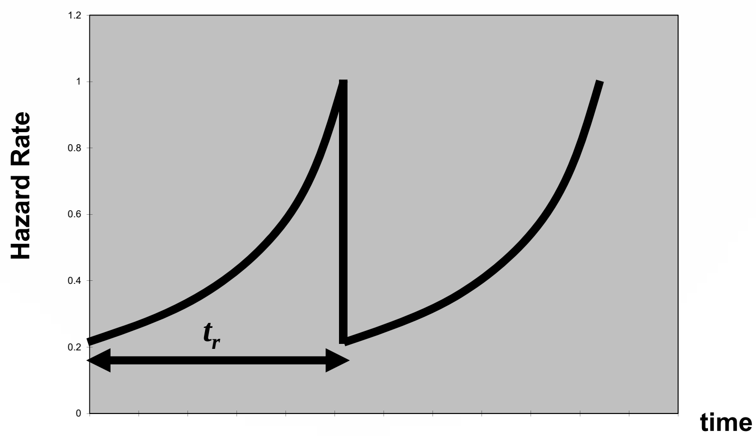
- The scheduled actions taken, not as a result of failure, to retain a system at a specified level of performance by such functions as scheduled replacement of critical items and overhauls

Maintenance Policies

Use Preventive Replacement only if :

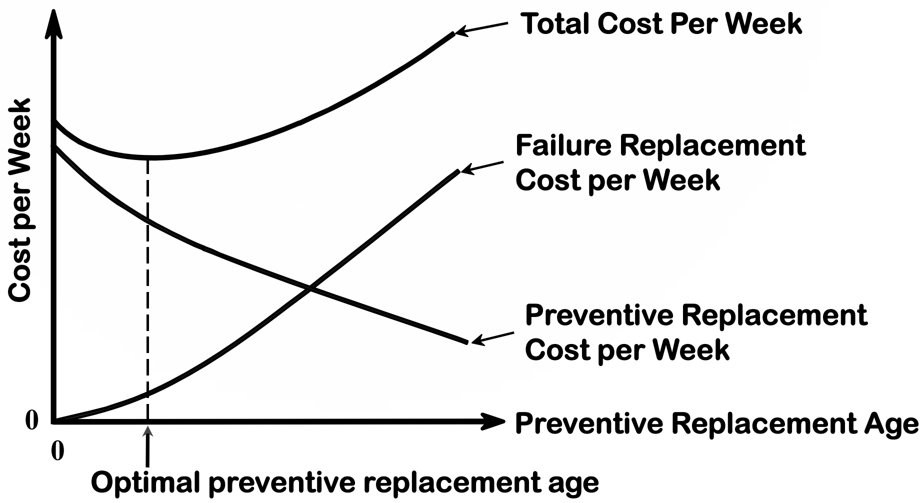
- ✓ the risk of failure increases with age or usage, i.e., wear-out effect is occurring
- ✓ total cost of a failure replacement is greater than total cost of a preventive replacement

Preventive Replacement



Preventive replacement will make sense only if it can reduce the risk of failure (hazard rate)

Preventive Replacement Cost Conflicts



Optimizing Preventive Replacement Costs

Maintenance data are stored in databases of CMM/EAM/ERP system

A typical scenario:

Data Rich, Information Poor

The risk of failure can be determined from analysis of the item's failure data

2. Characterizing the Risk of Failure

Why Do Things Fail?

Stresses applied to an item are generally due to environmental and operational factors

Applied Stresses (Load) > Strength

Criteria of a Reliable Design

$$\textbf{Safety Factor} = \frac{\mu_S}{\mu_L}$$

$$\textbf{Margin of Safety} = \frac{\mu_S - \mu_L}{\mu_L}$$

Safety Factor and **Margin of Safety** do not consider uncertainty of both strength and load

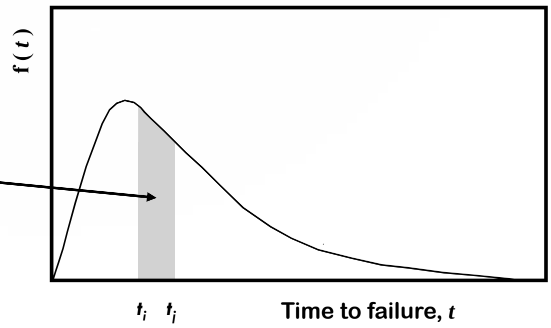
Uncertainty of Load and Strength

- Uncertainty of load is due to variability of operating environment and usage
  - **Environmental Stresses**: temperature, humidity, contamination, vibration and other conditions that action on the component
  - **Operational Stresses**: voltage, current, flow, amplitude, dynamic loading and other stresses that manifest themselves during operation when the item is active
- Variability of strength is due to the uncertain impact of operating environments on the inherent failure modes of the item

Probability Density Function
(Failure Density / Mortality function)

p.d.f. or f(t) is the number of failures per unit time, expressed as a fraction or original total of parts under examination

$$\text{Prob.}(t_i \le t \le t_j) = \int_{t_i}^{t_j} \text{f}(t)dt$$



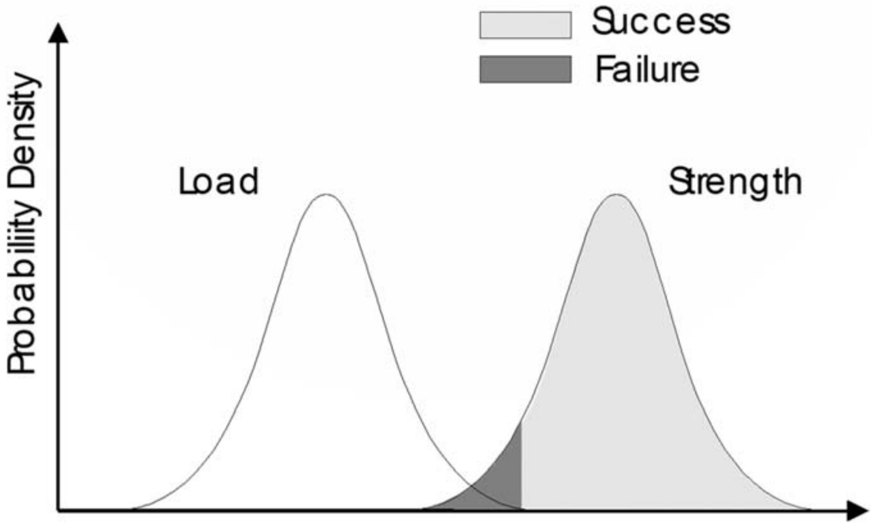
Failure Rate (Hazard Rate), r(t)

This is a conditional probability, with r(t)dt being the probability that an item fails during the interval [t, t + dt], given that it has survived to time t.

$$\text{r}(t) = \lambda(t) = h(t) = \frac{\text{f}(t)}{\text{R}(t)}$$

This is also known as the **instantaneous failure rate**, or **mortality rate**

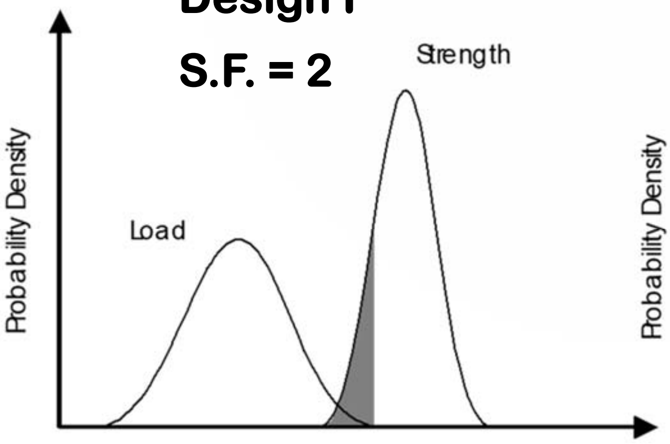
Load-Strength Interference



Which Design is More Reliable?

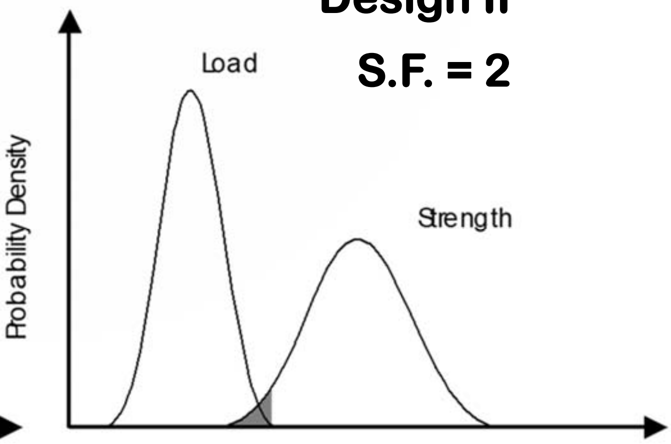
Design I

S.F. = 2

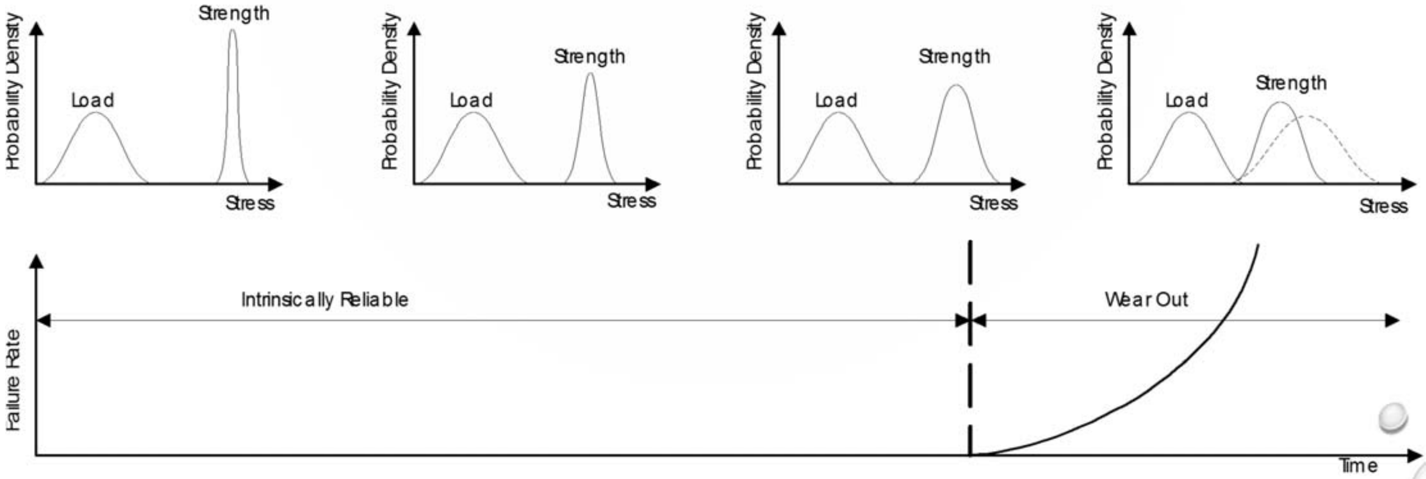


Design II

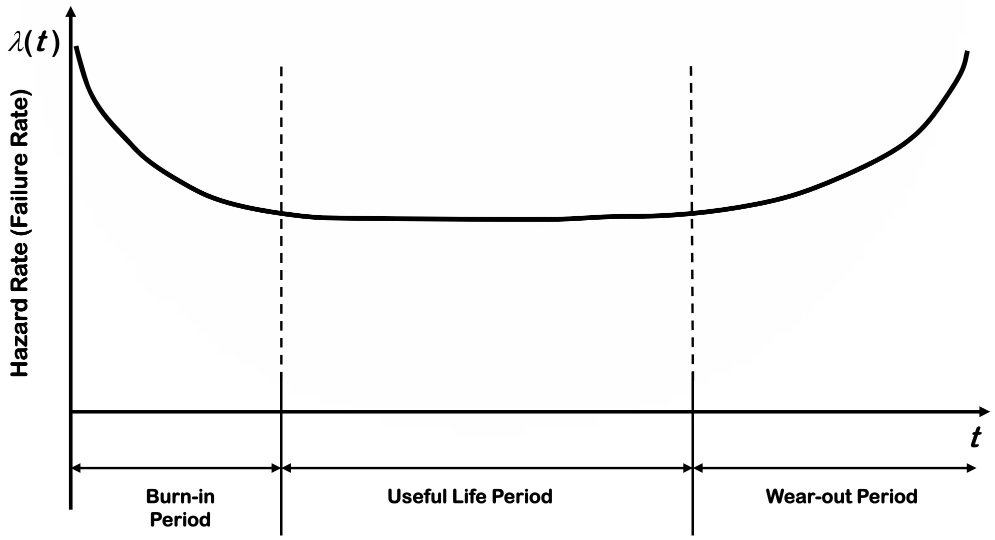
S.F. = 2



Time-Based Degradation



The Bathtub Model



Weibull Distribution

Wallodi Weibull
1887 – 1979

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta\text{-}1} \exp\left(-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right)$$

t **is a continuous variable**

A versatile distribution model often used to characterize time to failure

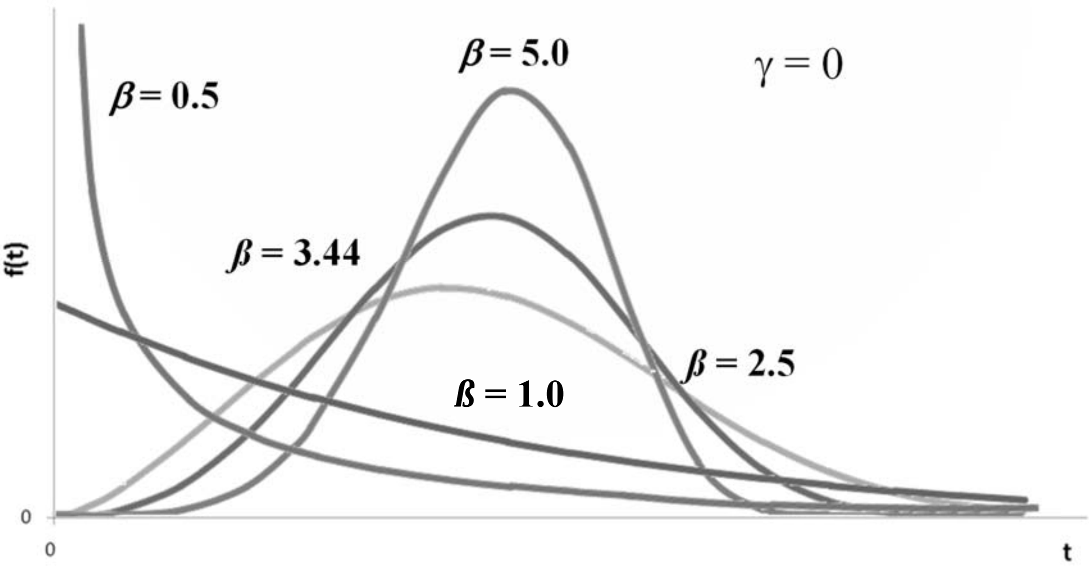
β : **Shape parameter,** $\beta > 0$

η : **Scale parameter,** $\eta > 0$

γ : **Location parameter,** $\infty \geq \gamma \geq -\infty$

Weibull Distributions with Different Shape Parameters, β

Wallodi Weibull
1887 – 1979



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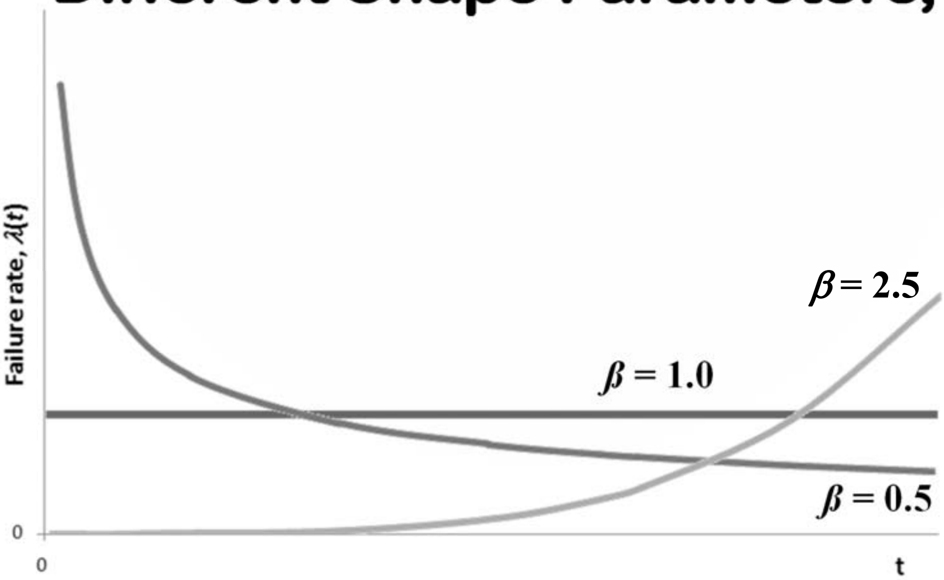


3. Life Data Analysis

Life Data Analysis

Techniques for determining an item's reliability function:

- **Weibull Analysis**
- **Maximum Likelihood Estimation (MLE)**

Sources of Product Life Data

- In-house laboratory testing
- Beta site testing
- Audit testing
- Warranty and other field data

Two Types of Failure

Hard Failures

Complete loss of function

Soft Failures

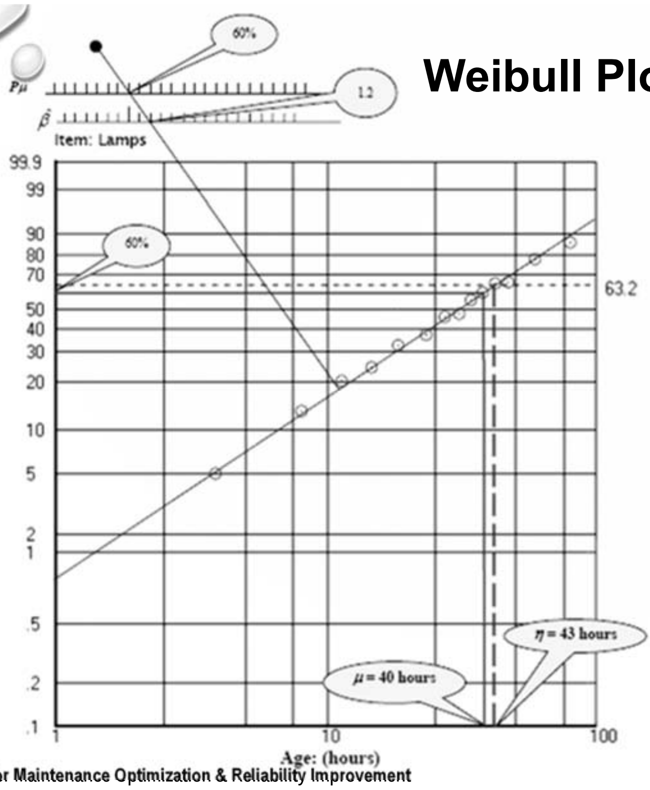
Occur when a critical performance parameter has degraded to a predefined level – the item continues to function, but unsatisfactorily

Lamp Failure Data

Time to Failure $t_{i-1} < t_i$	Cumulative Probability $F(t_i)$ (%)
00<04	5
04<08	14
08<12	20
12<16	25
16<20	32
20<24	38
24<28	46
28<32	48
32<36	54
36<40	60
40<44	64
44<48	66
……	
56<60	78
……	
76<80	86

Source: Jardine & Tsang (2013) *Maintenance, Replacement and Reliability: Theory & Applications*, page 239

Weibull Plot of Lamp Failure Data



The Weibull model:

$$f(t) = \frac{1.2}{43}\left(\frac{t}{43}\right)^{0.2} \exp\left(-\left(\frac{t}{43}\right)^{1.2}\right)$$

Source: Jardine & Tsang (2013) *Maintenance, Replacement and Reliability: Theory & Applications*, page 240

Conclusions That Can be Drawn From a Weibull Plot / MLE

- **Hazard rate of the item – constant or age-dependent**
- **Risk of failure at a specified age**
- **The age at which a specified percentage of the item will have failed – the B_q Life**

The Point Estimates and Confidence Intervals of these Parameters

Assumptions of the Conclusions Drawn From a Weibull Plot / MLE

- The sampled items and the environment under which they are operated are representative of those covered by the conclusions
- Failures are due to a single failure mode, or set of failure modes that lead to the same form of statistical distribution
- The censored observations are uninformative – items were not removed from observation and declared unfailed when they provided an indication of imminent failure

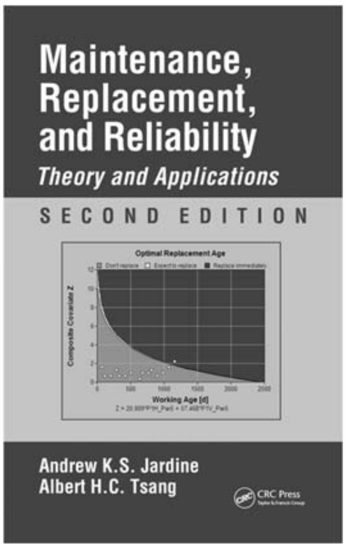
4. Statistical Tools for Reliability Improvement

Statistical Tools for Reliability Improvement

Beware of extrapolating beyond the range of the available life data

- **Evaluating individual failure modes**
- **Stratified and regression analysis**
- **Degradation analysis**
- **Accelerated testing**
- **Robust-design experiments**

References



http://www.hksq.org/RCM.pdf

The Speaker

Dr. Albert H.C. Tsang is an advocate of quality and reliability in Hong Kong. He is the representative of American Society for Quality (ASQ) in Hong Kong, a former Chairman, founding member, and Fellow of Hong Kong Society for Quality (HKSQ). He had developed and conducted many customized training courses on various aspects of quality and engineering asset management for many organizations and professional bodies in Hong Kong, the Americas, Middle East and South Africa. He has also provided consultancy services to organizations in the public, governmental, business and industrial sectors on matters related to quality, reliability, maintenance and performance management.

Dr. Tsang is a co-author of the best selling book: ***Maintenance, Replacement, and Reliability: Theory and Applications***, the 2nd edition of which was published in 2013. He is also the author of "***WeibullSoft***", a computer-aided self learning package on Weibull analysis.