Topic 2

RELIABILITY IN DESIGN AND DEVELOPMENT

RELIABILITY RESEARCH

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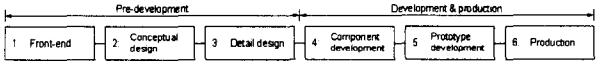
RELIABILITY SPECIFICATION AND PERFORMANCE

Joint program with the Norwegian University of Science and Technology, Trondheim, Norway

PRODUCT LIFE CYCLE



PERFORMANCE

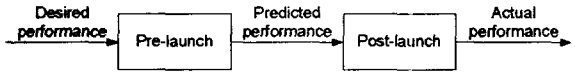
Product performance is described as the response of a product to external actions in its working environment. The performance of a product is realised through the performance of its constituent components.

PERFORMANCE

- **Desired performance may be defined as *"a statement about which performance is desired from an object, i.e. stating what performance an object should have".***
- **Actual performance may be defined as *"observed performance throughout the field operation of an object".***

PERFORMANCE

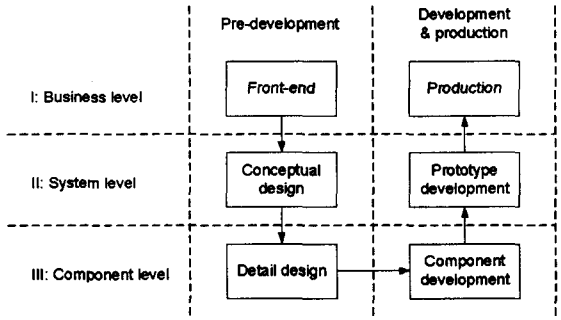
- **Predicted performance may be defined as *"an estimate of an objects performance, attained through analyses, simulation, testing etc."***

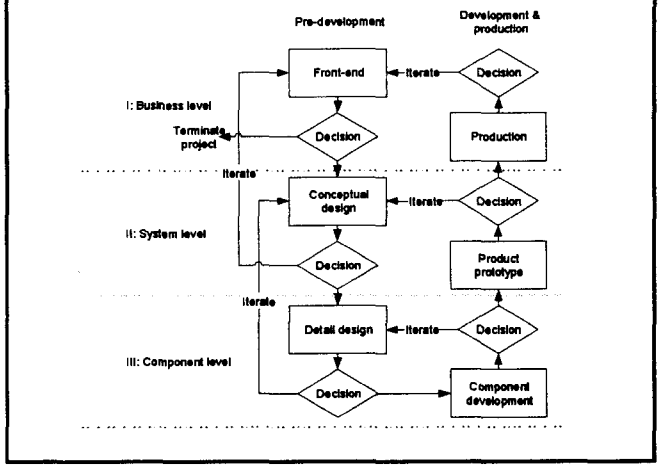


PRODUCT RELIABILITY

Reliability of a product (system) conveys the concept of dependability, successful operation or performance and the absence of failures. Unreliability (or lack of reliability) conveys the opposite.

THREE LEVELS





SPECIFICATION

A set of statements about the object at a given stage in the development process, to ensure the objective of the NPD (New Product Development) process and the associated desired performance of the object.

PERFORMANCE TO SPECIFICATION

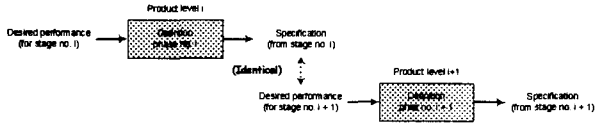
The desired performance outlines *what* is to be achieved in the NPD process. The specification describes *how* this performance may be arrived at (using a synthesis process, involving evaluation of alternate solutions to select the best solution), with desired performance as input to that process.

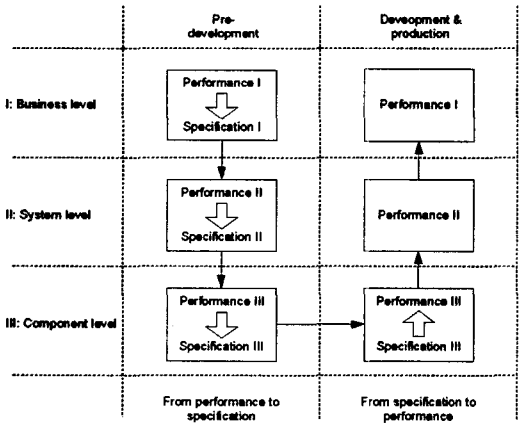
SPECIFICATION TO PERFORMANCE

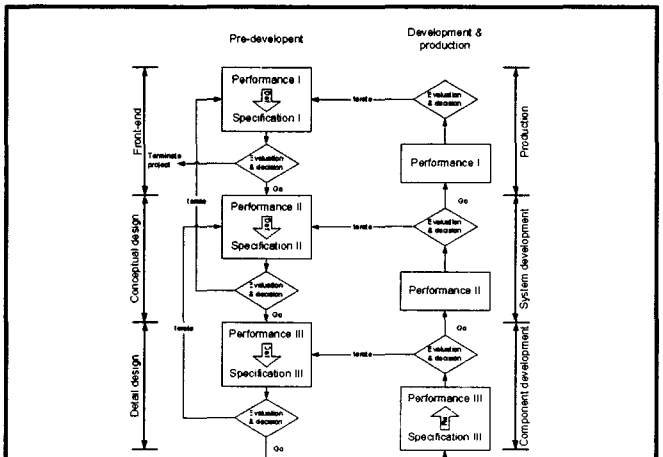
Building a product to specification results in an actual performance that may differ from the desired performance.

In this context, the actual (or predicted) performance is a function of the specification.

LINK BETWEEN PERFORMANCE AND SPECIFICATION







FRONT END

- Performance I
  - Impact of product on business performance: Market share, revenue, profit, warranty cost, customer satisfaction etc
- Specification I
  - Product characteristics and attributes: Performance, reliability, durability etc

FRONT END

- Performance to Specification: One-to-many mapping
- Specification to Performance: One-to-one mapping
- Models for evaluating performance from specification
- Tools and techniques needed

FRONT END

- Constraints - Time, resource, manpower etc
- Reliability implications for R&D (time, cost, resources needed)
- Reliability implication on business performance (sales, costs etc)
- Data needed

CONCEPTUAL DESIGN

- Performance II
  - Same as Specifications I
- Specifications II
  - Characteristics and attributes of sub-systems - Performance, reliability, durability
- Other issues: Similar to front end
- Focus on technical aspects

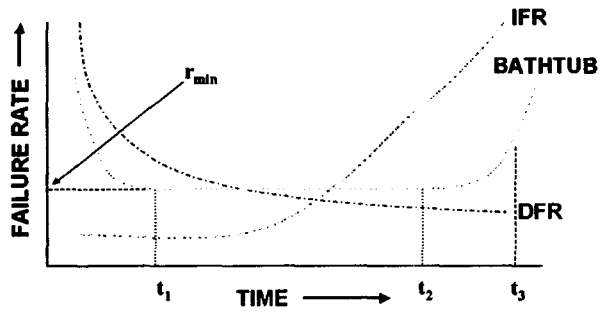
DETAILED DESIGN

- Similar to conceptual design
- Can involve several sub-stages
- Reliability at the lowest level links to material and manufacturing issues

COMPONENT LEVEL

- Reliability R(t): The probability that it will not fail before t (age of component)
- F(t) = 1 - R(t): Failure distribution
- f(t) = dF(t)/dt: Failure Density
- r(t) = f(t)/[1 - F(t)]: Failure (hazard) rate
- r(t)dt: is the probability that a working item of age t will fail in [t, t+dt)

FAILURE RATE



RELIABILITY SPECIFICATION

- Many different ways of specifying reliability requirement. For example,
  - r_{min} < some specified value [Implications for failures over time]
  - t_1 < some specified value
  - $t_2 - t_1$ > some specified value [Implications for useful life]
  - $t_3 - t_2$ > some specified value minimum

RELIABILITY SPECIFICATION

- r(0) < some specified value [Implications for early failure]
- Probability of no failure in [0, W) is below some specified value [Implications for customer satisfaction]
- Probability of failures over [0, L) is below some specified value (say k) with some specified probability [Implication for spares and replacements]

SOME ISSUES

- How to link performance to requirements to specifications in the pre-development stage?
- Project with universities and various businesses in Finland to look at this issue
- Several other challenging problems that need further study. One of these is accelerated testing

REFERENCE

- Osteras, T., Murthy, D.N.P. and Rausand, M. (2004): *Reliability Performance and Specifications in New Product Development*, NTNU Report, Trondheim Norway
  - Part I: Conceptual Framework
  - Part II: Tools and Techniques
  - Part III: Case Studies

ACCELERATED TESTING

- GAP BETWEEN MODELS AND DATA
- NEW RESEARCH

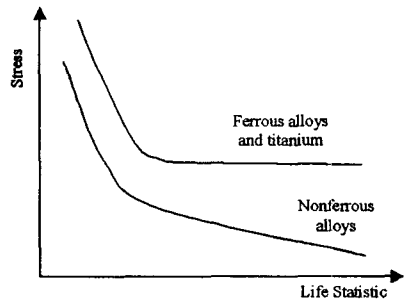
LIFE-STRESS RELATIONSHIP

- **The life of a component depends on the stress on the component. The stress can be electrical, mechanical, thermal etc. The life of the component decreases as the stress level increases.**
- **Modelling the stress-life relationship is of great interest for many different reasons.**

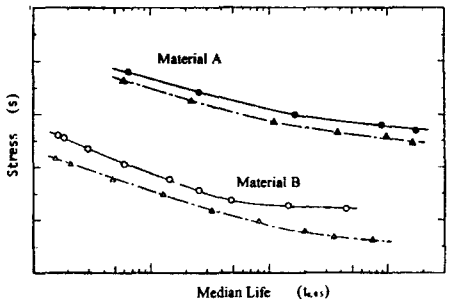
STRESS-LIFE DATA

- **Component subjected to different stress levels and yield data (failure/censored)**
- **Data displayed as plots**
  1. **S-N Plot (mean life versus stress)**
  2. **P-S-N Plot (Fractile versus stress)**
  3. **Histogram (Empirical Density Function)**
  4. **WPP and Lognormal Plot**

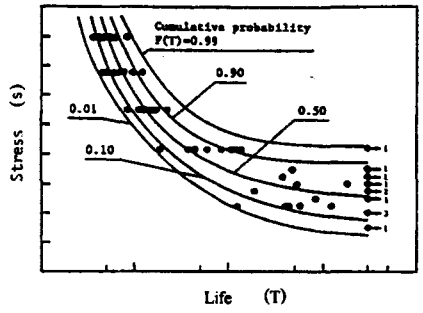
S-N PLOT



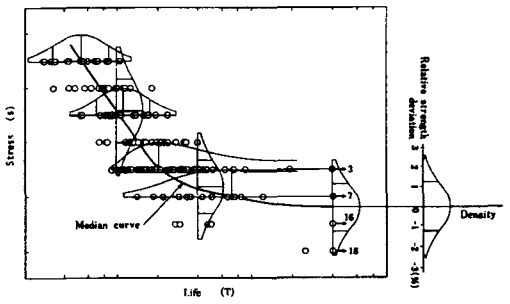
S-N PLOT



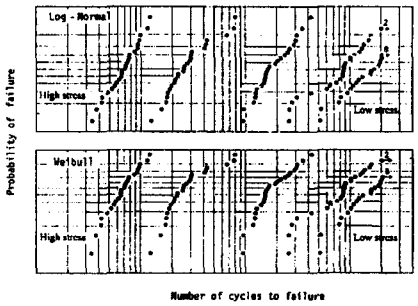
P-S-N PLOT



HISTOGRAM



WPP AND LOGNORMAL PLOTS



SALIENT FEATURES

- **The S-N plot for the mean is**

  P1: Continuous and concave

  P2: μ_s and $\ln(\mu_s)$ are decreasing (or more correctly non-increasing) functions of s

- **The S-N plot for the median is**

  P3: Continuous and concave

  P4: $t_{s,0.5}$ and $\ln(t_{s,0.5})$ are decreasing (or more correctly non-increasing) functions of s

SALIENT FEATURES

- **P-S-N Plot**

  P5: They are continuous and concave

  P6: $\hat{t}_{s,\gamma}$ and $\ln(\hat{t}_{s,\gamma})$ are decreasing (or more correctly non-increasing) functions of s

  P7: The variability in the lifetime (defined by $t_{s,0.99} - t_{s,0.01}$) decreases as s increases

- **Histogram (EDF) Plot**

  P8: The plots move to the right as the stress level increases

SALIENT FEATURES

P9: The spread (defined by $t_{s,0.99} - t_{s,0.01}$) is a decreasing (or more correctly non-increasing) function of s

- **WPP Plots**

  P10: The plots move from right to left as the stress level increases.

  P11:In most cases the curves are convex for low stress values. In a few cases the curves are s-shaped

  P12: They are linear for high stress

STRESS LIFE MODELS

- **Several Models**
  - **Accelerated time to failure (AFT)**
  - **Proportional Hazard (PH)**
  - **Parametric**
- **2- and 3-parameter Weibull distributions**
- **Lognormal distribution**

MODEL INADEQUACY

Weibull models studied

1. **2-Parameter Weibull**
2. **2-fold Mixture Weibull**
3. **2-fold Competing Risk Weibull**
4. **Piecewise Weibull (Two Weibulls for different stress intervals)**

MODEL EVALUATION

	S-N Curves (mean)		S-N Curves (median)		P-S-N Curves			WPP Plots		
Model	P1	P2	P3	P4	P5	P6	P7	P10	P11	P12
Single	×	✓	×	✓	×	✓	×	✓	×	✓
Mixture	✓	✓	×	✓	×	✓	×	✓	✓[c]	✓[c]
Competing	×	✓	×	✓	×	✓	×	✓	×	×
Piecewise	✓[a,b]	✓[a]	✓[a,b]	✓[a]	✓[a,b]	✓[a]	×	✓	×	✓

a: not all cases

b: S-N and P-S-N curves all continuous for only one case

c:– P11 and P12 not satisfied simultaneously

REFERENCE

Townson, P. and Murthy, D.N.P. (2004)
Stress life modelling - Part I: Empirical plots

Stress life modelling – Part II : Weibull based models

Submitted for publication

FUTURE RESEARCH

- Examine other Weibull models (See, Murthy, D.N.P., Xie, M and Jiang, R. (2003) *Weibull Models*, Wiley New York) to see if they match the data
- Carry out a similar study for lognormal distribution
- More complex Stress-life models?