Reliability Engineering: "Engineering for Product Reliability"

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V2i *Vors* to Innovate

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- Understanding Variation
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Further reading

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- Consultant and owner at V2i (*Vors* to Innovate): consulting and services on Systematic Innovation, Materials Performance, Product Reliability and Process Improvement
- Board member PLOT-FHI and chairman Reliability work group (theme: Physics of Failure)
- Background: Mechanical Eng., Industrial Eng., Electronics Industry (10 yrs.) and Applied Research (18 yrs.)
- ASQ Certified Reliability Engineer (CRE), Quality Engineer (CQE) and Six Sigma Black Belt (CSSBB)

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Reliability

"Betrouwbaarheid is eigenschap van mensen, bij producten spreken we bij voorkeur over bedrijfszekerheid" [E.E. de Kluizenaar]

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What is Reliability?

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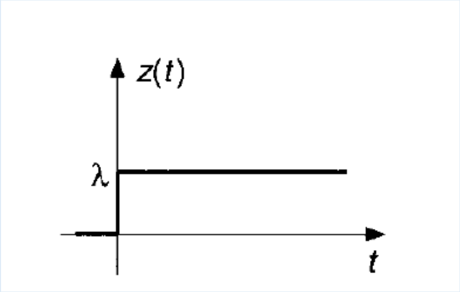
"The probability that an item can perform its intended function for a specified interval under stated conditions." [MIL-STD-721C, 1981]

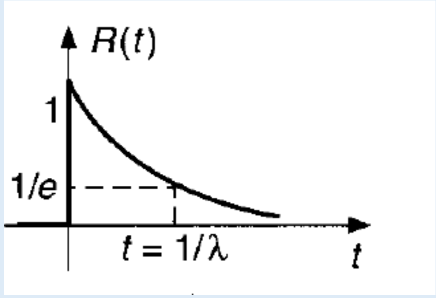
To define (product) reliability one must address:
1) A probability of an item functioning as intended
2) An operational interval (time or cycles)
3) A definition of the operating environment

"Fitness for use" [J.M. Juran]

$$R(t) = e^{-\lambda t}$$

λ = failure rate (constant)
t = time





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What is Reliability Engineering?

Contributing to the design objectives:

1) Determine feasibility of meeting design goals
2) Understand the impacts on design performance (single point failures, key design parameters, predominant failure modes / mechanisms)
3) Use proper parts and apply correctly
4) Address all sources of components, materials etc.
5) Validate design

** Benchmarking Commercial Reliability Practices (1996). Rome, NY: Reliability Analysis Center.*

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Short Historical Perspective

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- Theory of probability (Pascal and Fermat, 17th century)
- Solving practical problems with probability and statistics (LaPlace, 19th Century)
- Development of (statistical) reliability tools (1940s, →)
- Need for reliable electronics (WWII)
- Reliability Engineering as a discipline (1950s, →)
- Wide use of analytical instrumentation and microscopic techniques like SEM (1980s , →)
- Development of computer simulation methodologies and tools (2000, →)

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Understanding Variation

"If I had to reduce my message to just a few words,
I'd say it all had to do with reducing variation."
[W. Edwards Deming]

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(Control of) Variation

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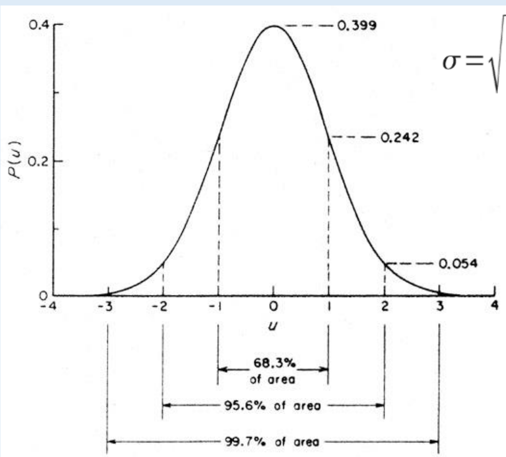
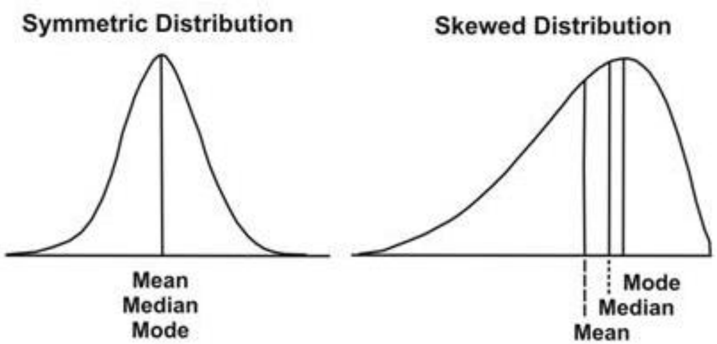
- Definition: Variation is the dispersion or spread about a certain value. For example, the variation about the mean is called deviation
- Control of variation makes products predictable and ready for structural improvement (systematic reduction of losses and costs)



$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$



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Exploring Lifetime Variation

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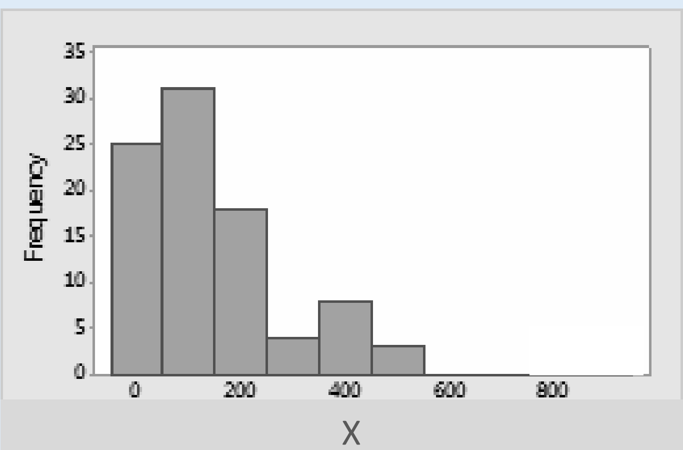
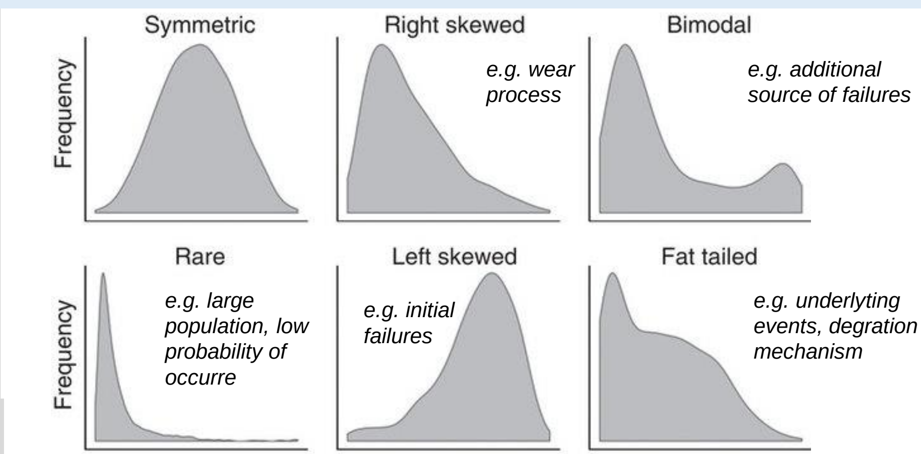
- Frequency Histogram (binary distribution) → Probability Density Functions (PDF)
- Approach: 1) X-axis range: difference between the largest and smallest data values, 2) Number of bins: k=√n and 3) fitting / testing curves → Analysis!





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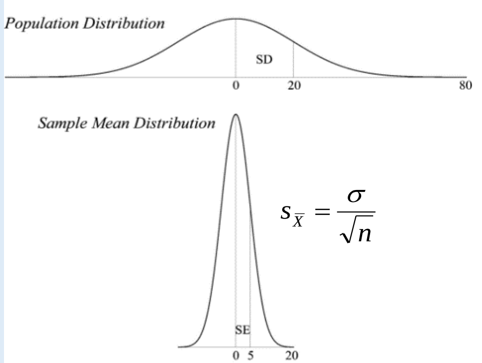
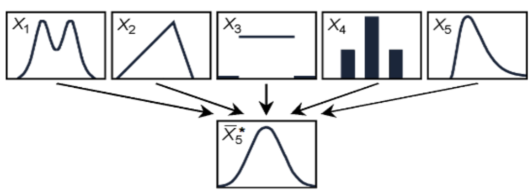
Central Limit Theorem

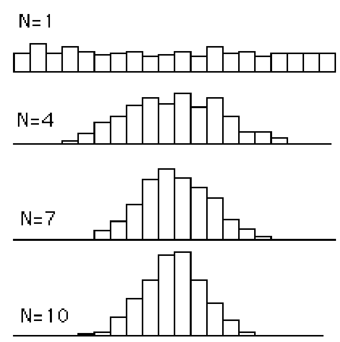
- <u>Statement</u>: Sample means ($\overline{X}$) will be more normally distributed around the population mean (μ) than individual values. The distribution of sample means approaches normal regardless of the shape of the parent population.



Normal distribution example



All shapes converge to normal

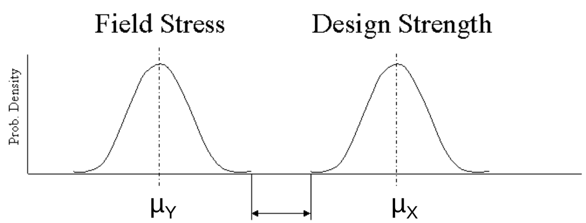


Effect of sample size

"Central Limit Theorem is the underlying reason why control charts work"

Stress-Strength Analysis (I)

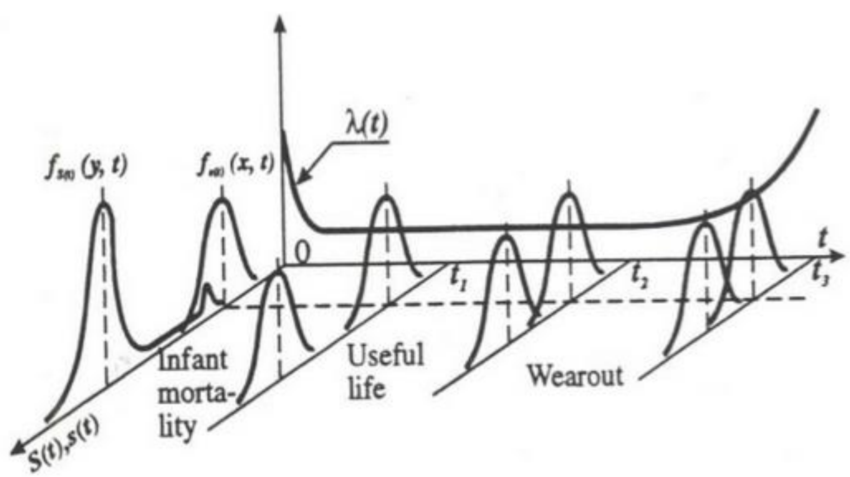
- A part fails when the applied stress exceeds the strength of the part. Understanding operational conditions, product performance and the statistics is crucial.
- Possible strategies: increasing design margins, reducing product strength variation, changing specifications



SF, Safety Factor: $\frac{\mu_X}{\mu_Y}$

MOS, Margin of Safety: $\frac{\mu_X - \mu_Y}{\mu_Y}$

Prob. of Failure: $Z = \sqrt{\frac{\mu_X - \mu_Y}{\sigma_X^2 + \sigma_Y^2}}$



Stress-Strength over time

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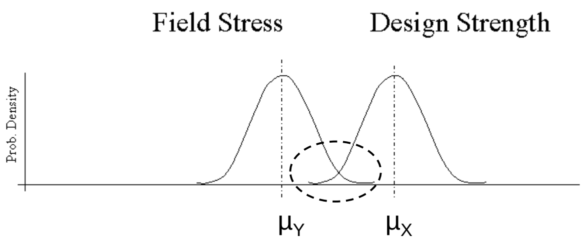
Stress-Strength Analysis (II)

- <u>Example</u>: the stress distribution of a high-power LED has a mean stress of 1,0 W with a standard deviation of 0,2 W. The device is designed to handle 2,5 W with a standard deviation of 0,3 W. Question: Determine the probability of failure (assuming normal distributions):

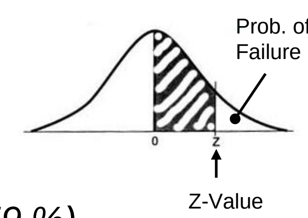
Approach: calulate Z value of stress-strength interference distribution



$$Z = \sqrt{\frac{\mu_X - \mu_Y}{\sigma_X^2 + \sigma_Y^2}} \qquad Z = \sqrt{\frac{2{,}5 - 1}{0{,}2^2 + 0{,}3^2}}$$

Z = 4,160 (4,160 standard deviations)

Probability of Failure = 1,59 x 10^{-5} (0,0159 %)



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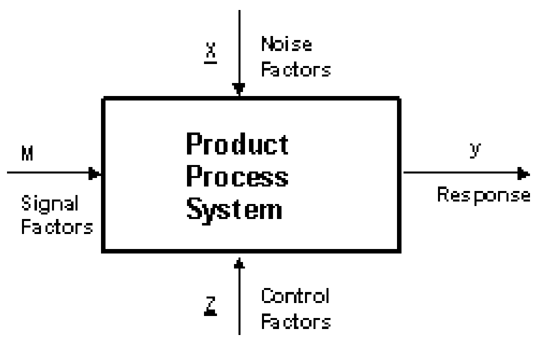
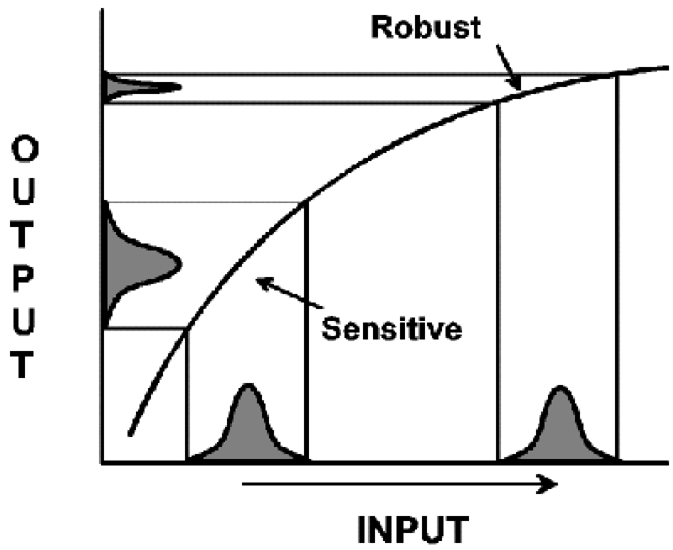
Robust Design

- <u>Principle</u>: Robust design is making the product performance insensitive to input variations (including possible interaction effects and noise factors)



Robust design schematic



E.g. Roy, R., “A Primer on the Taguchi method, Second edition”, 978-0872638648, 2010

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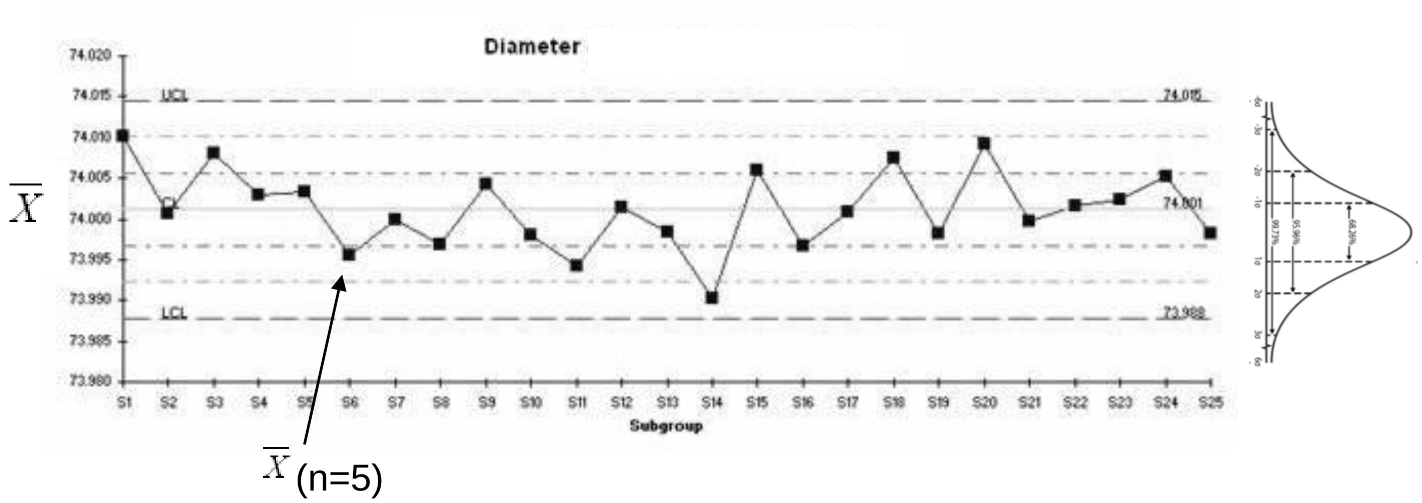
Controlling CtR Parameters

- Statistical Process Control (SPC) on parameters which are Critical to Reliability (CtR)



E.g. Out of control detection based on "Nelson Rules"

Note: Control means "beheersen" rather than "Controleren"

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Reliability in Design

"Design for Reliability (DfR) is a process for ensuring the reliability of a product or system during the design stage before physical prototype."
[DfR Solutions]

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Approaches in Design

- Reliability growth v Design for Reliability

Reliability Growth *	Design for Reliability
"The only way to improve (grow) reliability is to find and fix failure modes"	"Improving designs based on design rules and knowlegde about failure behaviour"
"The only way to find a hidden failure modes is to stress it"	"The use of early design evalutions and modelling / simulation tools should prevent designing in failures"
"Raising the level of appropriate stress is the only way to accelerate this process"	"Continuously learning and updating the knowledge system is the way to systematically improve designs and accelerate the design process"

* *Crowe, D., Feinberg, A., "Design for Reliability", CRC Press, ISBN-13: 978-0849311116, 2001.*

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Failure Mode & Effect Analysis (FMEA)

- Single most important reliability tool: 1) Identifying, 2) scoring and 3) managing potential failure modes

Basic format:

Potential Failure Modes and Effects Analysis

System ____________________
Subsystem ____________________
Part Number ____________________
Designer ____________________

FMEA Revision ________
FMEA Prepared By ___________
FMEA Date ____________
FMEA Revision Date ___________

Item/ Function	Potential Failure Modes	Failure Mode Effects	SEV	Potential Failure Causes	PF	Current Controls	DET	RPN	Actions Req'd	Owner/ Target Date	Actions Taken	SEV2	PF2	DET2	RPN2

Risk Priority Number (RPN) = Severity x Occurrence x Detectability

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Crucial to Succes of FMEA

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- Input based on customer requirements

  (e.g. VOC → QFD →FMEA)
- Analysis based on products functions
- Cross-functional teams
- Continuous action follow-up / revising throughout the design phases

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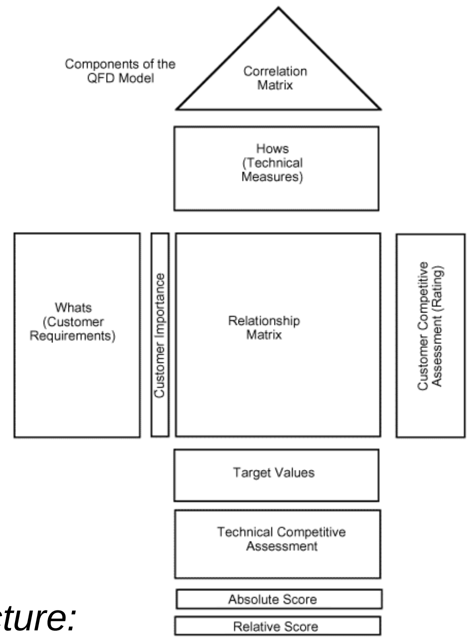
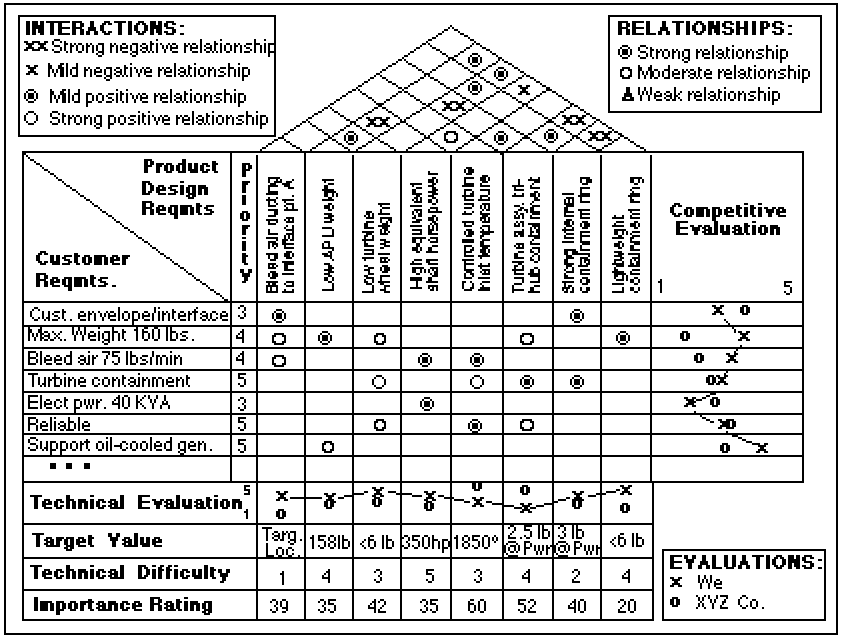
(The best) Preparation for an FMEA (I)

- Quality Function Deployment (QFD) "House of Quality": Translating the Voice of the Customer (VOC) into design requirements and ultimately reliable products

QFD structure:





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(The best) Preparation for an FMEA (II)

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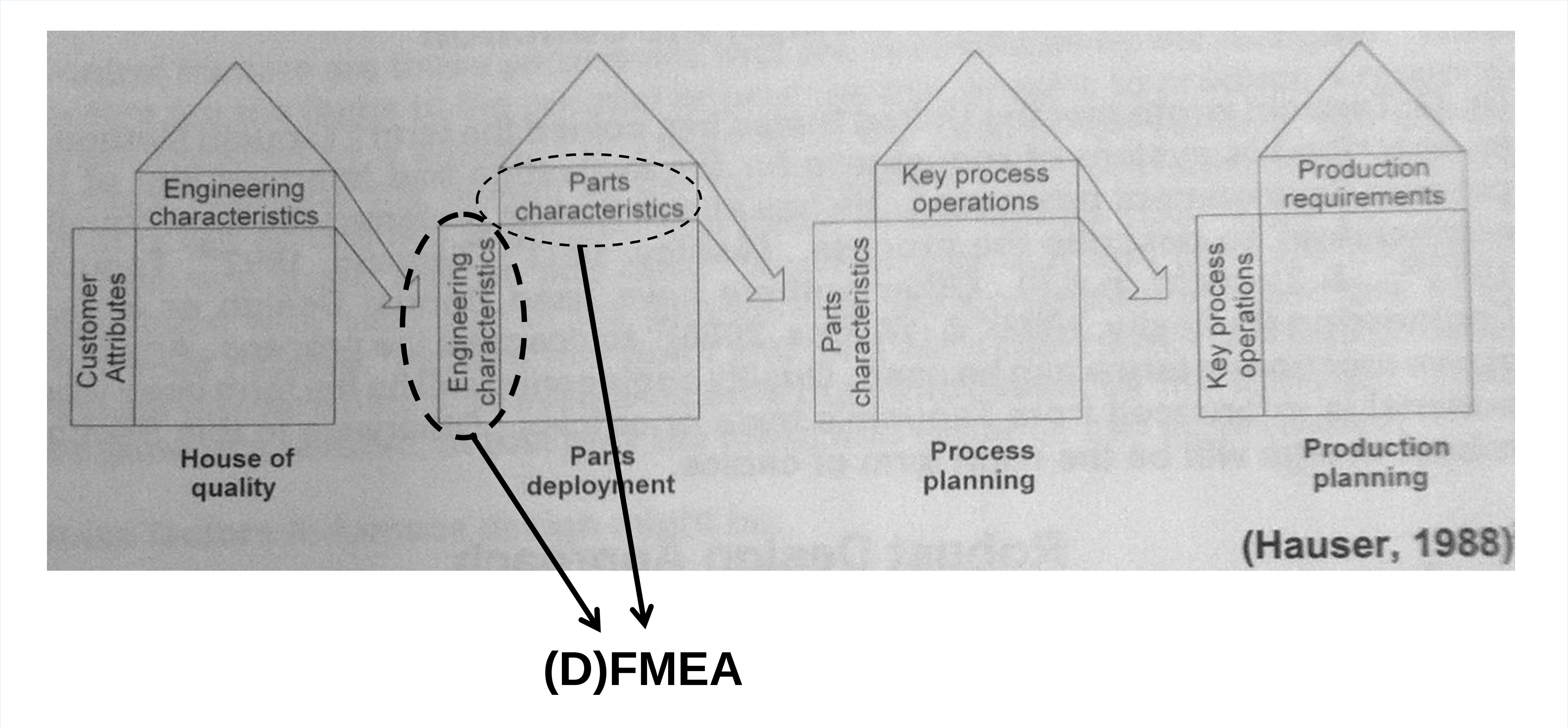
- Linked Houses of Quality: from VOC to functions and parts



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Reliability Testing

Testen is een middel, nooit een doel"
[J. Geerse]

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(Reliability) Testing

Reasons for (reliability) testing:

- Identify weaknesses in parts / designs
- Monitor reliability growth over time
- Find dominant failure modes / mechanisms
- Predict lifetime based on accelerated testing
- Determine safety margin in design
- Determine if systems meets requirements
- Acceptance testing
- Environmental Stress Screening
- Burn-in Testing

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Benchmarking Reliability Practices*

The three major benchmarks of reliability practices are:

1) **Completely analyse all failures**, regardless of when or where they occur in development, to identify the root cause of failure and determine the necessary corrective action, including redesign and revision of analytical tools.
2) **Avoid dedicated reliability demonstration testing**. If required, demonstrations should focus on new components or assemblies, or the integration of old items in a new way. Emphasise engineering development testing to understand and validate the design process and models. Accelerated testing should be used to age high reliability items and to identify their failure mechanisms.
3) **Assign responsibility for reliability to a product development team**. Give the team the authority to determine the reliability requirements and to select the design, analysis, test and manufacturing activities needed to achieve that reliability.

* *Benchmarking Commercial Reliability Practices (1996). Rome, NY: Reliability Analysis Center.*

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Further reading

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- *MIL-HDBK-338B, "Electronic Reliability Design Handbook", 1998.*
- *MIL-HDBK-217F, "Reliability Prediction of Electronic Equipment", 1995.*
- *MIL-STD-883J, "Test Methods and Procedures for Microelectronics", 2013.*

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Thank you for your Attention

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