Reliability Engineering:
"Engineeren voor Product Reliability"

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Contents

Reliability

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

What is Reliability?

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

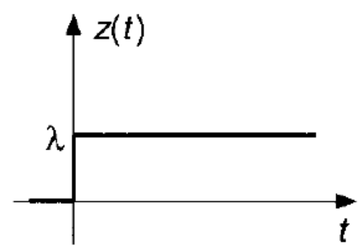
<u>To define (product) reliability one must address</u>:

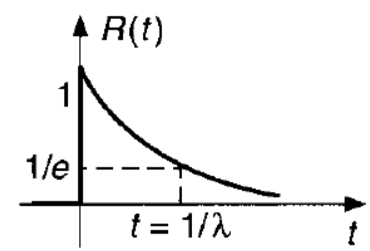
1) A probability of an item functioning as intended
2) An operational interval (time or cycles)
3) A definition of the operating environment

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

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

λ = failure rate (constant)
t = time





Short Historical Perspective

- 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 microscopic techniques like SEM (1980s , →)
- Development of computer simulation methodologies and tools (2000, →)

Reliability Management

- Definition of reliability program (e.g. "A statement of reliability policy", tasks, tools, methods, training)
- Design evaluation / requirements management
- Modelling and prediction
- Safety and risk management
- Reliability testing
- Failure and data analysis

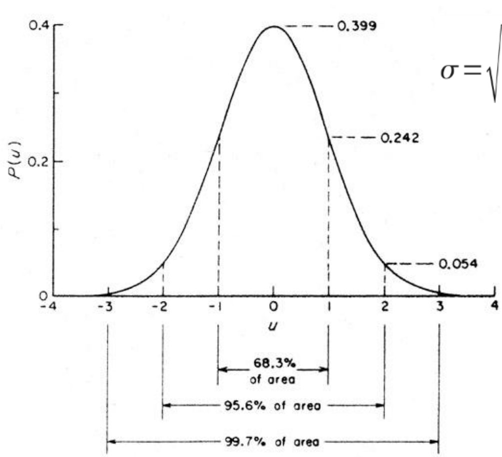
Understanding Variation

“If I had to reduce my message to just a few words,
I'd say it all had to do with reducing variation.”

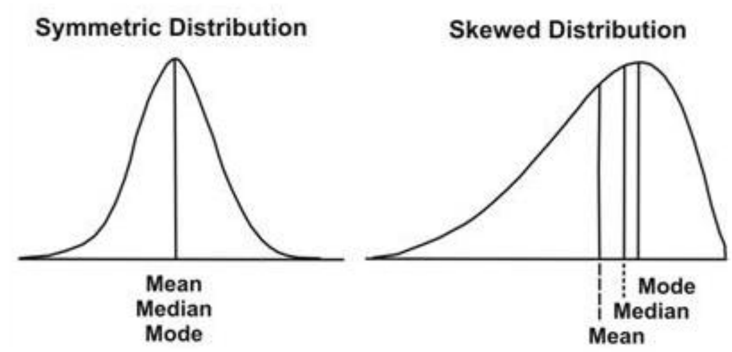
[W. Edwards Deming]

(Control of) Variation

- 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)

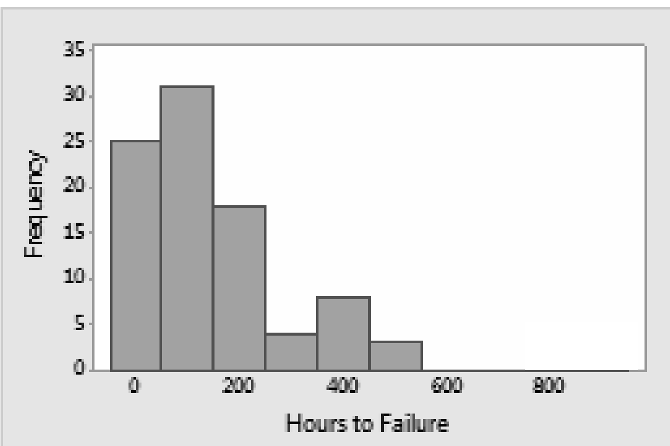


$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

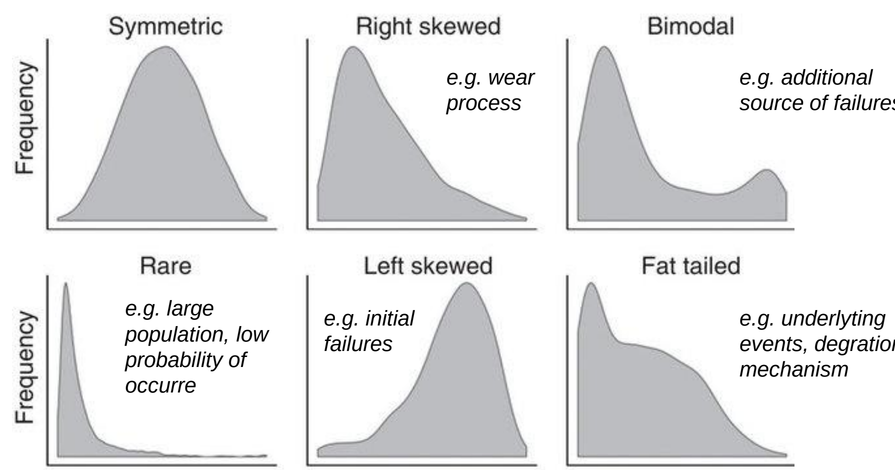


Exploring Lifetime Variation

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



Histogram example (early failures)



Examples of distributions

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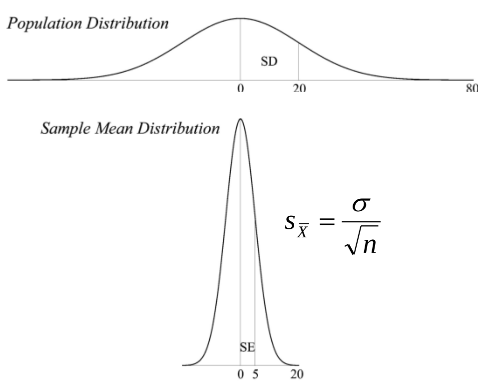
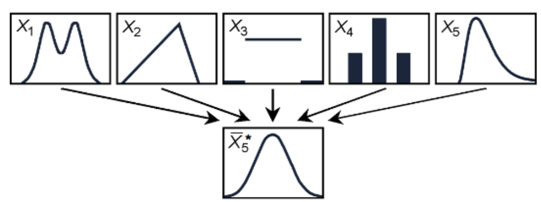
Central Limit Theorem

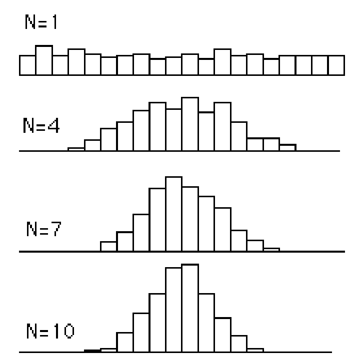
- <u>Statement</u>: Sample means ($\bar{X}$) will be more normally distributed around the population mean (μ) than individual values. The distribution of sample means approaches normal regardless of the shape of the parent population.



Normal distribution example



All shapes converge to normal

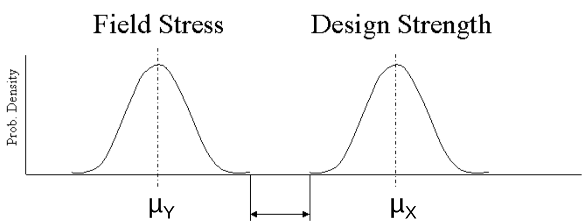


Effect of sample size

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

Stress-Strength Analysis (I)

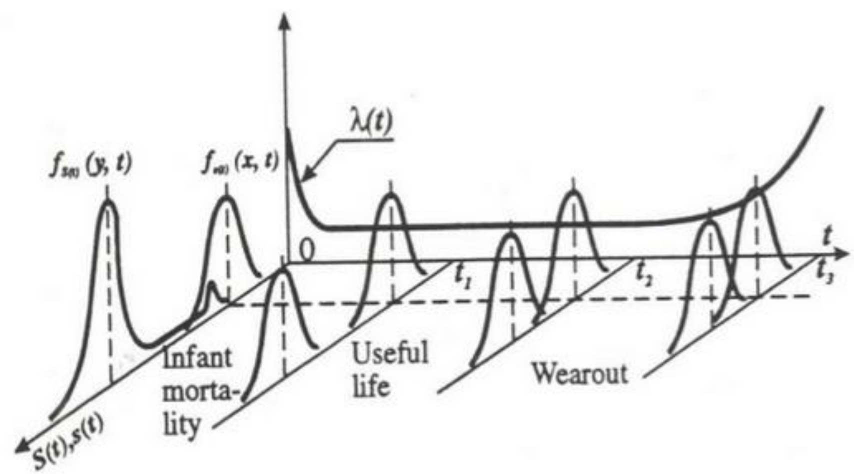
- A part fails when the applied stress exceeds the strength of the part. Understanding operational conditions, product performance and the statistics is crucial.
- Possible strategies: increasing design margins, reducing product strength variation, changing specifications



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

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

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

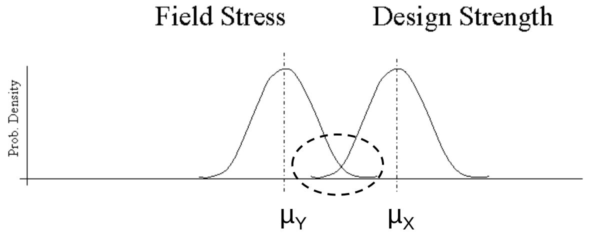


Stress-Strength over time

Stress-Strength Analysis (II)

- Example: 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):

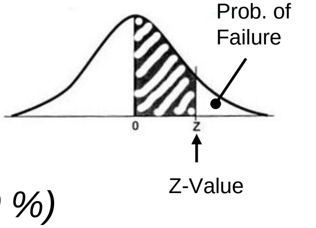
Approach: calulate Z value of stress-strength interference distribution



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

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

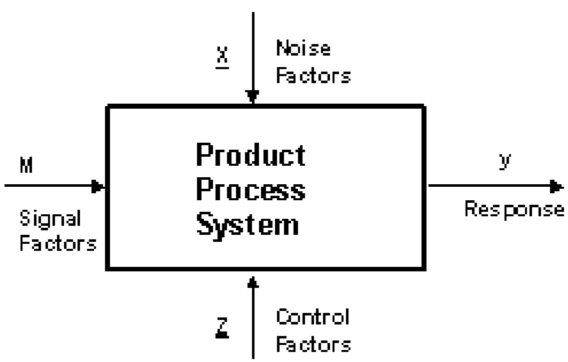
Probability of Failure = 1,59 x 10^{-5} (0,0159 %)



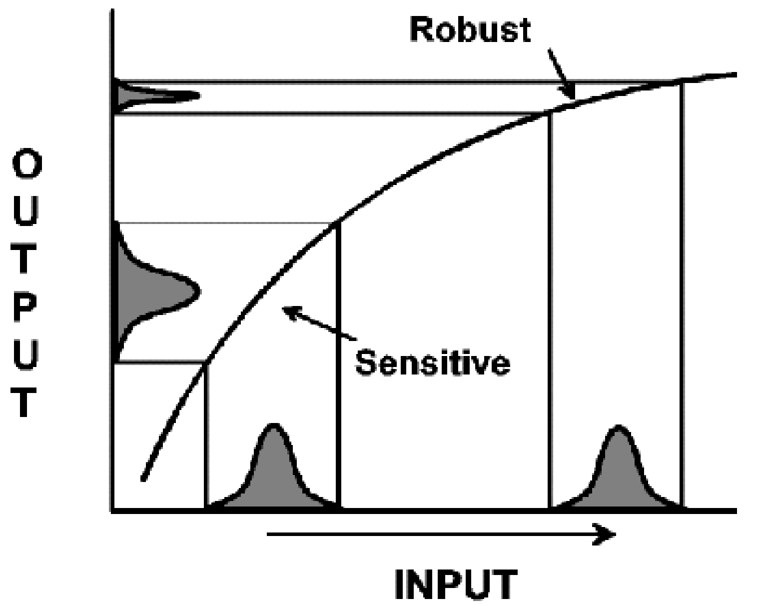
Note: Use table of Z values or XLS function: =NORMSDIST(Z-value) to find probability values

Robust Design

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



Robust design schematic



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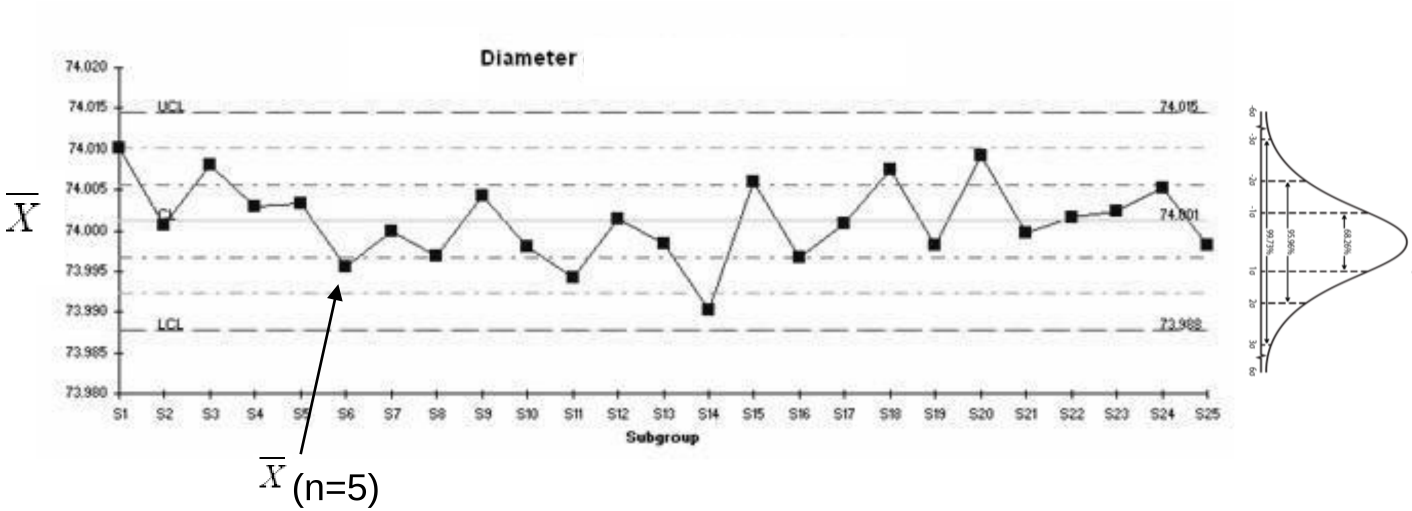
Controlling CtR Parameters

- 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"*

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]

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.*

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 ____________________ FMEA Revision ________

Subsystem _________________ FMEA Prepared By ___________

Part Number _______________ FMEA Date ____________

Designer ___________________ 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	SEV 2	PF 2	DET 2	RPN 2

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

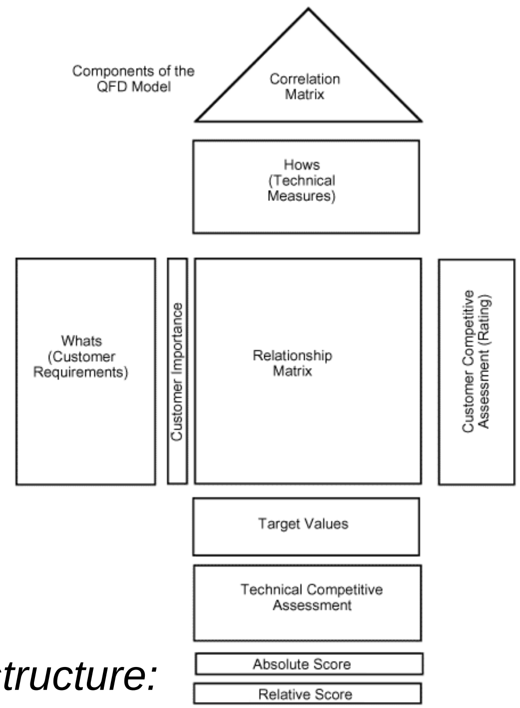
Crucial to Succes of FMEA

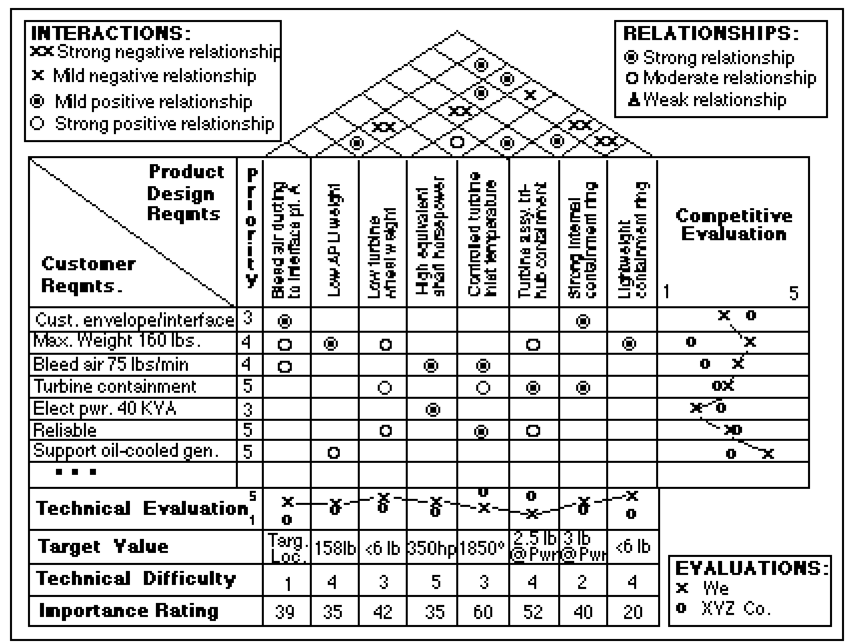
- Input based on customer requirements
  (e.g. VOC → QFD →FMEA)
- Analysis based on products functions
- Cross-functional teams
- Continuous action follow-up / revising throughout the design phases

(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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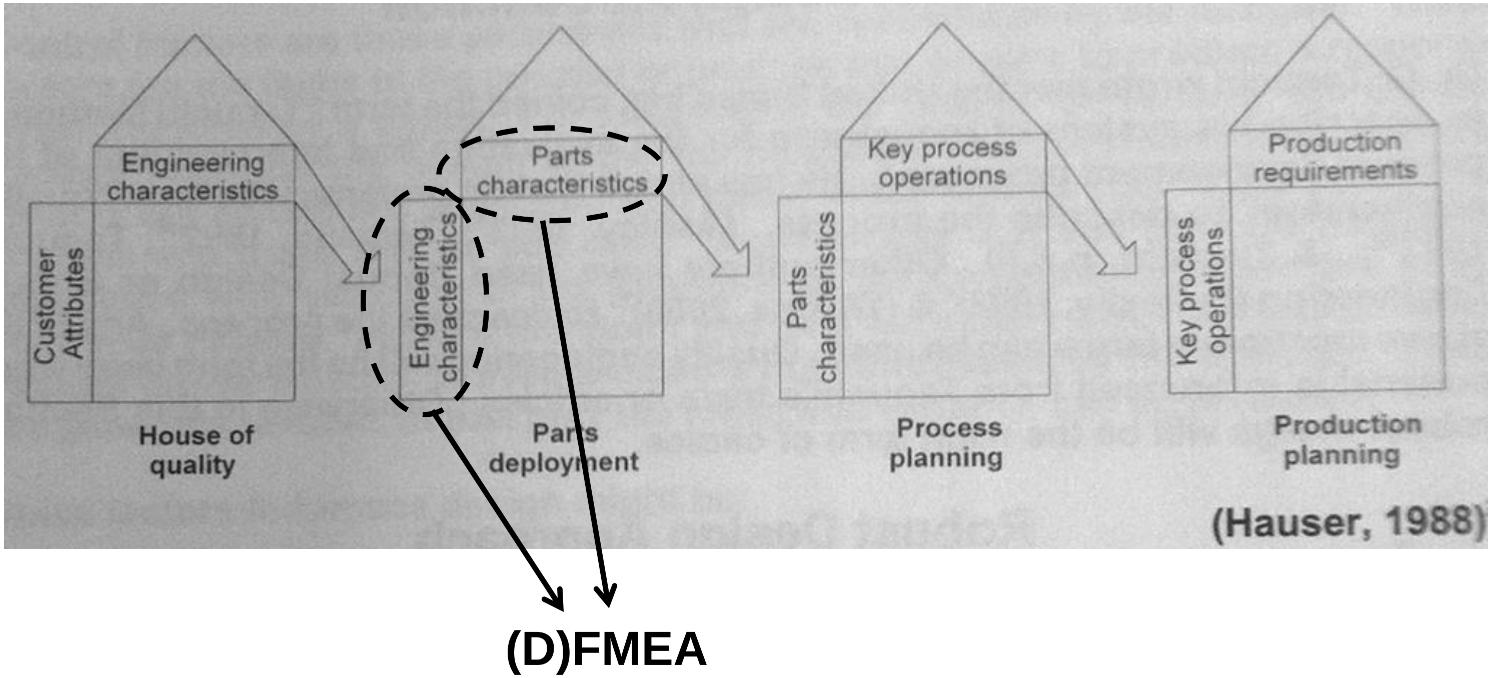
(The best) Preparation for an FMEA (II)

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



Reliability Testing

"Testen is een middel, nooit een doel"

[J. Geerse]

(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

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.*

Further reading

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Thank you for your Attention

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