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Reducing Product Development Risk with Reliability Engineering Methods

Mike McCarthy
Reliability Specialist

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Who am I?

- Mike McCarthy, Principal Reliability Engineer
  - BSc Physics, MSc Industrial Engineering
  - MSaRS (council member), MCMI,
  - 18+ years as a reliability practitioner
  - Extensive experience in root cause analysis of product and process issues and their corrective action.
    - Identifying failure modes, predicting failure rates and cost of 'unreliability'
  - I use reliability tools to gain insight into business issues - 'Risk' based decision making

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Agenda

		‘Probable’ Duration
1.	Risk	2 min
2.	Reliability Tools to Manage Risk	4 min
3.	FMECA	6 min
4.	Design of Experiments (DoE)	5 min
5.	Accelerated Testing	5 min
6.	Summary	3 min
7.	Questions	5 min
		Total: 30 min

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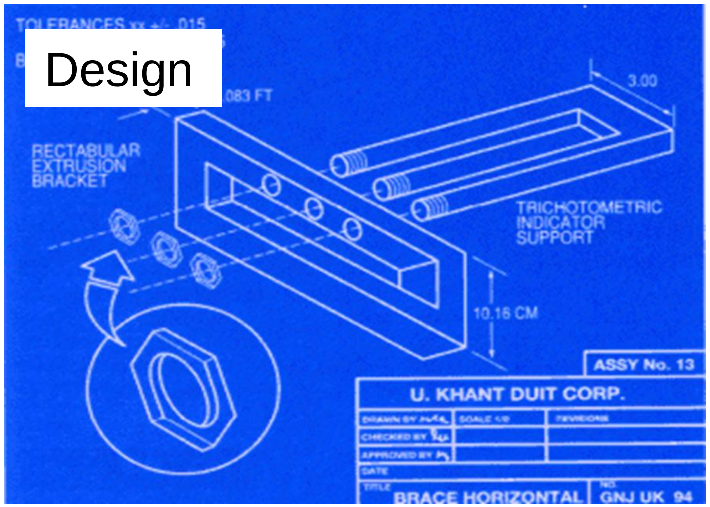
Managing Risk?



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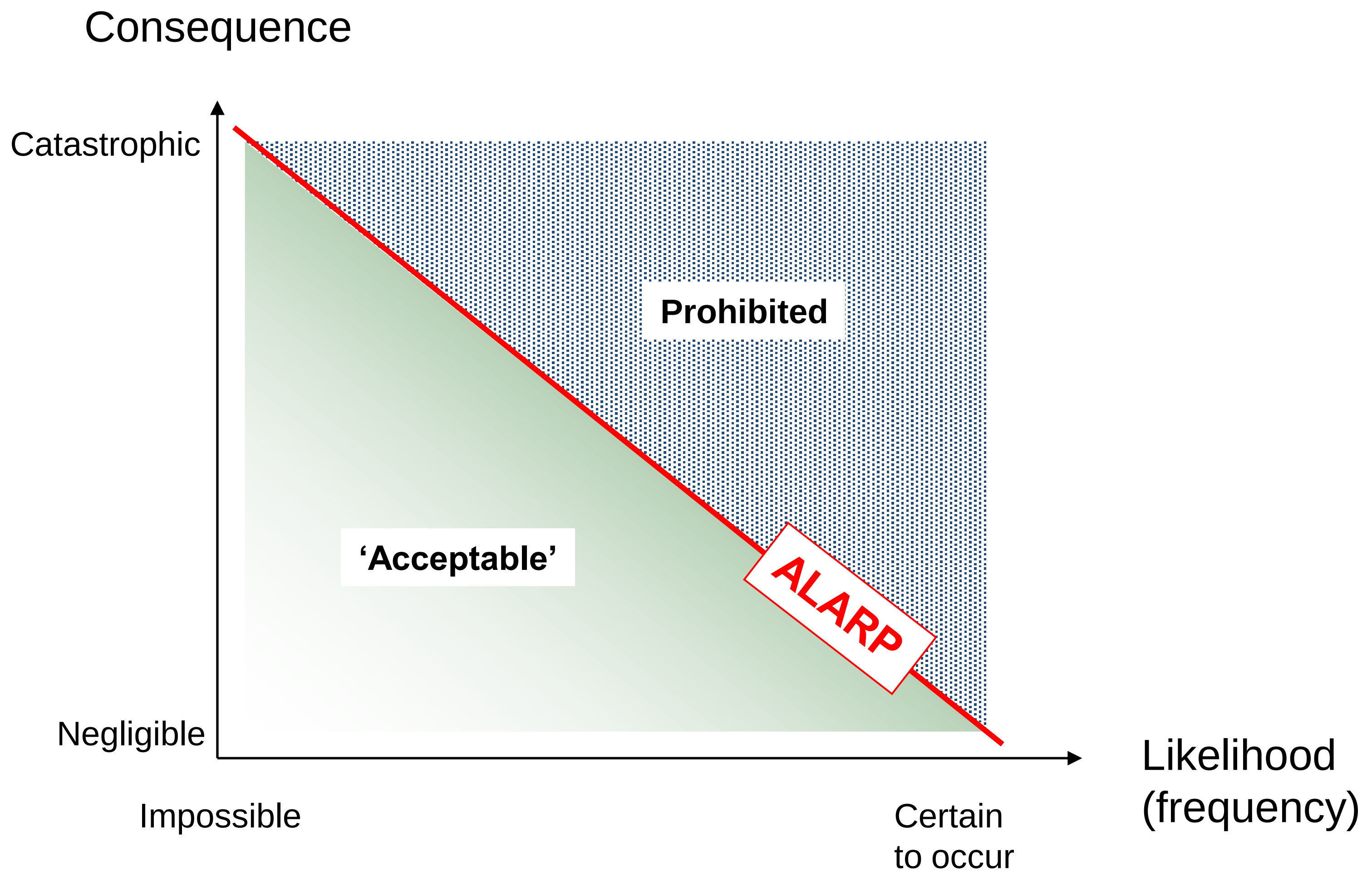
Likelihood-Consequence Curve



Risk = Likelihood x Consequence

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Reliability Tools to Manage Risk

Tools to Manage Risk

- Design Reviews
- FRACAS/DRACAS
- Subcontractor Review

Review & Control

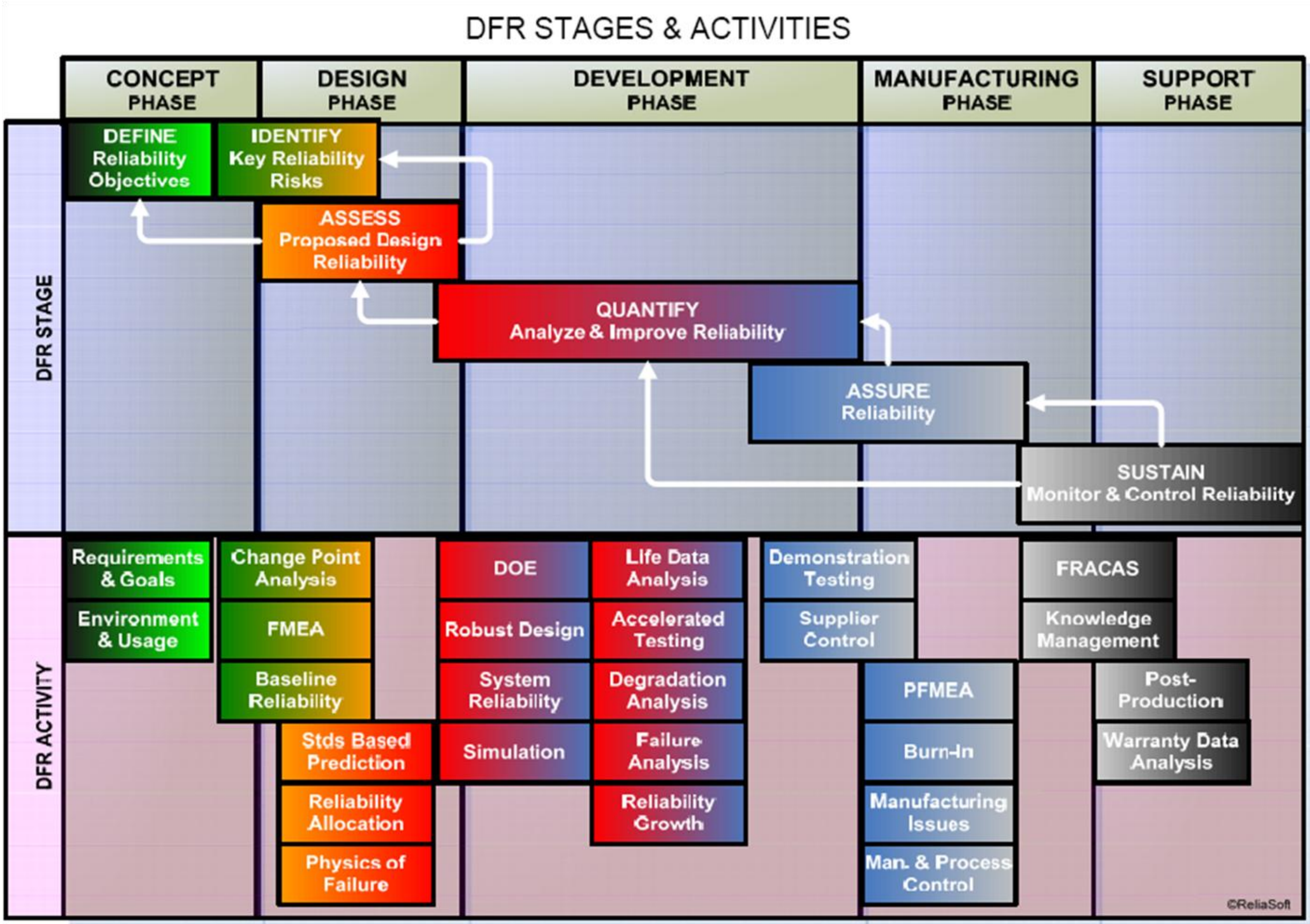
- Part Selection & Control (including de-rating)
- Computer Aided Engineering Tools (FEA/CFD)
- **FME(C)A** / FTA
- System Prediction & Allocation (RBDs)
- Quality Function Deployment (QFD)
- Critical Item Analysis
- Thermal/Vibration Analysis & Management
- Predicting Effects of Storage, Handling etc
- Life Data Analysis (eg Weibull)

Design & Analysis

- Reliability Qualification Testing
- Maintainability Demonstration Testing
- **Accelerated Life Testing**
- Production Reliability Acceptance Tests
- Reliability Growth Testing

Test & Evaluation

Design for Reliability



FMECA
Failure Modes, Effects & Criticality Analysis

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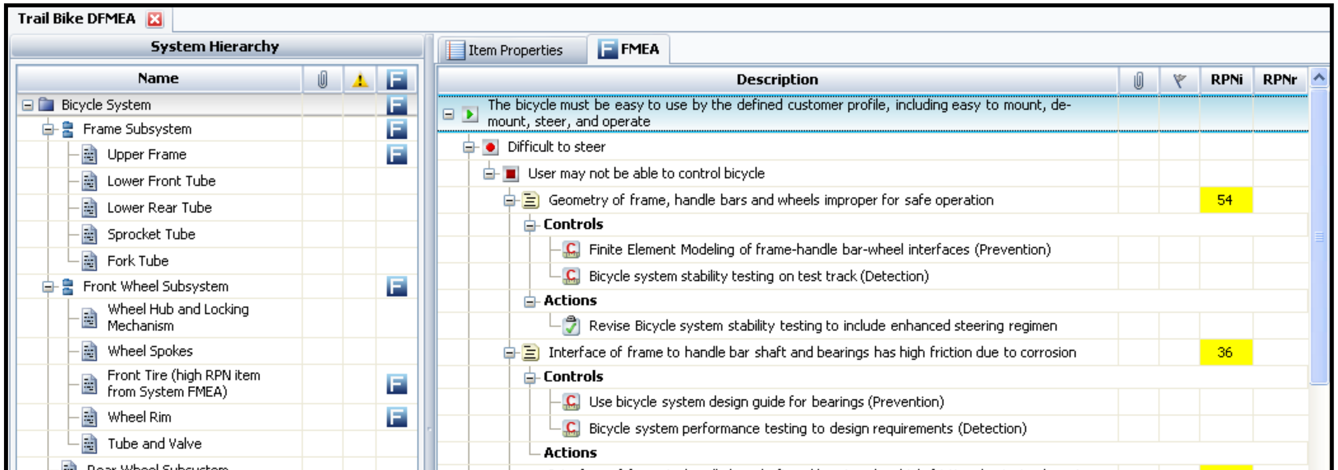
Types of FMECAs

- Design
- Concept
- Component
- BoM
- Automotive
- Piece-part
- Process
- Application
- **Functional**
- Machinery
- Material
- Service
- Health
- Preventative Maintenance
- Supplier Quality

- All have the similar structure - some are identical!
- Some are aimed at specific points in product life cycle

FMECAs



Function	Potential Failure Mode	Potential Effect(s) of Failure	SEVi	Potential Cause(s) of Failure	OCCi	Current Design Controls	Control Type	DETi	RPNi	Recommended Action(s)	Responsibility	Target Completion Date
1 - Bicycle System												
The bicycle must be easy to use by the defined customer profile, including easy to mount, de-mount, steer, and operate	Difficult to steer	User may not be able to control bicycle	9	Geometry of frame, handle bars and wheels improper for safe operation	3	Finite Element Modeling of frame-handle bar-wheel interfaces	Prevention	2	54	Revise Bicycle system stability testing to include enhanced steering regimen		
						Bicycle system stability testing on test track	Detection					
				Interface of frame to handle bar shaft and bearings has high friction due to corrosion	2	Use bicycle system design guide for bearings	Prevention	2	36			
						Bicycle system performance testing to design requirements	Detection					
				Interface of frame to handle bar shaft and bearings has high friction due to inadequate geometric clearances	3			5	135			
				Interface of frame to handle bar shaft and bearings has high friction due to debris	1			2	18			
	Difficult to operate the pedals	User may not be able to propel the bicycle forward	6	Pedal material too slippery	5	Bicycle system performance testing to design requirements	Detection	2	60	Change pedal material to higher coefficient of friction		
										Add pedal feel to overall bicycle design review agenda		
										Modify Bicycle performance testing to include pedal friction		
				Frame and pedal geometry inadequate for shorter user who is within the customer profile	1	Marketing performance packaging clinic	Prevention	2	12			
				Excessive friction with chain and sprocket	3	Bicycle system performance testing to design requirements	Detection	3	54	Begin research on new chain material with less friction and more corrosion resistance. Report back at next Product Team meeting.		

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FMECAs

There are many reasons why FMECAs are performed:

- To understand an existing system better
  - Evaluate effects and sequences of events caused by a specific failure mode
- Identify weak spots
  - To determine the criticality of each failure mode as to the systems correct function or performance and the impact on availability and/or safety
- Manage life cycle issues
  - Classification of identified failure modes according to their detectability, testability, replaceability and operation provisions (tests, repair, maintenance, logistics etc…)
- Demonstrate performance levels likely to be met
  - Estimate significance and probability of failures
  - Justify level of availability/safety to user or certification agency
- Create risk based test plans

Successful FMECAs

- FMECA is a team activity requiring contributions from knowledgeable / experienced individuals:
  - Project Management
  - Design Engineers
  - Test & Development Engineers
  - Reliability Engineers
  - Maintenance Engineers
  - Procurement Specialists
  - Supplier Quality Assurance staff
  - Suppliers/OEM representatives
  - Manufacturing Engineers
  - Assembly staff
  - Field Support staff
  - Senior Management

FMECAs create knowledge databases of reliability data

Successful FMECAs

- The mechanics of the process are:
  - Assemble the team.
  - Establish the ground rules.
  - Gather and review relevant information.
  - Identify the item(s) or process(es) to be analyzed.
    - Components/systems.
    - Similar procedures can be used to analyze processes.
  - Identify the function(s), failure(s), effect(s), cause(s) and control(s) for each item or process to be analyzed.
  - Evaluate the risk associated with the issues identified by the analysis (RPNs).
  - Prioritize and assign corrective actions.
  - Perform corrective actions, re-evaluate risk.
  - Distribute, review and update the analysis, as appropriate.

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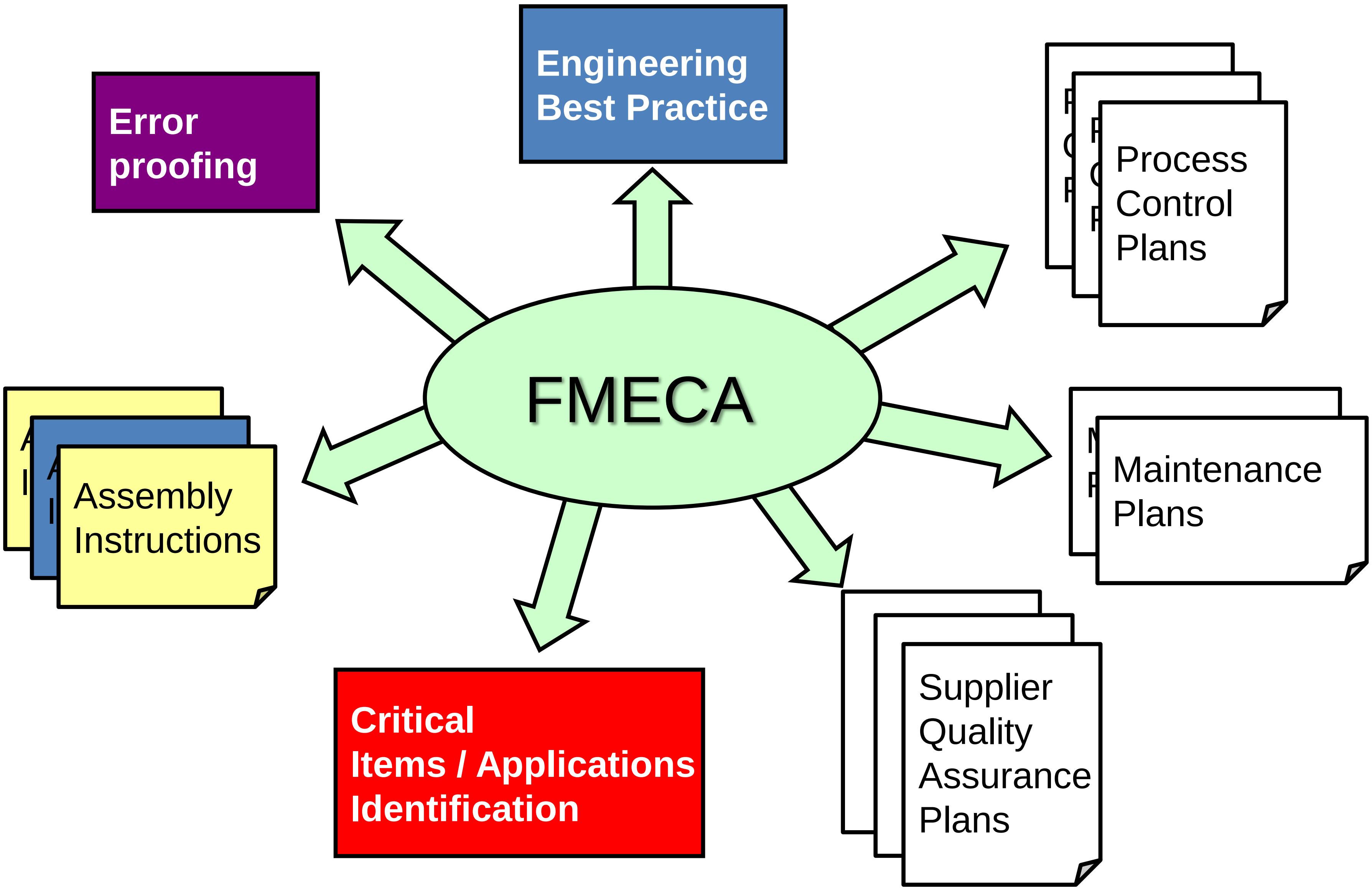
Possible Outcomes of FMECA

As a result of the FMECA it may be necessary to:

- Change design, introduce redundancy, reconfigure…
- Introduce specific tests, preventative maintenance
- Focus quality assurance on key areas
- Use alternative materials, components
- Change operating conditions (eg duty cycles to avoid early wear-out failures)
- Adapt operating procedures (eg allowed temperature range…)
- Perform design reviews
- Closely monitor problem areas during testing and use
- Exclude liability for specific applications

- The ACTION PLAN is the real deliverable

Possible Outcomes of FMECA



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DoE
Design of Experiments

Design of Experiments

- An 'experiment' is a series of systematic tests done in order to understand or optimise a product or process.
- DoE is a statistical tool that aims to maximise insight using minimum resources
  - Follows on naturally from FMECA analysis
  - Experimental observations recorded in a randomised way using a predetermined pattern (the 'design' in 'DoE')
  - Simultaneous changes to a set of factors
  - Analysis of response of system to changing factors
  - Goal is usually to find optimum value of chosen factors
    - To increase output
    - To reduce variation
    - To reduce cost
    - Compare different designs
    - Identify most important factors affecting performance

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Terminology

- Factor
  - The entity whose affect on the response is being studied
- Response
  - The performance measure used to investigate the effect of the chosen factors on the system
- Level
  - The setting of the factor used in the experiment
- Treatment
  - The particular instance of all the levels of the factors in a given experimental run
- Replicates
  - Experimental runs corresponding to the same treatments that are conducted in a random order

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Terminology

- Nuisance factor
  - Factors affecting the response that are not of interest to the experimenter (can be known or unkown!)
- Blocking
  - The separation of the runs of an experiment based on a known nuisance factor.
  - eg   If one person performed half the runs and another person performed the other half, you could assign the first person's runs to one block and the second person's runs to another in order to eliminate any variation in response
  - Blocking and randomising are important DoE concepts

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DoE Phases

- Planning
  - Creation of an efficient DoE plan
    - Several smaller DoEs are more efficient/cost effective
    - Needs precise definition of objective of experimentation
    - Definition of time and resources available
    - A good FMECA & cross functional team to define factors and responses
- Screening
  - Reduce number of possible factors to most important only
    - Usually look at many 2 level factors, then filter down to top 2 to 4
- Optimization
  - Find best combination of factor settings
    - Usually, best factor settings provide a max/min or a target value for the response function

DoE Phases

- Robustness Testing
  - Find control factor settings that counteract or minimize noise factors
    - A Control factor is one we can control, a Noise factor is one that affects response but is difficult to control
- Validation
  - Confirmation runs to verify/validate the strongest factors and their optimum settings
  - Essential!

Common Experimental Designs

- Factorial Designs
  - Multiple factors applied simultaneously
  - Identifies the factors that have a significant effect on the response
  - Investigates the effect of interactions between factors
  - Full Factorial
    - General (eg 2 factors, with m & n levels respectively creates (m x n) runs per replicate)
    - Two Level (if there are k factors, total number of runs = 2^k per replicate)
  - Fractional Factorial
    - Two Level (Some factor/level combinations are excluded)
    - Plackett-Burman (main effects, ie no interactions studied)
    - Taguchi Orthogonal Arrays (highly fractional and not limited to 2 levels)
- Response Surface Designs
  - Special designs to determine factor settings giving optimum response values
  - Usually follow on from screening designs
- Reliability DoE Designs
  - Combines traditional designs with reliability methods
  - Response is a life metric (eg age, miles, cycles…)
  - Allows censored data (eg suspensions, interval data)

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EXAMPLE: 2 Level Full Factorial
Optimising a fabrication process

- The Experimental Design:

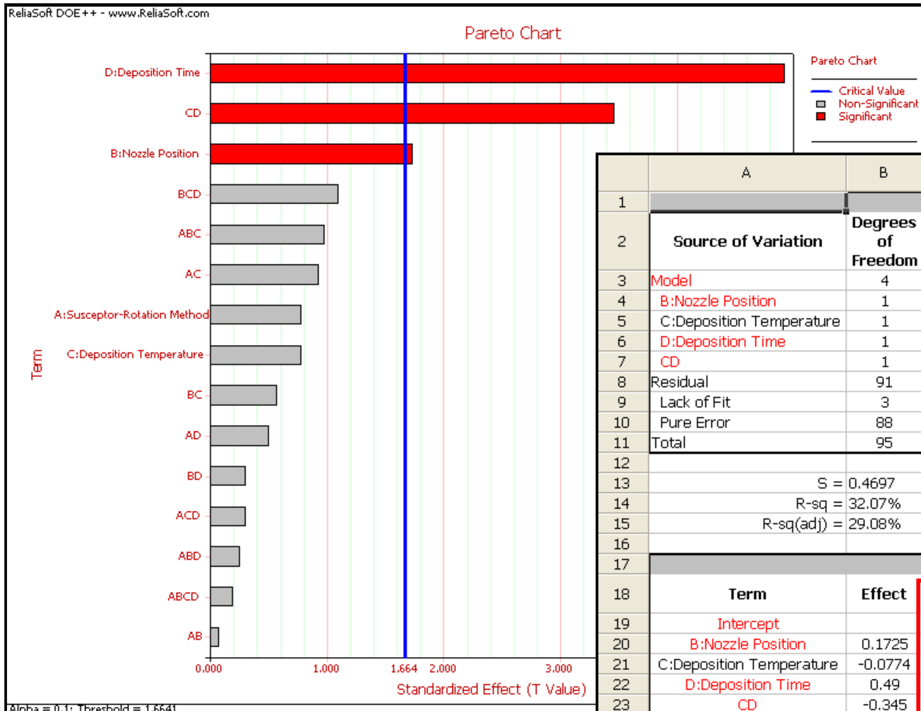
	Standard Order	Run Order	Center Points	Block Number	A:Susceptor-Rotation Method	B:Nozzle Position	C:Deposition Temperature	D:Deposition Time	Thickness
1	1	24	1	1	Continuous	2	1210	Low	12.886
2	2	55	1	1	Oscillating	2	1210	Low	14.249
3	3	95	1	1	Continuous	6	1210	Low	14.059
4	4	57	1	1	Oscillating	6	1210	Low	13.775
5	5	8	1	1	Continuous	2	1220	Low	13.758
6	6	35	1	1	Oscillating	2	1220	Low	13.605
7	7	87	1	1	Continuous	6	1220	Low	13.707
8	8	25	1	1	Oscillating	6	1220	Low	14.031
9	9	29	1	1	Continuous	2	1210	High	14.506
10	10	86	1	1	Oscillating	2	1210	High	15.05
11	11	43	1	1	Continuous	6	1210	High	14.629
12	12	89	1	1	Oscillating	6	1210	High	14.274
13	13	60	1	1	Continuous	2	1220	High	13.926
14	14	13	1	1	Oscillating	2	1220	High	13.327
15	15	71	1	1	Continuous	6	1220	High	13.8
16	16	6	1	1	Oscillating	6	1220	High	13.723
17	17	84	1	1	Continuous	2	1210	Low	12.963
18	18	67	1	1	Oscillating	2	1210	Low	13.9

Display Factors
Coded Values
Actual Values

Sort By
Run Order
Standard Order

Design Summary
P(i)=...

2 Level Full Factorial Results



ANOVA Table

Source of Variation	Degrees of Freedom	Sum of Squares [Partial]	Mean Squares [Partial]	F Ratio	P Value
Model	4	9.479	2.3698	10.7395	3.57E-07
B:Nozzle Position	1	0.7145	0.7145	3.238	0.0753
C:Deposition Temperature	1	0.1438	0.1438	0.6519	0.4215
D:Deposition Time	1	5.7634	5.7634	26.1192	1.76E-06
CD	1	2.8573	2.8573	12.949	0.0005
Residual	91	20.0798	0.2207		
Lack of Fit	3	0.3911	0.1304	0.5828	0.6279
Pure Error	88	19.6886	0.2237		
Total	95	29.5588			

S = 0.4697
R-sq = 32.07%
R-sq(adj) = 29.08%

Regression Information

Term	Effect	Coefficient	Standard Error	Low CI	High CI	T Value	P Value
Intercept		14.1613	0.0479	14.0816	14.2409	295.3781	0
B:Nozzle Position	0.1725	0.0863	0.0479	0.0066	0.1659	1.7995	0.0753
C:Deposition Temperature	-0.0774	-0.0387	0.0479	-0.1184	0.041	-0.8074	0.4215
D:Deposition Time	0.49	0.245	0.0479	0.1654	0.3247	5.1107	1.76E-06
CD	-0.345	-0.1725	0.0479	-0.2522	-0.0929	-3.5985	0.0005

Response: Thickness
Transformation: Y' = Y
Risk Level (Alpha): 0.1
Analysis Settings: Partial SS, Individual, Calculated, Observations = 96
Analysis Summary: P(i)=...

Layer Thickness (Y)

$$Y = 14.1613 + 0.0863B - 0.0387C + 0.245D - 0.1725CD$$

If our specification is Y=14.5 +/-0.5mm, we can find the values of B, C & D that satisfy.
There may be several possible solutions
We can then use the relationship of variance with factor to choose the set with minimial variance of Y

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Accelerated Testing

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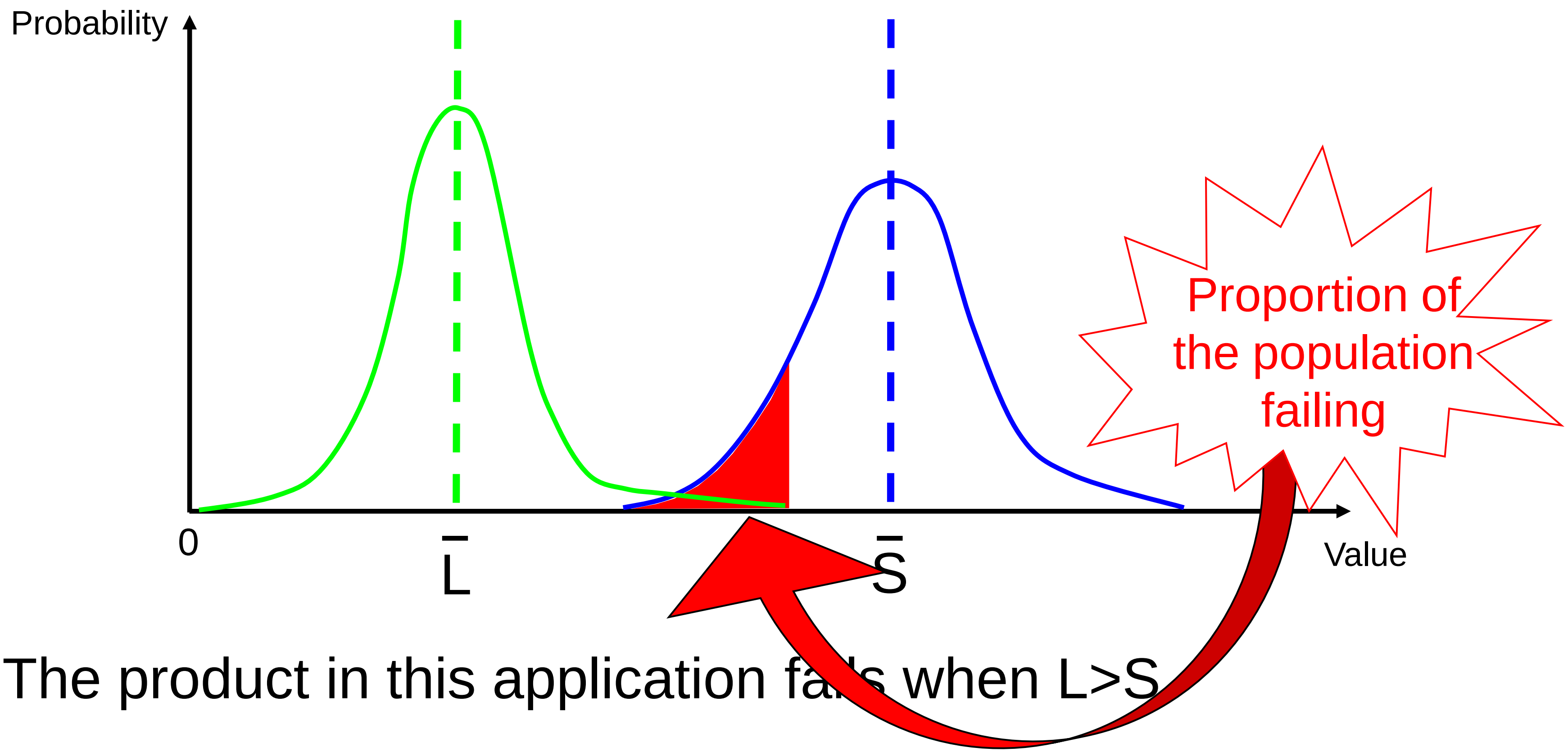
Accelerated Testing

- A Qualitative accelerated test is one that exposes failure modes only
  - Also called shake & bake tests, HAST, elephant tests, etc…
  - Does not estimate Reliability metrics
  - Designing-out failure modes will (usually) increase reliability
- A Quantitative Accelerated Life Test is designed to quantify the life characteristics of the product in a reduced time and with fewer samples.
  - eg a product has 5 year operating life and a 12 month development period
    - QALT can provide reliability, availability & spares predictions
  - Data is obtained using higher stress levels or higher usage rates compared to normal operating conditions then extrapolated back.
  - Must ensure that the environment that created the failure can be quantified with respect to the use condition
    - Physics of failure may indicate a life-stress relationship.

Load-Strength Analysis

:

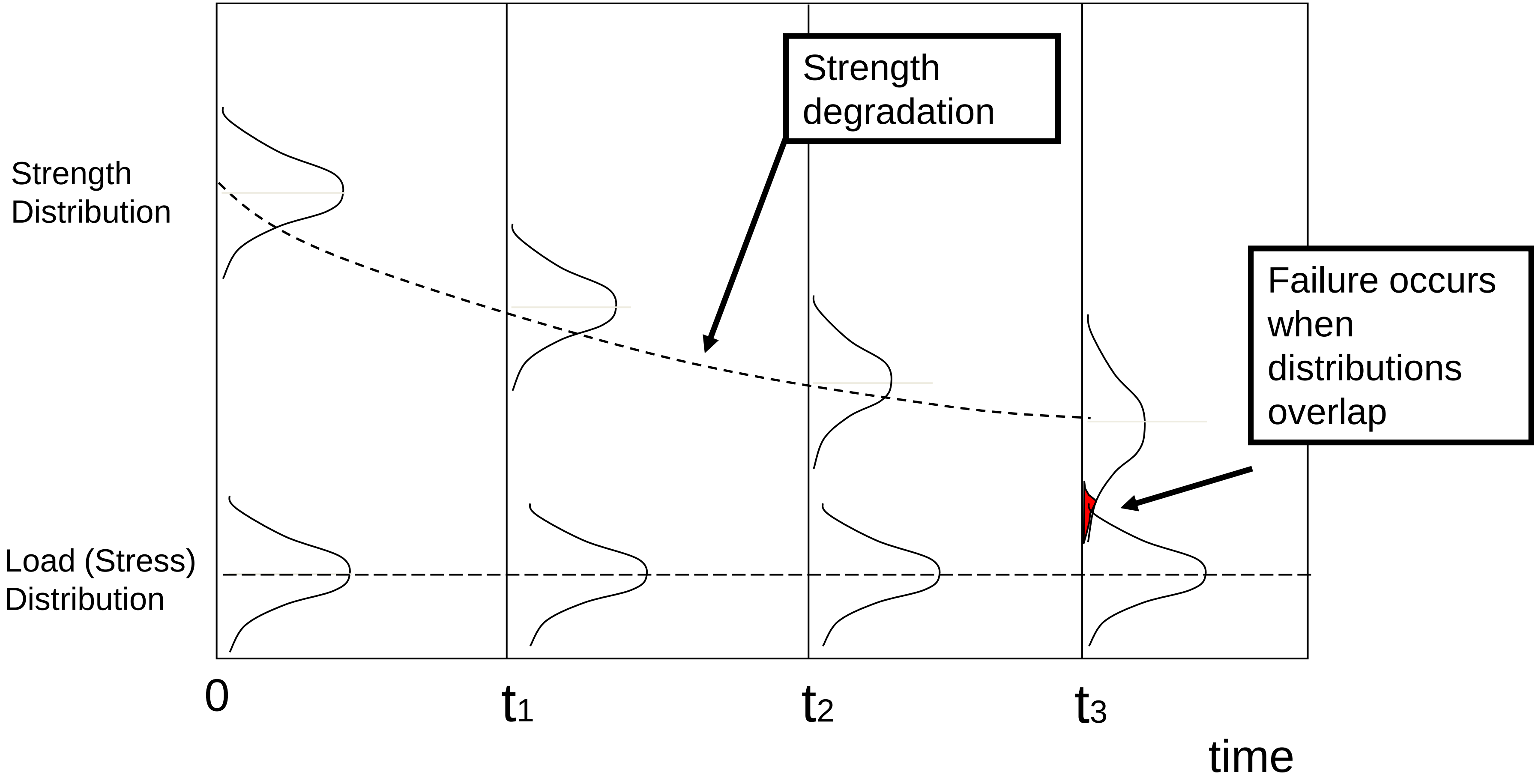
- We can model typical Load and Strength variation



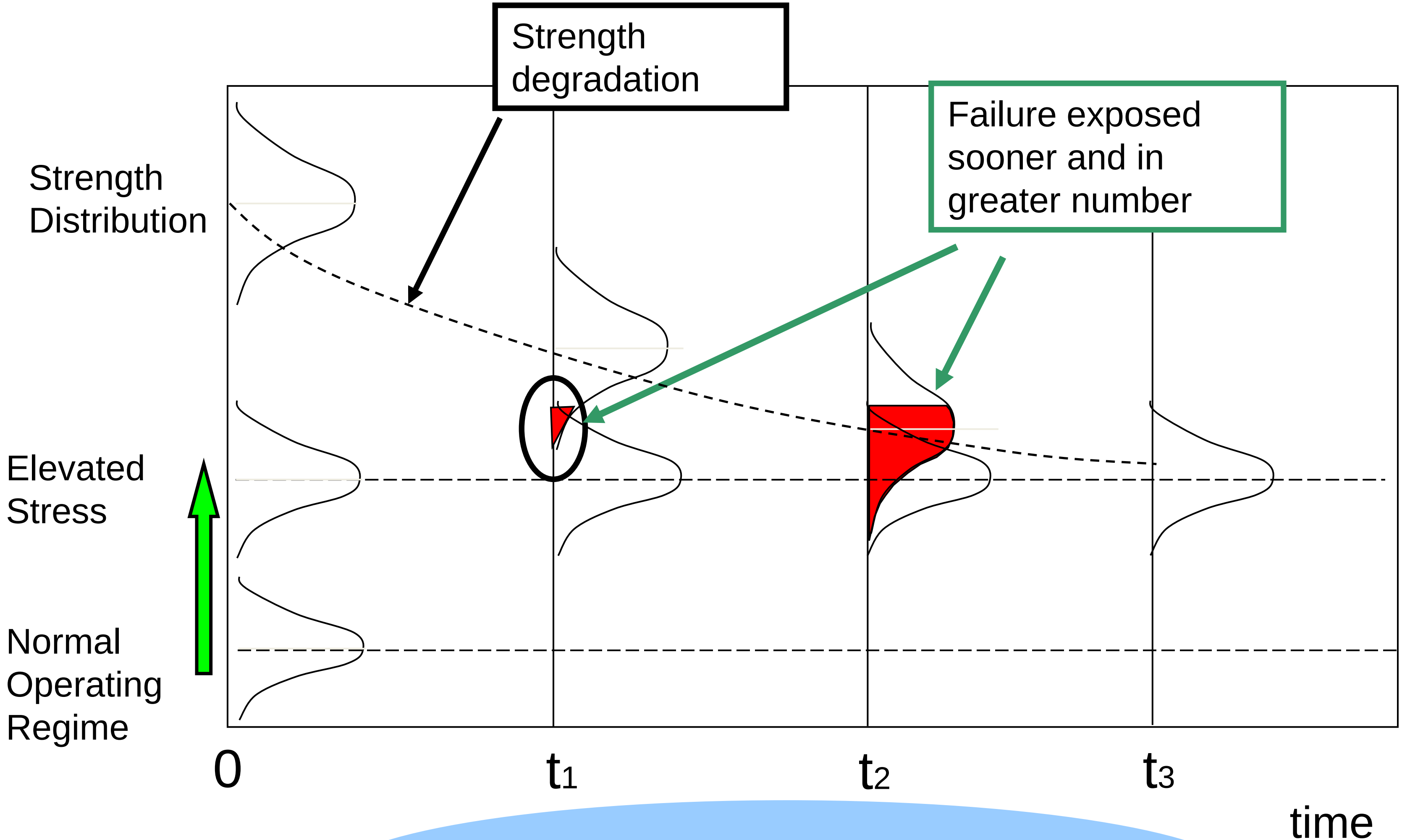
The product in this application fails when L>S

Load-Strength Analysis

- What might happen over time?



Load-Strength Analysis

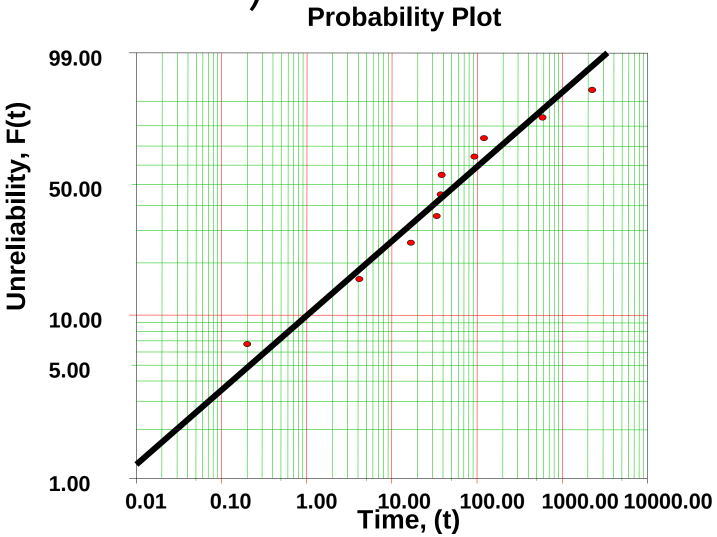


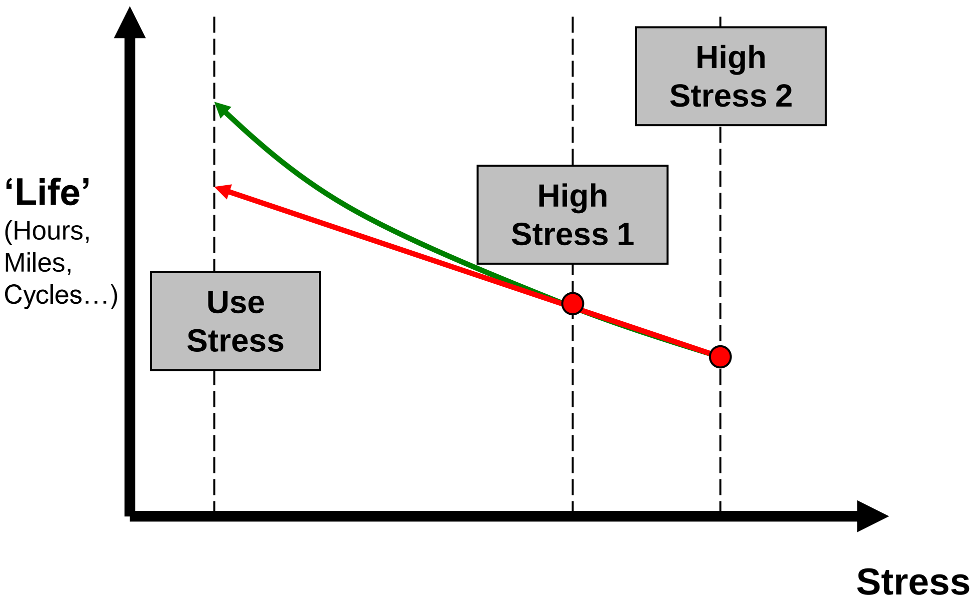
'Accelerated Testing'

Accelerated Testing

Accelerated life models usually consist of:

- A life distribution at each stress level (from Weibull analysis)
- A Life-stress relationship (from 'physics of failure' or a statistical model)





- Use engineering knowledge to choose a life-stress model
- Need enough data to find our model parameters
- **Important role for simulation**

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Life-Stress Relationships

- General exponential function:

$$L(V) = A \cdot e^{BV}$$

- General power function:

$$L(V) = A \cdot V^{B}$$

- These functions describe the life characteristic (*L*) as a function of stress (*V*).

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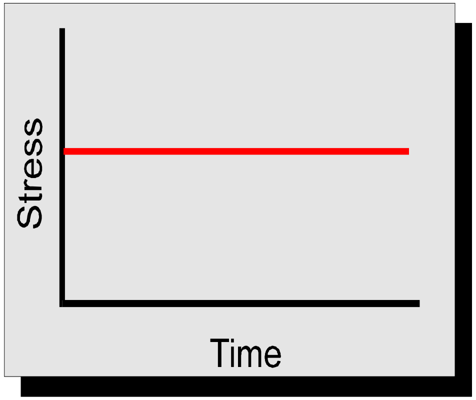
Best Practice

- Use exponential life-stress relationships for thermal stimuli.
    - Temperature (Arrhenius)
    - Humidity (Eyring)
- Use power life-stress relationship for non-thermal stimuli.
    - Voltage
    - Mechanical
    - Fatigue
    - Other…
- Remember, model choice will significantly affect extrapolation

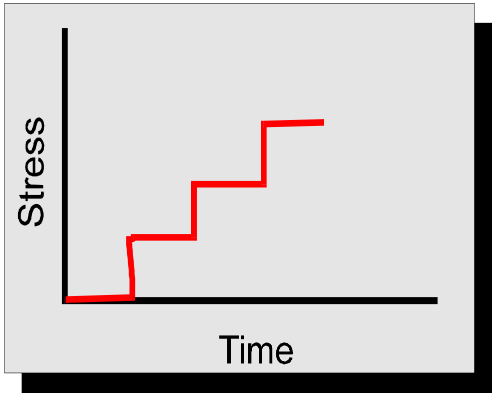
Types of Stress Loading

Stress is time-independent



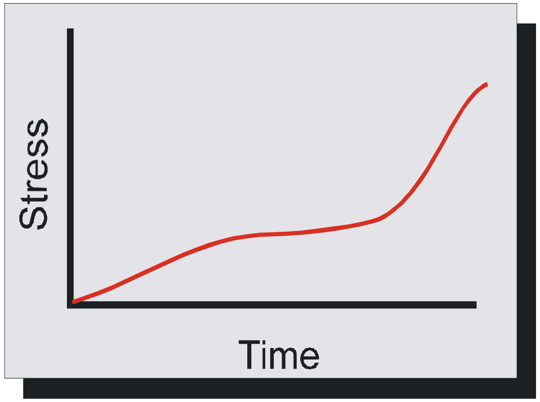
• A single specimen experiences a single stress over time.
• Different specimens may be tested at different stress levels.

Stress is time-dependent
(Quasi time-independent)



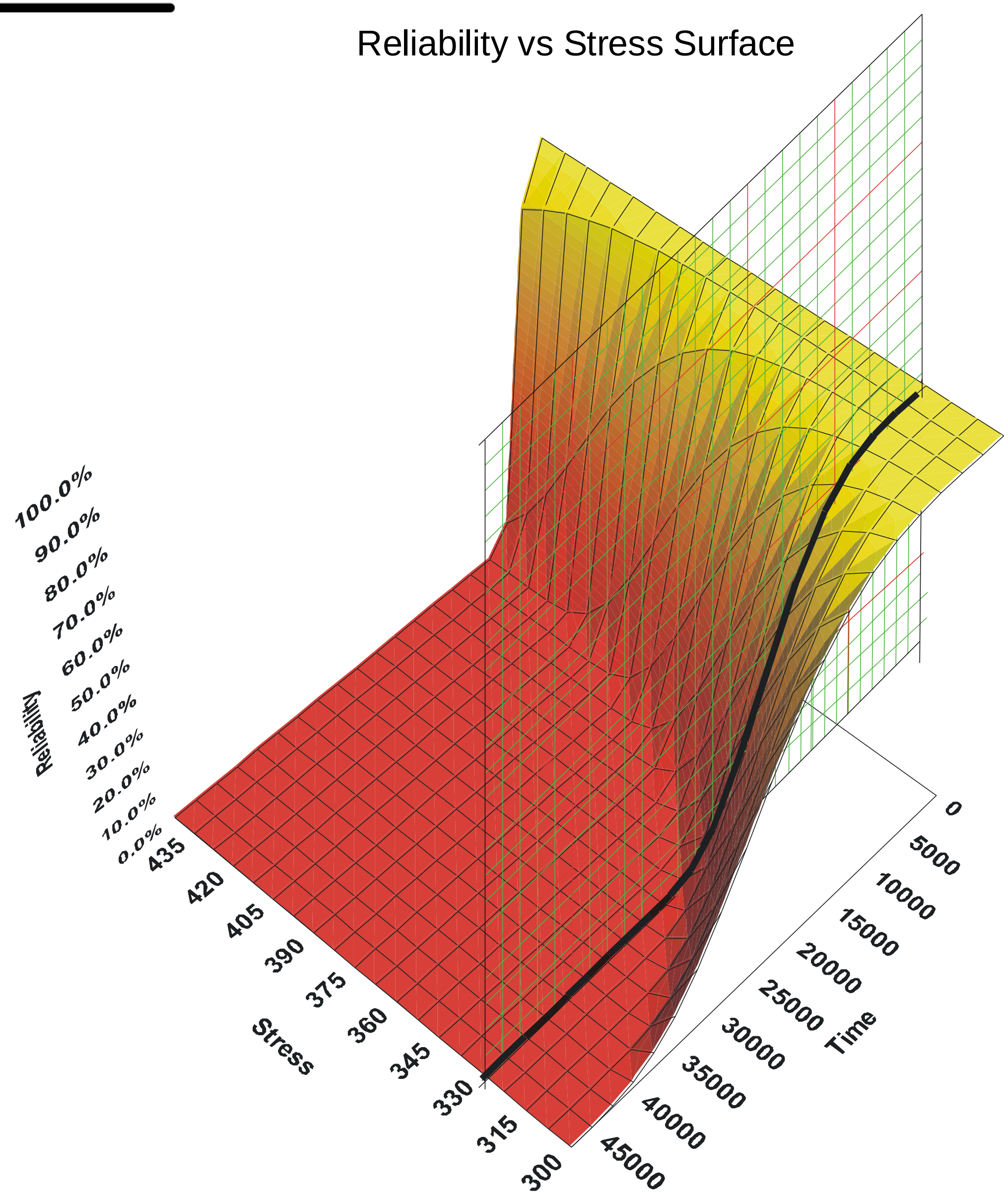
• A single specimen experiences a series of discrete stresses over time.

Stress is time-dependent



• A single specimen experiences continuously varying stresses over time.

Accelerated Testing



Gives early insight into impact of operating environment on product life and can indicate if current design is 'fit for purpose'.

Provides input to appropriate specifications and applications

More than just an 'MTBF' number

Summary

Summary

- No amount of good manufacturing can correct a poor design
- However, poor manufacturing can ruin the best designs
- Hence three requirements for achieving reliable products:
  - *The design must have **margin** with respect to the stresses it is subjected to during production and operational use.*
  - *The production process must be **stable** and completely **documented**. Any variations should be considered experimental until proven.*
  - *There must be an effective **feedback and corrective action system** which can identify and resolve problems quickly in engineering, production and in the field.*

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Summary

- Quantify risk (££)
- Learn new tools for solving old problems
- Use CAE tools as early as possible (even in concept stage)
  - Define the operating environment, mission profile & expected level of reliability (& maintainability) and communicate openly with suppliers.
- Tailor processes to critical design objectives
- Understand and disposition all failures in product development cycle – never ignore outliers!
- Reduce operational stresses
- Reduce production variation
- Foster a culture of reliability improvement and risk management (in-house and with suppliers)

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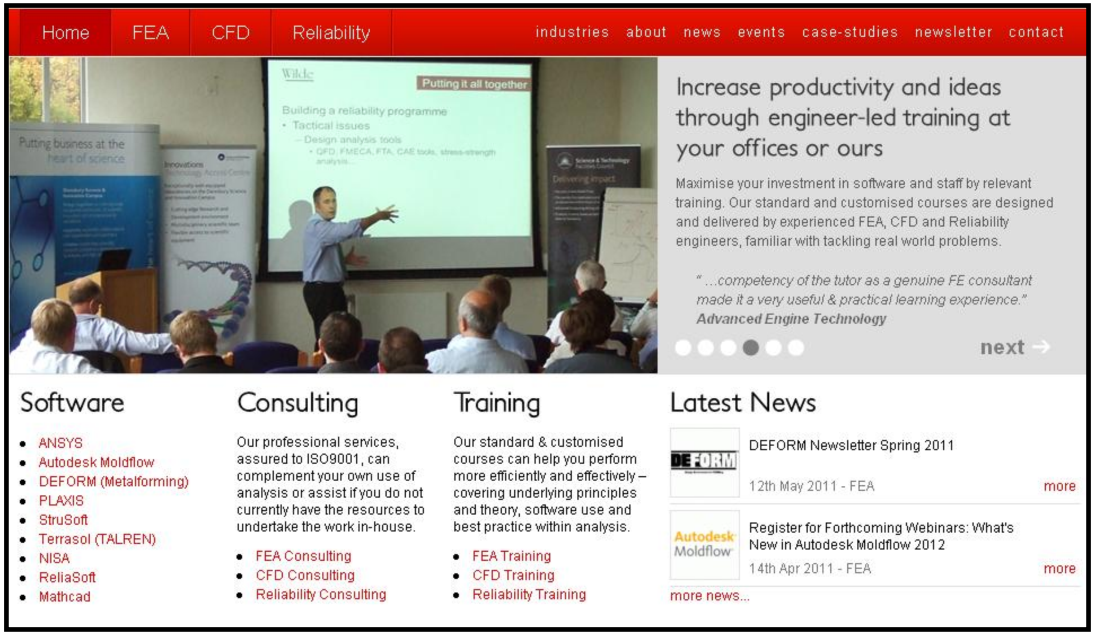
References

- Background information on Reliability:

  www.wildeanalysis.co.uk

  www.reliasoft.co.uk

  www.weibull.com



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improving design by analysis

FEA CFD Reliability

Software Consulting Training