ECE 480

Six Sigma Overview & Introduction to Design for Six Sigma

Six Sigma Companies

3M	ADT Security	Air Products
Allied Signal	American Standard	Americhem
Armstrong	Armstrong World Industries	Asahi Kasai
Astrazeneca	Atlantic Health	Avery Denison
Avnet	Bank of America	BASF
Bayer	BC Hydro	Becton Dickenson
Black & Decker	Boeing	Bombardier
Boston Financial Services	Calloway Golf	Caterpiller
Celanese	City Bank	Chlorox
Conoco	Corning	Cott Beverages
Covenant Health	Crompton	Dannon
Decoma	Degussa	Dell
Delphi	Deutsche Bank	Dow Chemical
Dow Corning	DuPont	Eastman Chemical
Eastman Kodak	Eaton Corp.	Eli Lily
Emerson	Energizer	Florida Light & Power
Ford	Fortis Health	General Electric
General Motors	Georgia Pacific	Gillette
GlaxoSmithKline	Goodrich Goodyear	
Harley Davidson	HP	Hitachi

More Six Sigma Companies

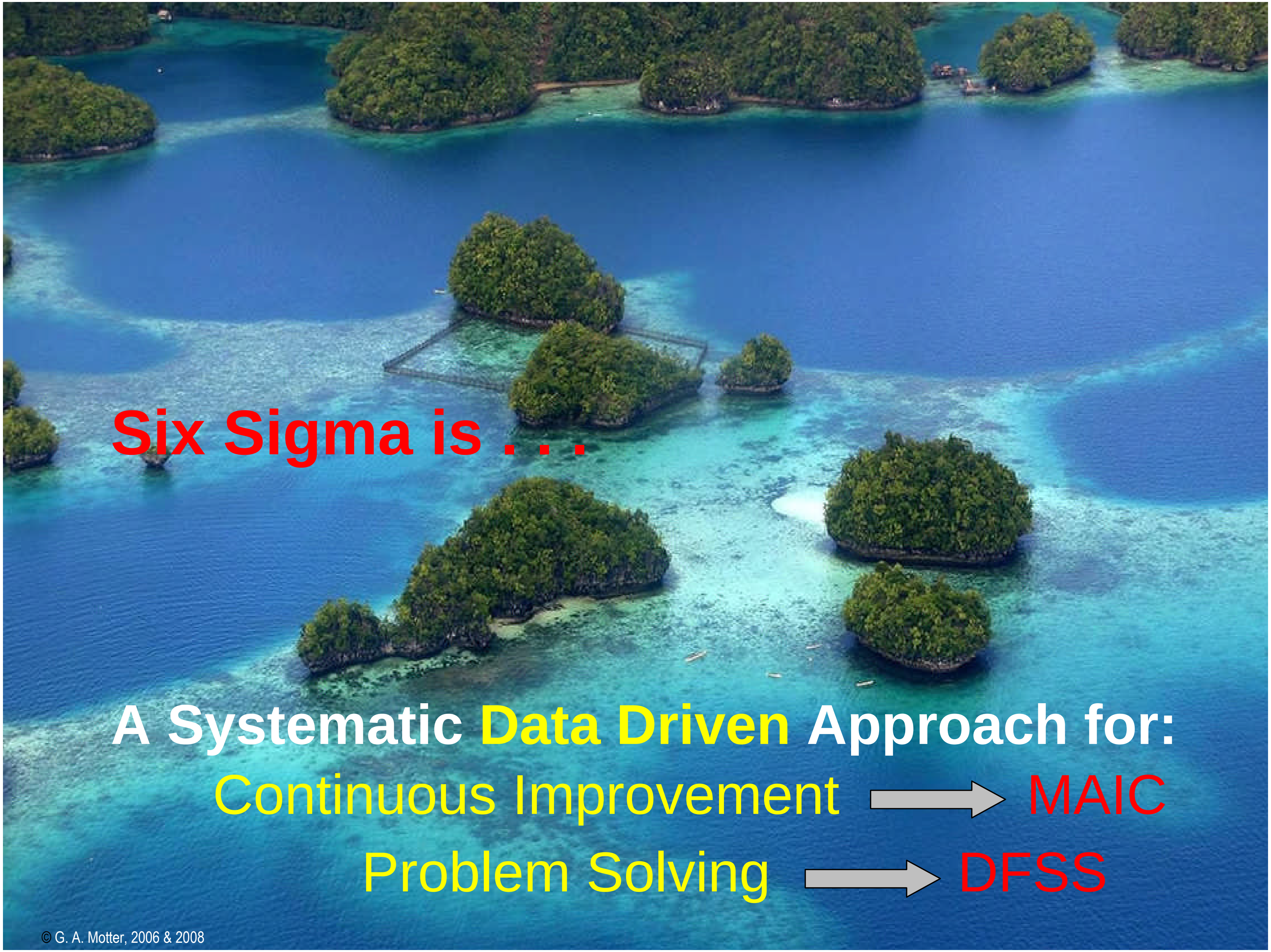
Honeywell	IBM	Intel
ITT Industries	ITW	John Deere
Johns Manville Corp.	Johnson & Johnson	Kellogg
Kohler Corp.	LG Chemical	Lockheed Martin
Lord	Lubrizol	Maytag
Mckesson	Moog	Motorola
National Semiconductor	NBC News	NCR Corp.
Noranda	Northrop Grumman	Noveon
Omnova Solutions	Owens Corning	Phillips
Pitney Bowes	PPG Industries	Praxair
Raytheon	Rogers Corp.	Rhom & Haas
Royal Bank of Canada	Saint-Gobain	Samsung
SAS Inst.	Scott Seeds	Seagate Technologies
Sherwin Williams	Siemens	Silicon Graphics
Sony	Sprint	Square D
Sun Chemical	Sunbeam	Swagelok
Timken	Toyota	Trane
Transfreight	TRW	US Filter
Visteon	WR Grace	Xerox

Lecture	Six Sigma 'Tour' Lecture Title
1	WOWing Customers with Six Sigma Products - DFSS
2	Understanding the Customer's Viewpoint - VOC Homework Assignment
3	Quality Function Deployment (QFD) – Customer Driven Development
4	Function Definition & Analysis – Powerful Problem Analysis Technique Homework Assignment
5	Six Sigma Optimization - MAIC

WOWing Customers with Six Sigma Products . . . via Design for Six Sigma

DFSS Discussion Objectives

- Define Quality, Defect, and Sigma Level
- Describe generic DFSS Process flow
- Highlight the DFSS Process with an example
- Explain "What's different about DFSS" from traditional Engineering Design approach?

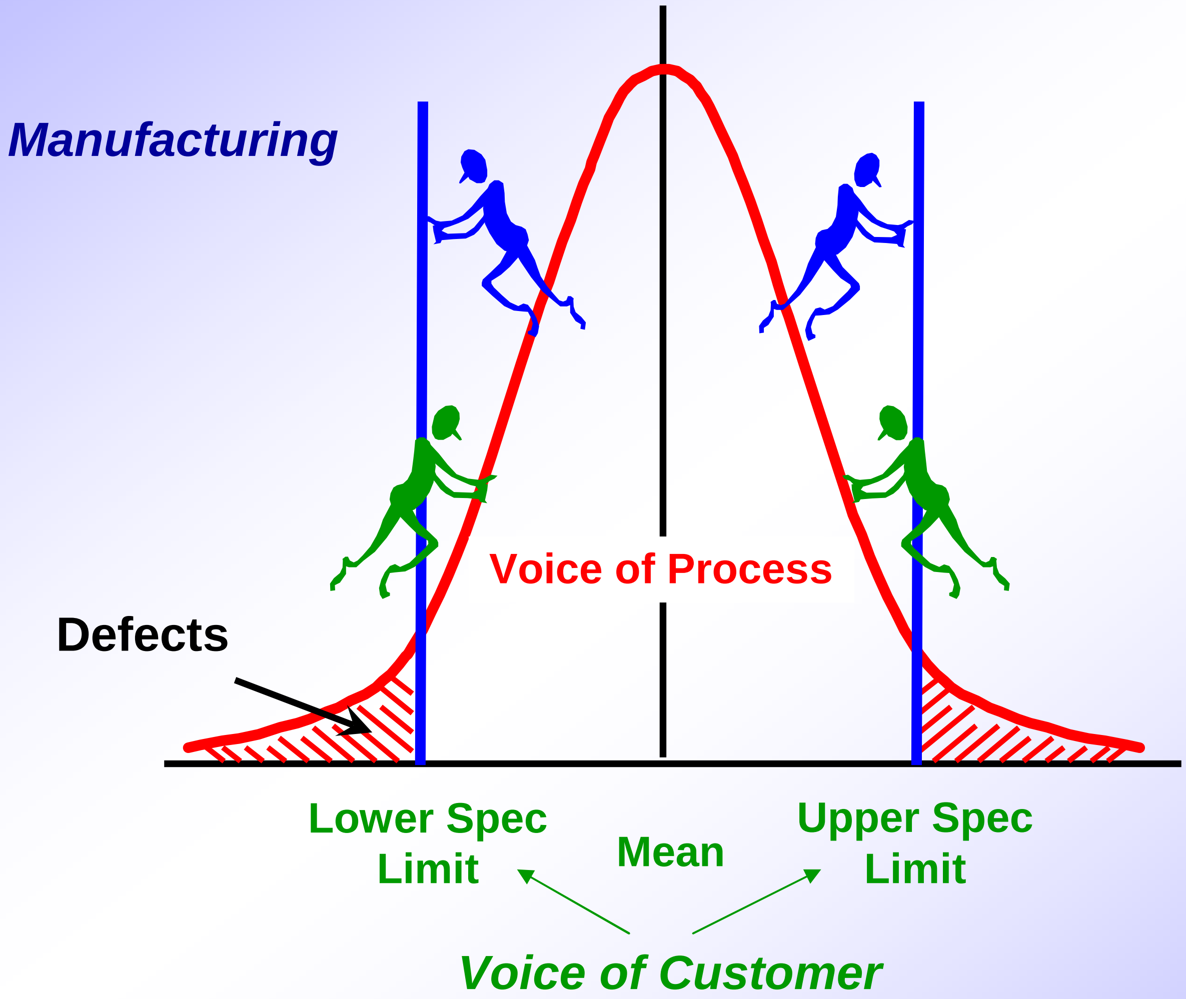

Six Sigma is . . .
A Systematic Data Driven Approach for:
Continuous Improvement → MAIC
Problem Solving → DFSS
© G. A. Motter, 2006 & 2008

Quality and Sigma Level Defined

- **“Quality”: degree of excellence of a Product, Process, Software, IT System, or Service . . . . from the *Customer’s Viewpoint***
- **Every process has Variation. If the outcome is too far from target value (beyond a spec limit), a Defect occurs**
- **Standard deviation is a measure of statistical variation (spread) about the mean**
- **Sigma Level of a process is an indication of how often defects are likely to occur**

  = Spec Width / 2 (Std. Deviation)

Matching Product Requirements and Process Capability

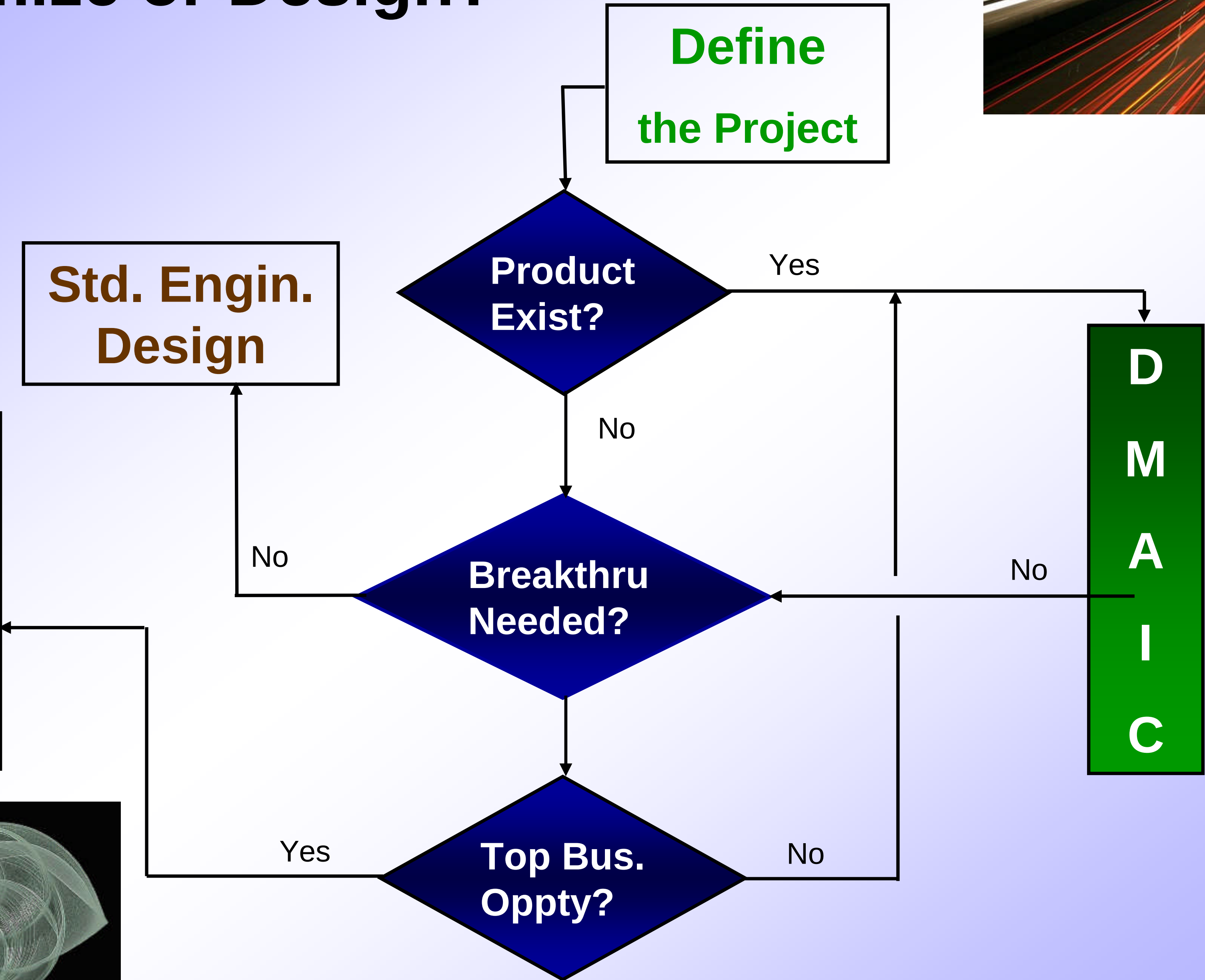


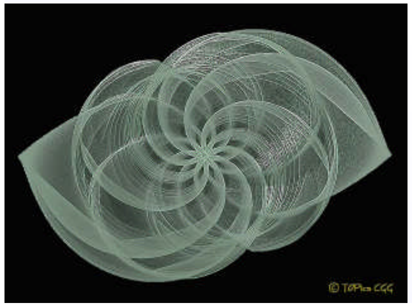
Sigma Level	% Out of Spec
6	0.00034
5	0.02327
4	0.62097
3	6.68072
2	30.85375
1	69.14625

Assuming a Long Term 1.5 Sigma Shift

Source: Implementing Six Sigma, F. Breyfogle III

Optimize or Design?





Source: Six Sigma for Growth, E. Abramowich

Why DFSS?: Revolutionize Product Development

Reactive Design Quality → **DFSS** → Predictive Design Quality

From

- Evolving design requirements
- Extensive design rework
- Product performance assessed by "build and test"
- Performance & manufacturability problems fixed after product in use; "fire fights"

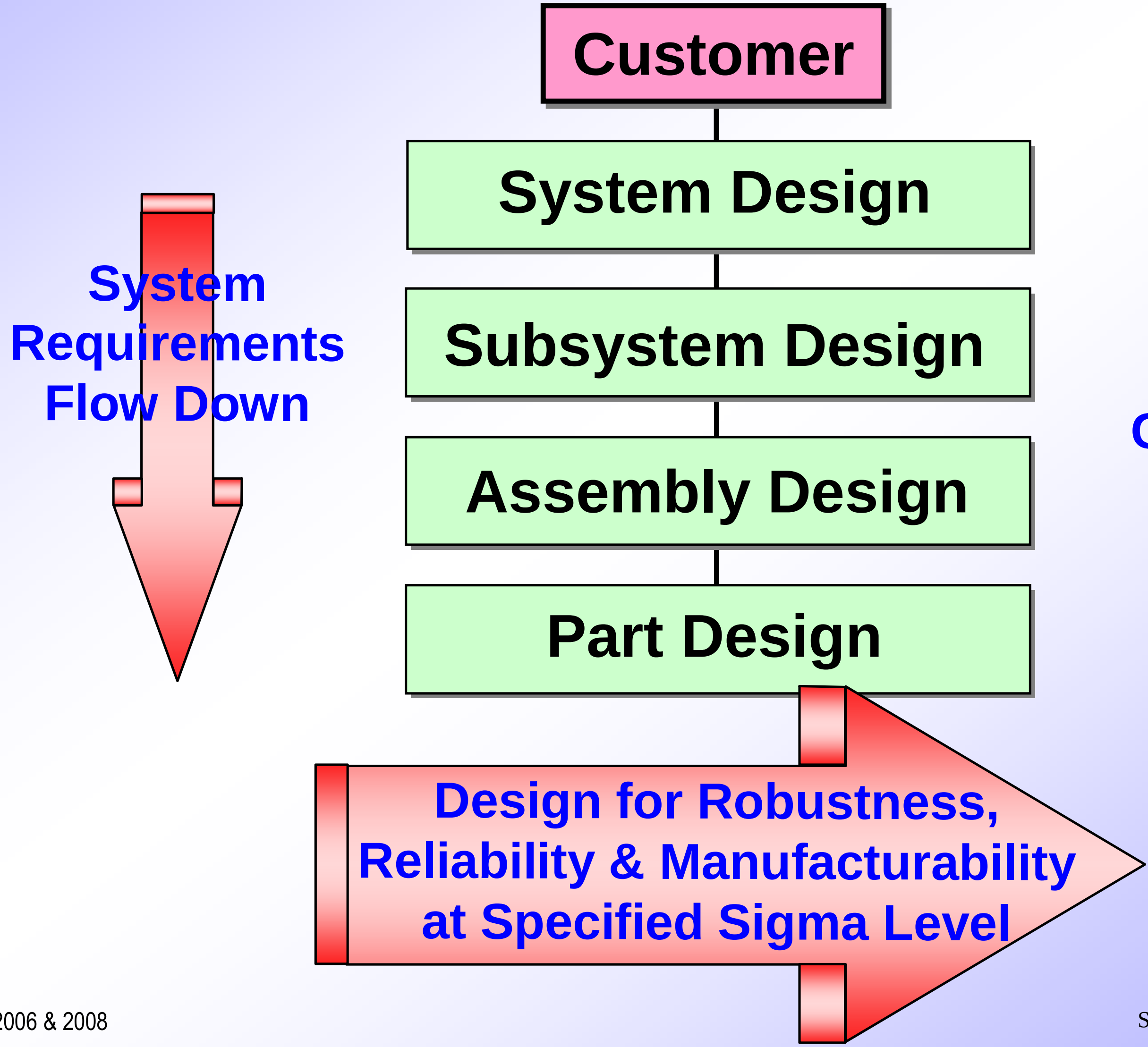
Quality "tested in"

To

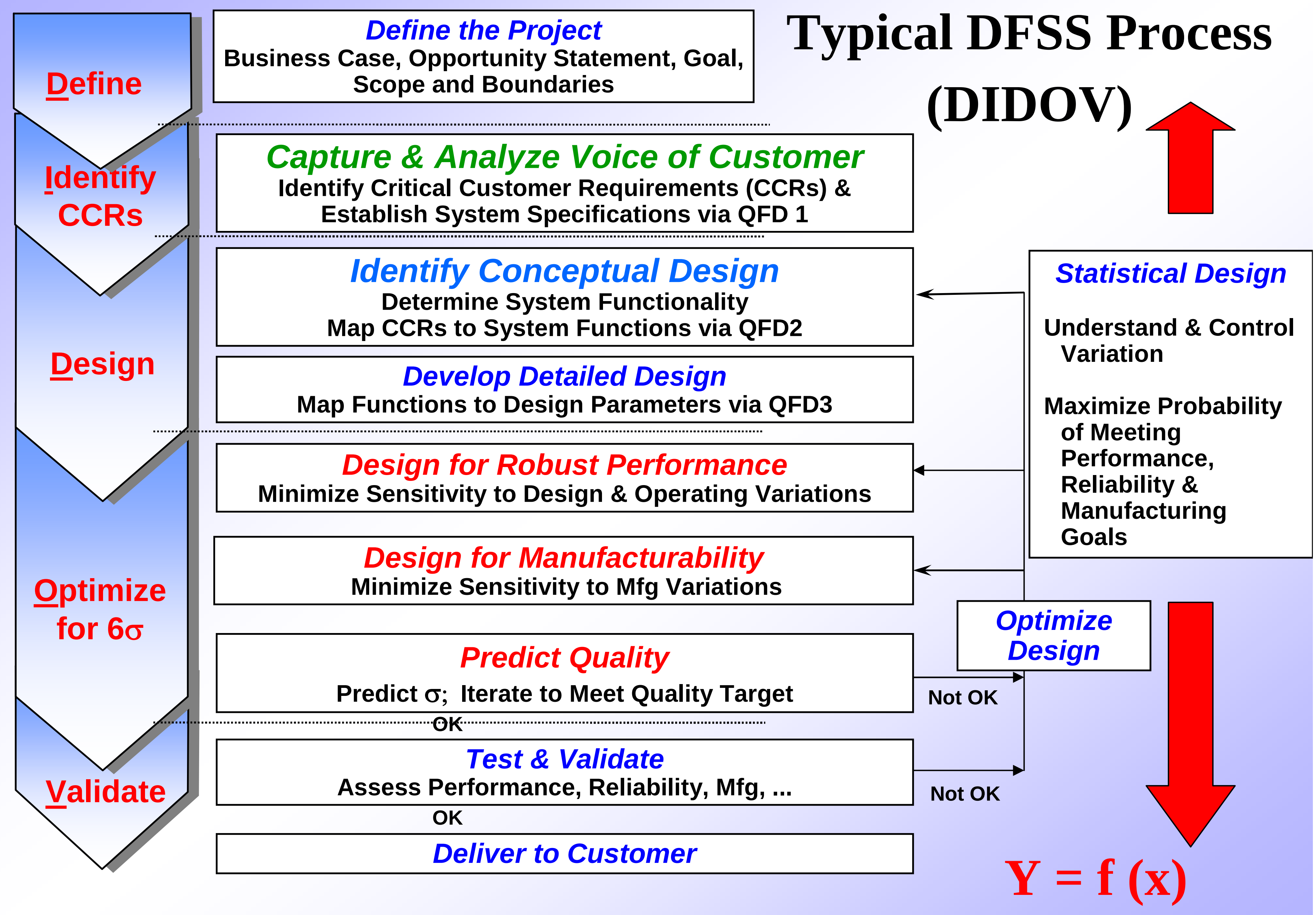
- Disciplined CCR flowdown
- Controlled design parameters
- Product performance modeled and simulated
- Designed for robust performance & manufacturability

Quality "designed in"

Requirements 'Flow Down' from Customer and Design Capabilities 'Flow Up'



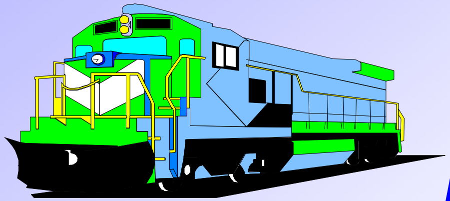
Source: Design for Six Sigma, C. Creveling



Source: Design for Six Sigma, K. Yang

Voice of the Customer and Quality Function Deployment

Identify



Customer Needs
Whats

- Voice of the Customer
- Surveys
- Focus groups
- Conjoint Analysis

Hows

Customer Importance

Customer Needs (Whats)	Customer Importance	Thrust	Tot Maint Cost	Mission Fuel Burn	Cycle Life Limits	Weight	Time To Remove	Disk Burst Speed
Target Direction		↑	↓	↓	↑	↓	↓	Targeted amount
High Power	3	Strong						
Low Oper. Cost	4		Strong	Medium	Weak		Weak	
Meet Range Req'ts	5	Weak		Strong		Medium		
Long Life	2				Strong			
High Payload	4	Strong				Strong		
Easy To Maintain	2						Strong	
Easy To Troubleshoot	1							
Units		Lb	$/Flt Hr	Gal/Flt	Flt Cycles	Lb	Minutes	RPM
System Level Importance		68	36	57	22	41	22	35

Target Direction
- ↑ More is better
- ↓ Less is better
- ⬭ Targeted amount

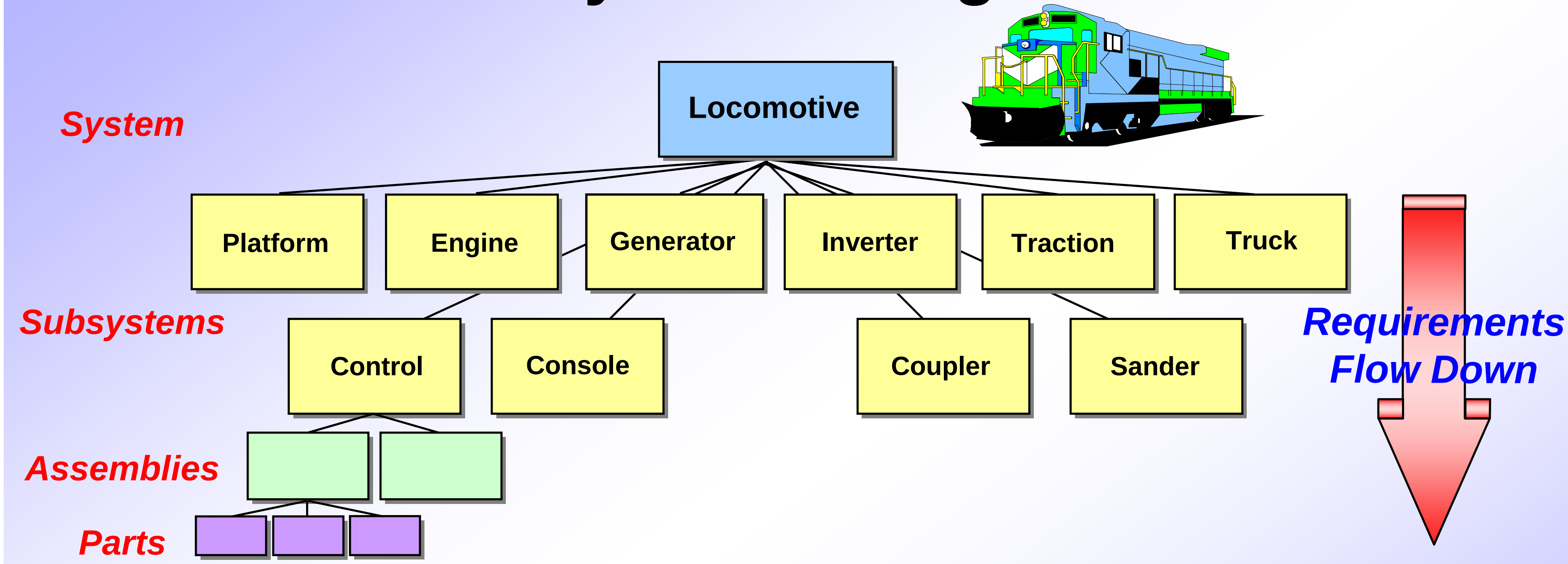
Relationships
- Strong - 9
- Medium - 3
- Weak - 1

System Level Importance

Intense Focus on what the *Customer* wants

Design

System Design



- Customers buy **System Performance and Reliability**
- **Design Decisions** are made at **Subsystem, Assembly** and **Parts**
- Systems engineering allows
  - **Flow Down of Customer Requirements** to lower design levels
  - **Rational Design Decisions** to achieve system-level goals

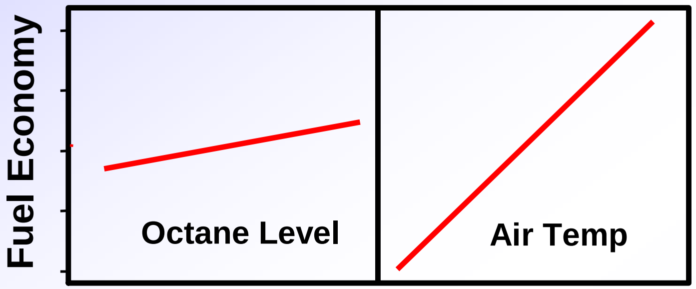
Design for Robust Performance

Optimize

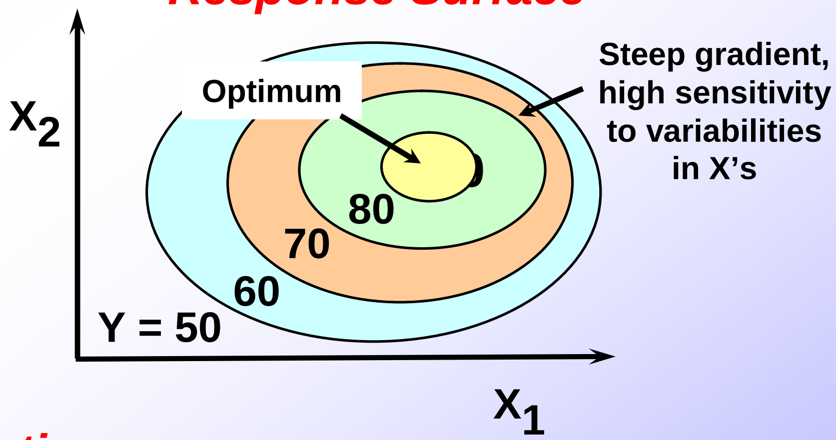
Quantify relationships between CCRs & Design Parameters

- ***First principles models***
- ***Numerical models (finite elements, lumped parameter, …)***
- ***Designed experiments (DOE)***
- ***QFD***

DOE Main Effects Plot



Response Surface



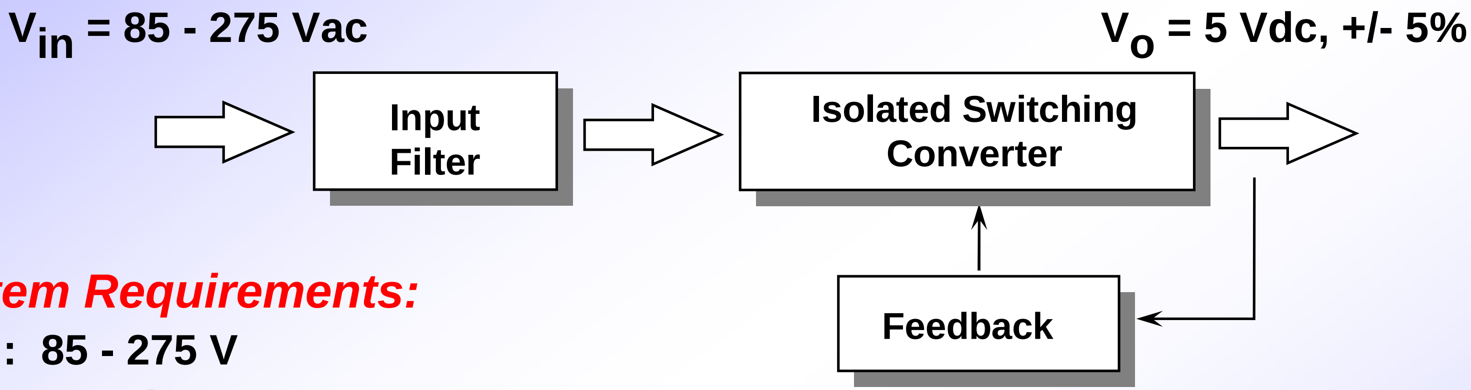
- ***Regression to obtain Transfer Function:***

$$Y = f(X_1, X_2, X_3) \cong a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_1X_2 + a_5X_1X_3 + a_6X_2X_3 + ...$$

Main Effects **2-Way Interactions**

Capture knowledge in Transfer Function libraries & design templates

Statistical vs Deterministic Design:
Switching Power Supply Example

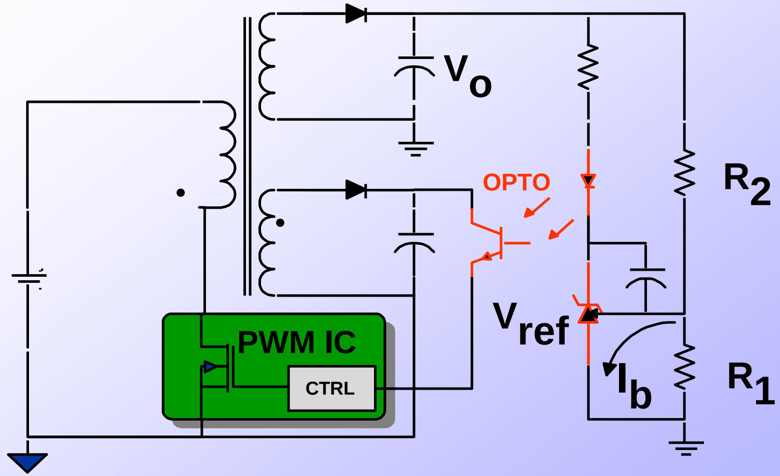


System Requirements:

- V_{in}: 85 - 275 V
- V_o: 5 V, +/- 5%
- 6σ quality
- Low cost

Baseline design

- Isolated switching converter/ feedback section
- Low cost, combine power MOSFET and control circuit in a 3-pin package



Deterministic Design

Analysis: **Transfer function**

$$V_o = V_{ref} + R_2 \left(\frac{V_{ref}}{R_1} + I_b \right)$$

Choose values for design parameters:

Design Parameter	***Value***
LM 431I ref voltage, V_{ref} (volts)	**2.495**
R_1 (ohms)	**10000**
R_2 (ohms)	**10000**
Bias current, I_b (amps)	**5.0E-06**

Substituting: **Output voltage = 5.04 volts**

Baseline design meets 5V, +/- 5% performance requirement
But, quality level is not yet determined

Statistical Design

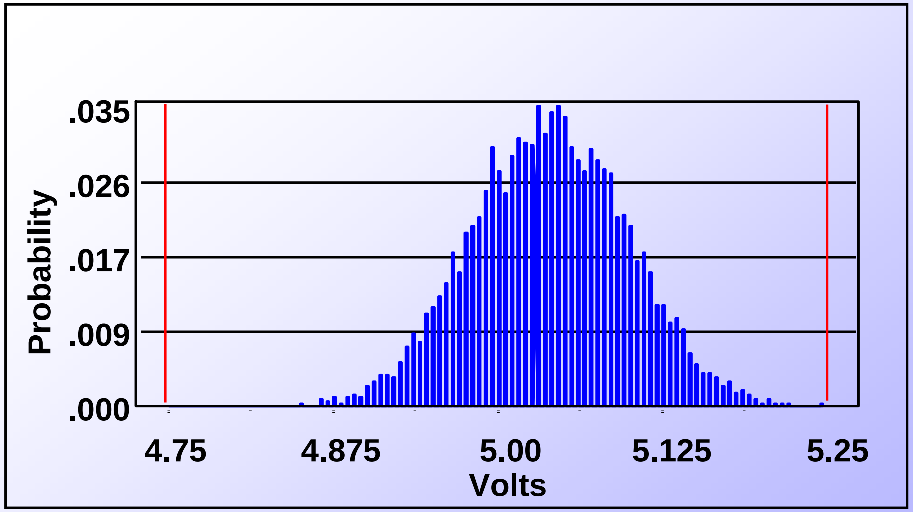
Analysis: **Transfer Function**

$$V_o = V_{ref} + R_2 \left(\frac{V_{ref}}{R_1} + I_b \right)$$

Design parameters are statistical. Engineer selects mean values and a measure of variability (e.g., standard deviation, based on component tolerance).

Design Parameter	Mean	Std Dev	Tolerances Lower	Tolerances Upper
LM 431I V_{ref} (volts)	2.495	0.0283	0.085	0.085
R_1 (ohms)	10000	33.3333	1%	1%
R_2 (ohms)	10000	33.3333	1%	1%
Bias current, I_b (amps)	5.0E-06	1.15E-06	2.00E-06	2.00E-06

Do a statistical analysis (e.g., Monte Carlo), using Transfer Function and statistical parameter values



Results:

- V_o mean 5.04 volts
- V_o std dev 0.059 volts
- Defects/million 188 (5.06s)

Baseline design meets 5V, +/- 5% performance
But quality level is only 5σ

Statistical Design: Approaching "6σ"

Design optimization analysis:

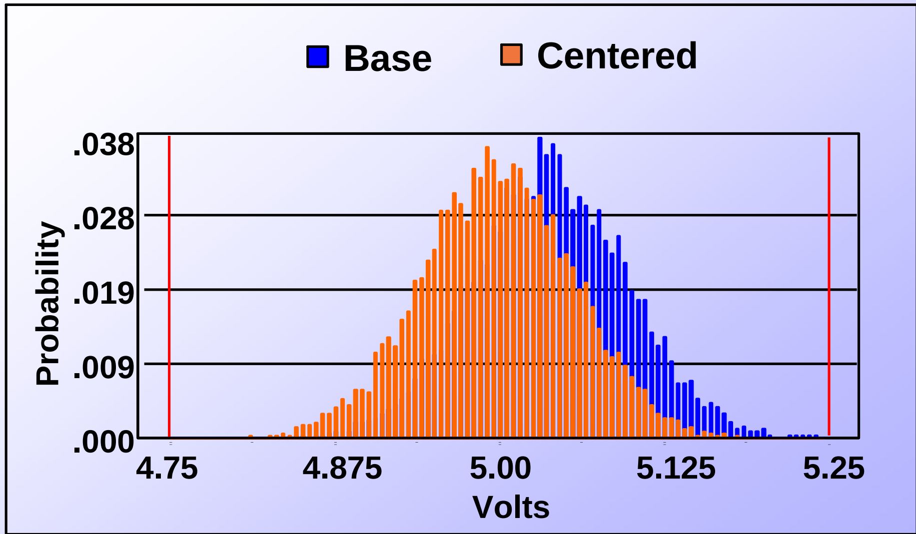
- **Use Transfer Function to understand response surface shape and output voltage sensitivity to each design parameter**
- **Reduce defect rate by: (1) shift mean values or (2) reduce design parameter variance**

Design Parameter	*Mean*	*Std Dev*	*Sensitivity*
LM 431I V_{ref} (volts)	2.495	0.0283	2
R_1 (ohms)	10000	33.3333	-0.0002495
R_2 (ohms)	10000	33.3333	0.0002545
Bias current, I_b (amps)	5.0E-06	1.15E-06	10000

***Design Mod 1*: Center distribution by increasing R_1 to 10160 ohms**

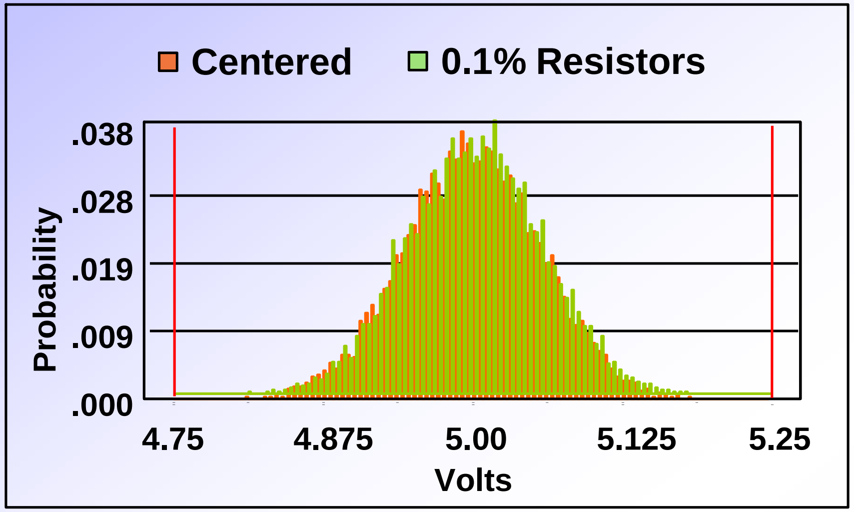
Results:

- **V_o mean 5.00 volts**
- **V_o std dev 0.058 volts**
- **Defects/million 20 (5.61s)**

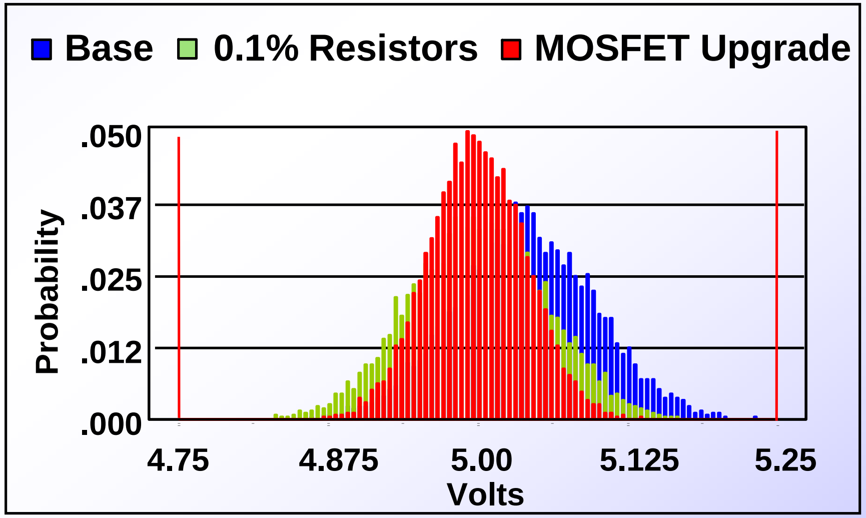


Statistical Design: Reaching "6σ"

Design Mod 2: Mod 1 plus reduce variance by using 0.1% resistors



Design Mod 3: Mod 2 plus LM 431AI MOSFET to reduce V_{ref} variance



Summary

	Mean	*Std Dev*	*DPMO*	Z_{ST}	*Cost*
Baseline Design	5.04	0.059	189	5.06	100%
Mod 1: Centered via R_1	5.00	0.058	20	5.61	100%
Mod 2: 0.1% Resistors	5.00	0.057	13	5.7	101%
Mod 3: LM 431AI	5.00	0.041	~0	7.58	105%

Statistical design enables prediction of performance, quality and cost during the design process

What's Different About DFSS?

- Disciplined, comprehensive process applicable to all Designs
- "Line of Sight" from Customer Needs to all System Design levels
- Statistical design to understand . . . and reduce Variation
- "New" tools: QFD, Function Analysis, TRIZ, DOE, DFM, statistical tolerance, Robust Design, multi-variable optimizations
- Quality prediction throughout development
- Dedicated Team can develop a Breakthrough Design in months

But, does not replace need for sound Engineering Judgment

Questions

&

Discussion

Appendix

Mapping of Common Tools to DFSS Stages

<table>
<tr><td>I</td><td>Voice of Customer</td><td colspan="2">Market Research & Brand Analysis</td><td>QFD</td><td>Kano Model</td><td>Bench Marking</td><td>Quality History: Surveys, Ratings, etc.</td><td>Quality History: Warranty, etc.</td><td>Quality Loss Function</td><td rowspan="4">FDVS: Target Setting & Verification</td><td rowspan="4">DFSS Scorecard</td></tr>
<tr><td>D</td><td>Concept Generation & Selection</td><td rowspan="2">Designed Experiment</td><td>System & Functional Diagrams</td><td>P-Diagram</td><td>FMEA</td><td>Axiomatic Design</td><td rowspan="3">Robust Engineering Design and R&R Checklist</td><td>Dimension Variation Analysis</td><td>Gage R&R</td></tr>
<tr><td>O</td><td>Numeric/ Heuristic Optimization</td><td>Parameter Design</td><td>Tolerance Design</td><td>Analytical Reliability & Robustness (AR&R)</td><td>Statistical Tolerance</td><td rowspan="2">Process Capability</td><td rowspan="2">Control Plan</td></tr>
<tr><td>V</td><td colspan="3">Design Verification Plan & Report</td><td colspan="3">Robustness/Reliability Demonstration</td></tr>
</table>