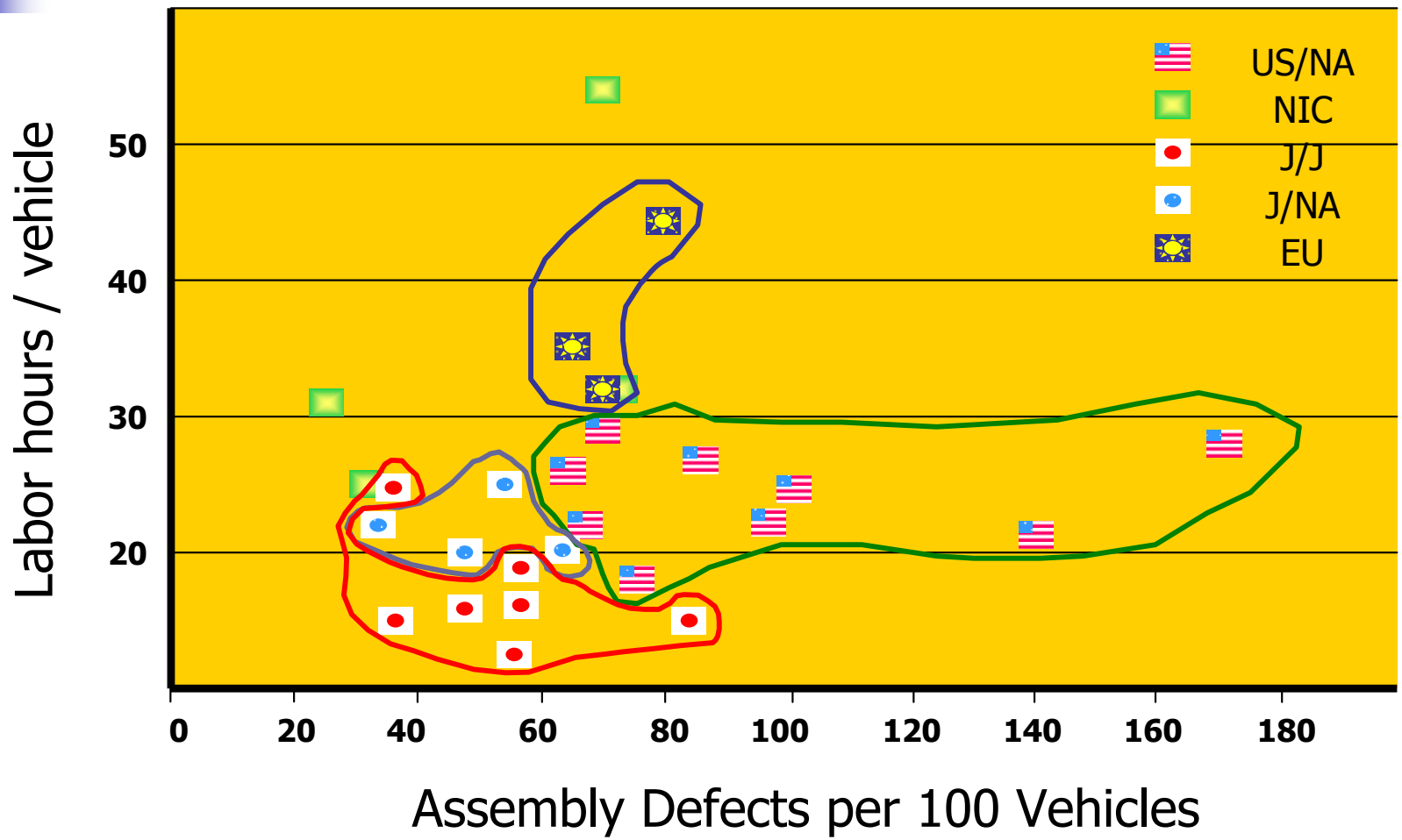
Quality and Productivity

$$\text{Productivity} = \frac{\text{Production Output (\$ created)}}{\text{Production Input (\$ consumed)}}$$

Materials + Direct Labor + Indirect Labor + Capital + Service

Scrap Rework Inspection Machine Warranty

Productivity vs. Quality in Automobile Assembly



Womack, James P., Daniel T. Jones, and Daniel Roos. "The Machine that Changed the World: The Story of Lean Production." New York, NY: HarperCollins, 1991, pp. 93.

MIT Sloan

Statistical Process Control

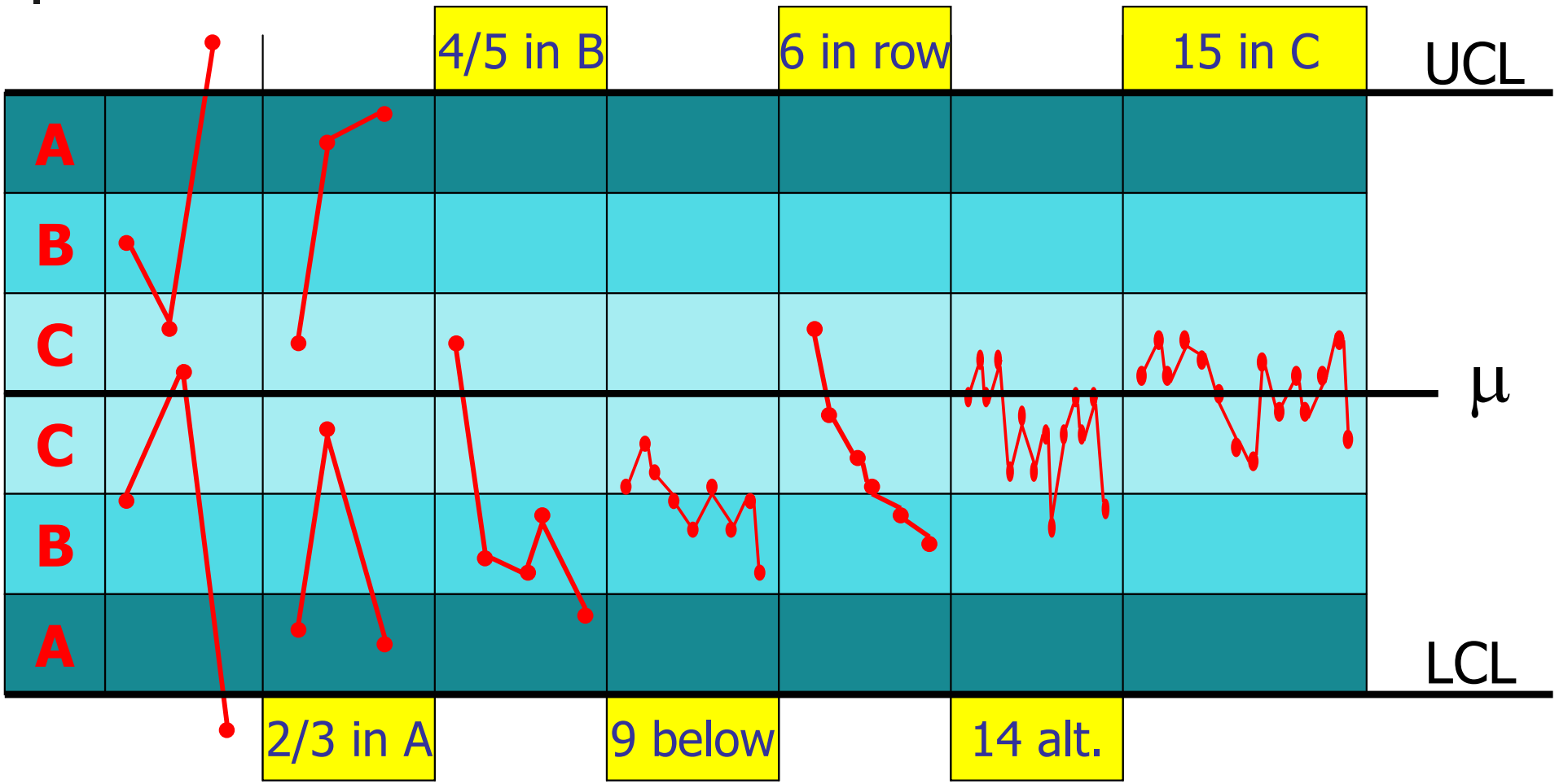
(Shewhart) Control Charts

MIT *Sloan*

$\bar{X}$ Charts *("X bar Chart")*

1. Periodical Random Samples x_i of n items
2. $$\bar{x} = \frac{x_1 + x_2 + ... + x_n}{n}$$
3. Assume μ, σ are known $\quad \Rightarrow \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$
4. $\mathbf{UCL} = \mu + 3 \cdot \sigma_{\bar{x}} \qquad \mathbf{LCL} = \mu - 3 \cdot \sigma_{\bar{x}}$
5. Plot $\bar{x}$'s
6. Is Process out of Control ?

Tests For Control



IF μ and σ are unknown

- Use Average of Sample Means $\overline{\overline{x}}$ for μ
- Instead of σ:
- If n $\leq$ 10 (typically)
  - Use Average Sample Range $\overline{R}$
  - **UCL** $= \overline{\overline{x}} + A_2 \cdot \overline{R}$, **LCL** $= \overline{\overline{x}} - A_2 \cdot \overline{R}$ or
  - Use Average Standard Deviation of Samples $\overline{s}$
  - **UCL** $= \overline{\overline{x}} + A_3 \cdot \overline{s}$, **LCL** $= \overline{\overline{x}} - A_3 \cdot \overline{s}$
- IF n > 10
  - **UCL** $= \overline{\overline{x}} + \dfrac{3 \cdot \overline{s}}{c_4 \cdot \sqrt{n}}$, **LCL** $= \overline{\overline{x}} - \dfrac{3 \cdot \overline{s}}{c_4 \cdot \sqrt{n}}$

$\bar{R}$ and $\bar{s}$ Charts

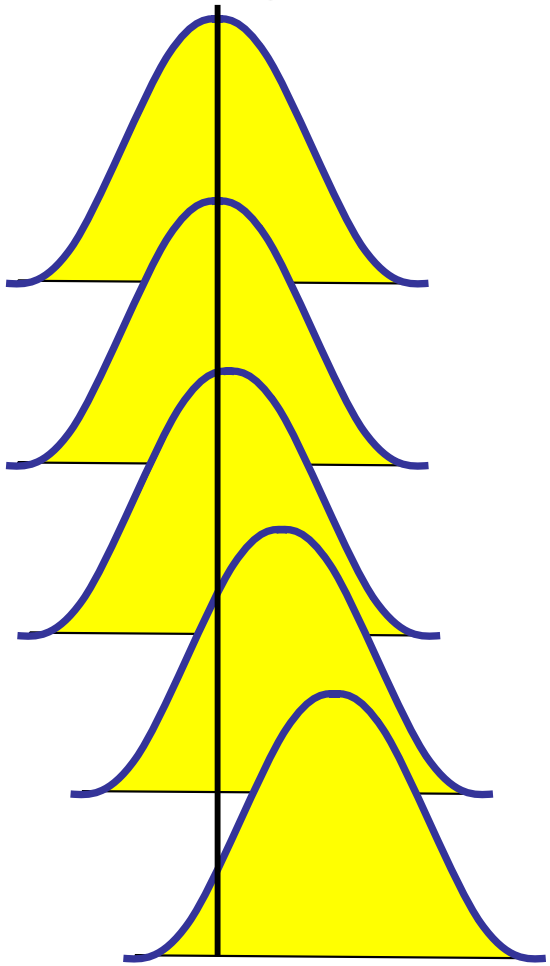
- Measure Process Variability
- Same Idea as X Chart
- Control Limits for $\bar{R}$-chart
  - UCL = $D_4 * \bar{R}$, LCL = $D_3 * \bar{R}$
- Control Limits for $\bar{s}$-chart
  - UCL = $B_4 * \bar{s}$, LCL = $B_3 * \bar{s}$

Parameter Values

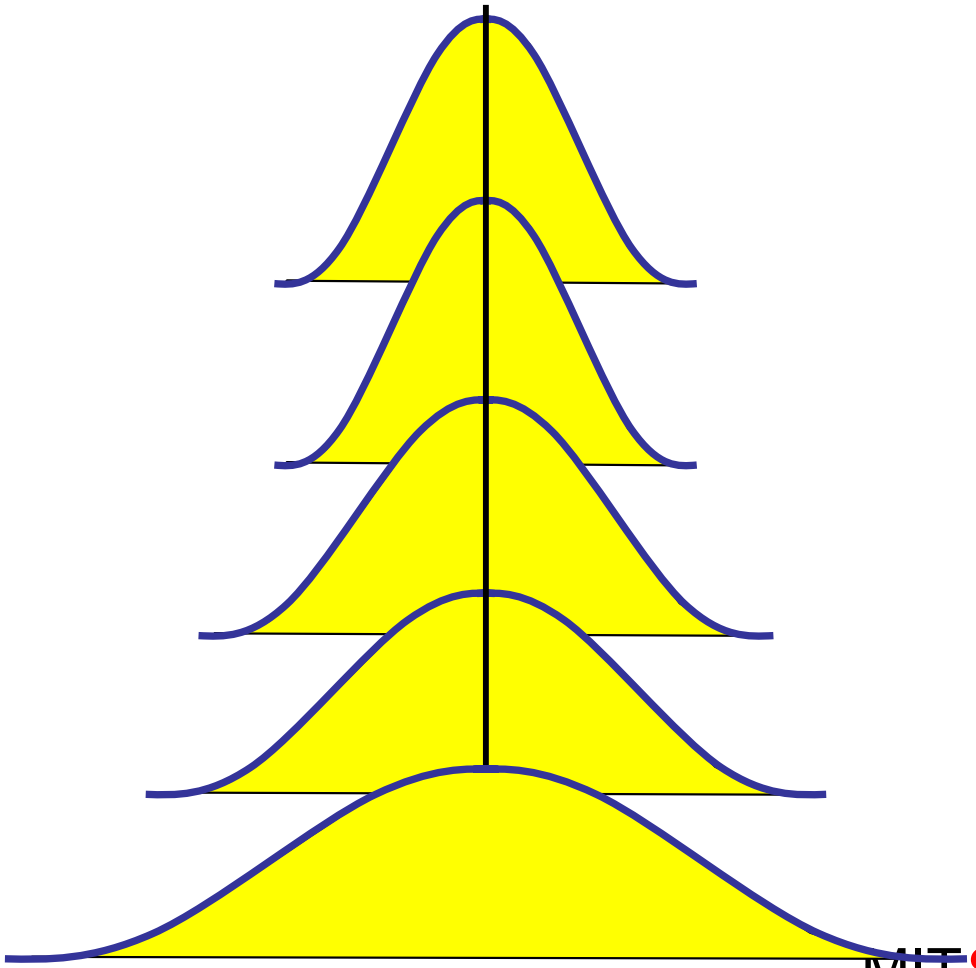
	For X Chart		For R Chart		For s Chart		To estimate σ
	R-based	s-based					
n	A2	A3	D3	D4	B3	B4	C4
2	1.880	2.659	0	3.267	0	3.267	0.7979
3	1.023	1.954	0	2.575	0	2.568	0.8862
4	0.729	1.628	0	2.282	0	2.266	0.9213
5	0.577	1.427	0	2.115	0	2.089	0.9400
6	0.483	1.287	0	2.004	0.03	1.970	0.9515
7	0.419	1.182	0.076	1.924	0.118	1.882	0.9594
8	0.373	1.099	0.136	1.864	0.185	1.815	0.9650
9	0.337	1.032	0.184	1.816	0.239	1.761	0.9693
10	0.308	0.975	0.223	1.777	0.284	1.716	0.9727
15	0.223	0.789	0.348	1.652	0.428	1.572	0.9823
20	0.180	0.680	0.414	1.586	0.510	1.490	0.9869
25	0.153	0.606	0.459	1.541	0.565	1.435	0.9896

$\bar{X}$ vs. $\bar{R}$ and $\bar{s}$ Charts

Wandering of Mean



Spreading of Variance



6 Sigma

"From 99.73 %

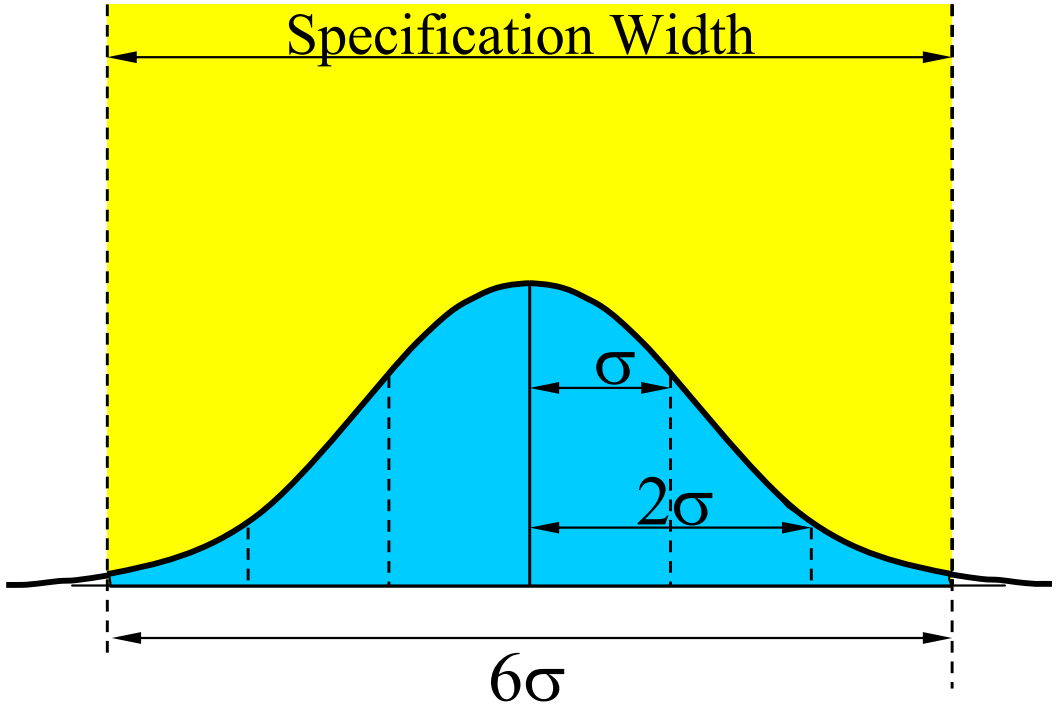
To 99.99966 %"

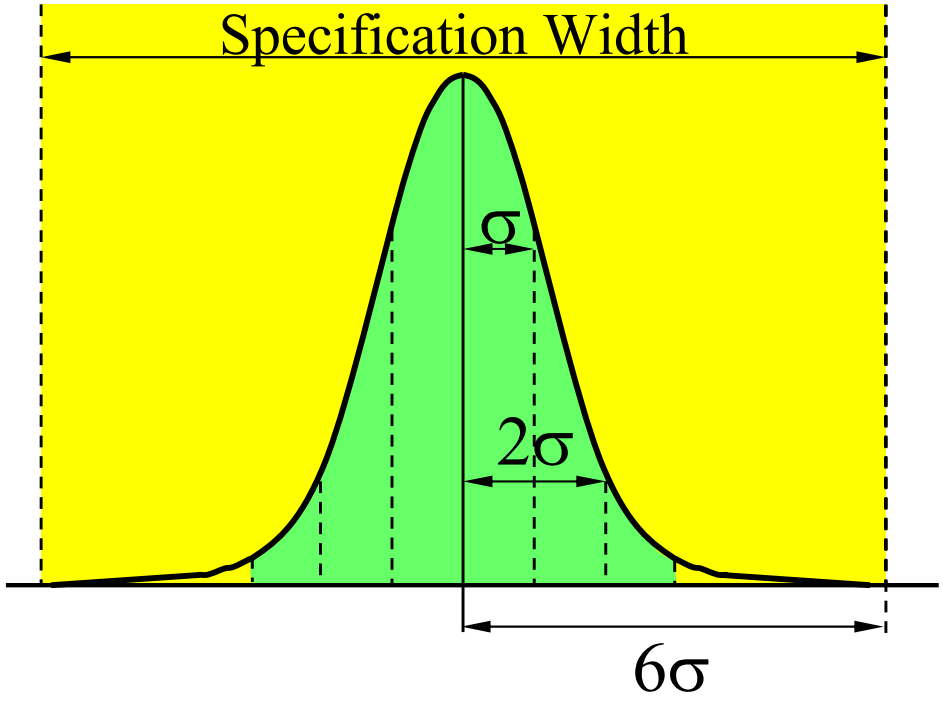
MIT *Sloan*

Companies Implementing Six Sigma

- Motorola
- Texas Instruments
- ABB
- AlliedSignal
- GE
- Bombardier
- Nokia
- Toshiba
- DuPont
- American Express
- BBA
- Ford
- Dow Chemical
- Johnson Controls
- Noranda

Machine Capability Index

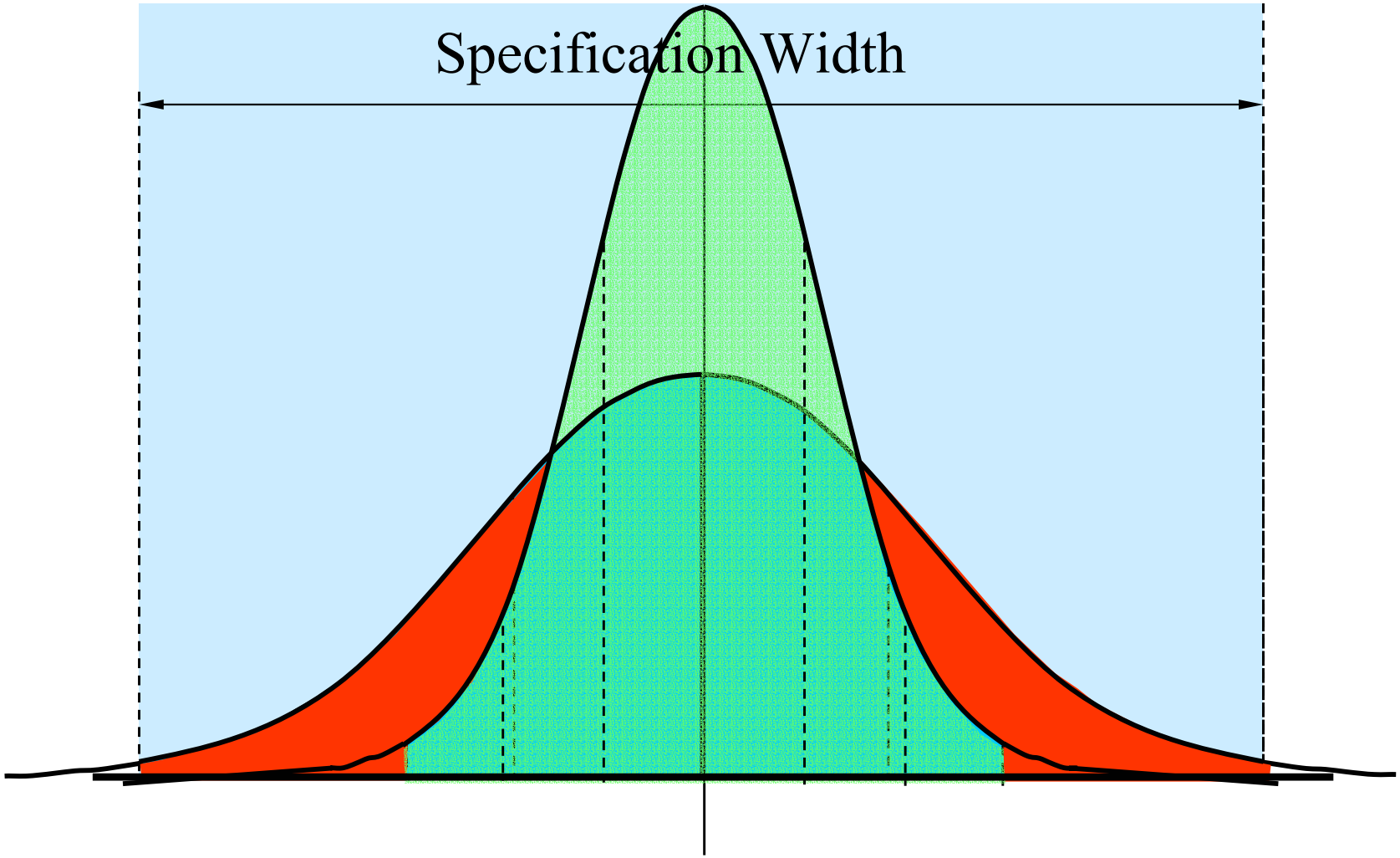




$$c_p = \frac{\text{Specification Width}}{\text{Process Width}\,[6\sigma]} = 1$$

$$c_p = \frac{\text{Specification Width}}{\text{Process Width}\,[6\sigma]} = 2$$

6-Sigma and Learning



Baldridge Award Winners

Year	Manufactruring	Services	Small Businesses
2000	• Dana Corporation • KARLEE Comp.	• Operations Mgmt. International	• Los Alamos National Bank
1999	• STMicroelectronics	• BI • Ritz-Carlton Hotels	• Sunny Fresh Foods
1998	• Boeing Airlift & Tanker • Solar Turbines,		• Texas Nameplates
1997	• 3M Dental Products • Solectron	• Merrill Lynch Credit	• Xerox Business Services
1996	• ADAC Laboratories	• Dana Commercial Credit Corp.	• Trident Precision
1995	• Armstrong World Ind. • Corning Inc, Telecomm.		
1994		• AT&T Consumer Comm. Serv. • GTE Directories Corp.	• Wainwright Industries
1993	• Eastman Chemical	•	• Ames Rubber Corp.
1992	• AT&T Network Systems (Now Lucent) • TI (Defense Systems)	• AT&T Universal Card Services • Ritz-Carlton Hotels	• Granite Rock Company
1991	• Solectron Corp. • Zytec Corp.	•	• Marlow Industries
1990	• Cadillac Motor Car • IBM Rochester	• Federal Express	• Wallace Co.
1989	• Milliken & Company • Xerox (Business Products & Systems)	•	•
1988	• Motorola • Westinghouse Elextric (Nuclear Fuel)	•	• Globe Metallurgical

Research On Quality Award Winners

- Hendricks & Singhal

  Management Science, 43, 9, Sep 1997

  - *107% (mean) 48% (median) higher Operating Income*
  - *64% (24%) higher Change in Sales*

  Management Science, 47, 3, Mar 2000

  - *36% to 46% better Stock Performance*

Overview of Approaches

- Crosby: General Road Map for Mgmt.
- Juran: Conceptual Model for Costs of Quality
- Deming: SPC - Application for Shop
- Taguchi: Finding the right Specs
- 6-Sigma: Narrowing down on Specs

Approach to Q-Improvement

1. Map Customer Needs to Product Specs
2. Optimize Design Parameters (Taguchi)
3. Get Consistent Inputs (weeks)
4. Get in Control (SPC) (months)
5. Get Capable (Kaizen) (year, ongoing)
6. If not capable, then radical Improvement

What it takes

- Understanding of Process
- Understanding of Customer
- Culture of Trust
- Quality Incentives
- Standardized Methods
- Education & Training
- Support Systems