Analyzing Risk through the Application of Six Sigma Concepts

Acknowledgment:

This course applies *Six Sigma* concepts developed by Motorola, Inc. These concepts include associating an equivalent *sigma* with a given defect level, a measurement of customer perceived quality using defects per unit (DPU), and the Six Steps to Six Sigma.

Objectives

- Familiarize participants with Six Sigma terminology and concepts needed for the course, “Six Sigma and Cost/Risk Management for S&T”
- Concepts include:
  - Process variation
  - Requirements and Capabilities
  - Variables & Attributes
  - Scorecard for Risk Analysis

What is Six Sigma?

Six Sigma is a:

- method
- metric
- benchmark
- stretch goal

Six Sigma has become a metaphor for world-class quality.

Definitions for Six Sigma

- Six Sigma is a way to measure the probability that a product being developed will have almost no risk.
- The probability of success is > 99.99966 % for each product characteristic.

Definitions for Six Sigma

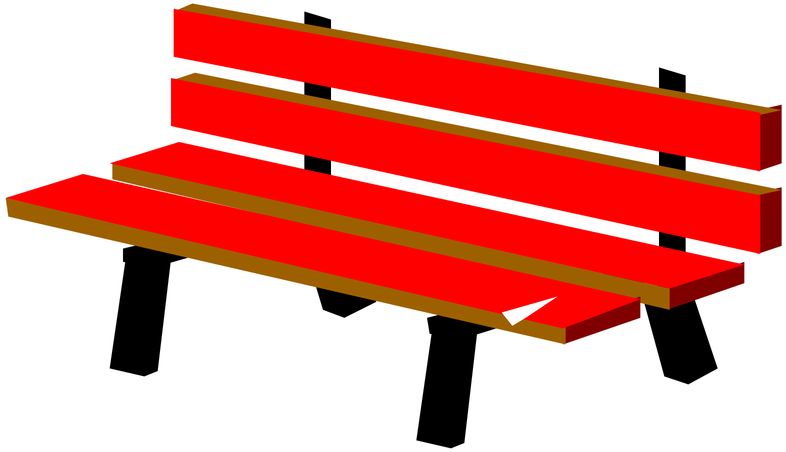
- Six Sigma is a way to measure the chance that a unit of product or a work process can be manufactured or performed with virtually zero defects.
- For variables, Six Sigma is $C_p \geq 2$ AND $C_{pk} \geq 1.5$
- For attributes, Six Sigma is no more than 3.4 defects per million.

Why Six Sigma?

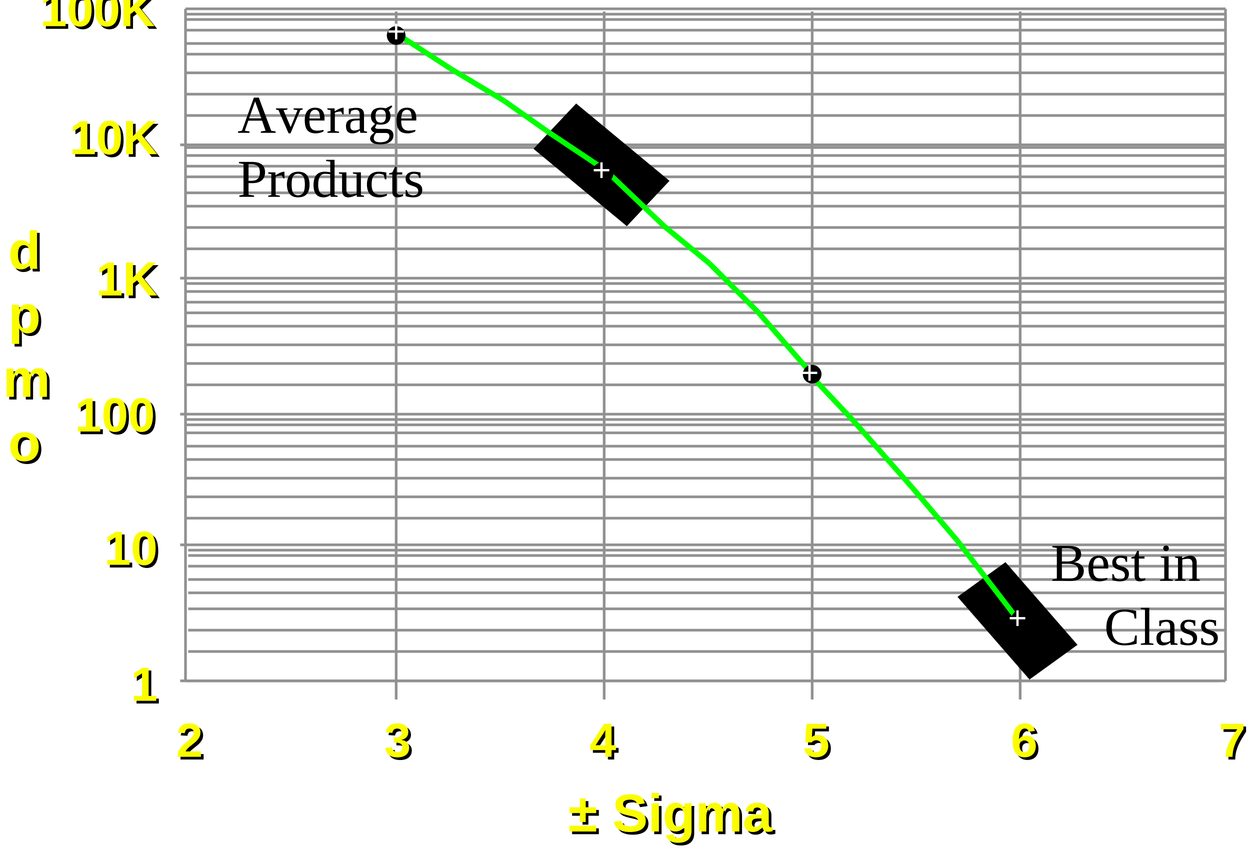
- The application of Six Sigma concepts to advanced technology projects increases the predictability of the result.
- The Six Sigma metrics allow us to assess the risk associated with prototype development and with production based on that prototype.
- Risk reduction helps us more effectively invest increasingly scarce development resources in a rapidly changing and competitive environment.

Benchmarking

- Looking for the best, inside and outside of the organization
- Comparing our processes to the best
- Incorporating best practices into our processes



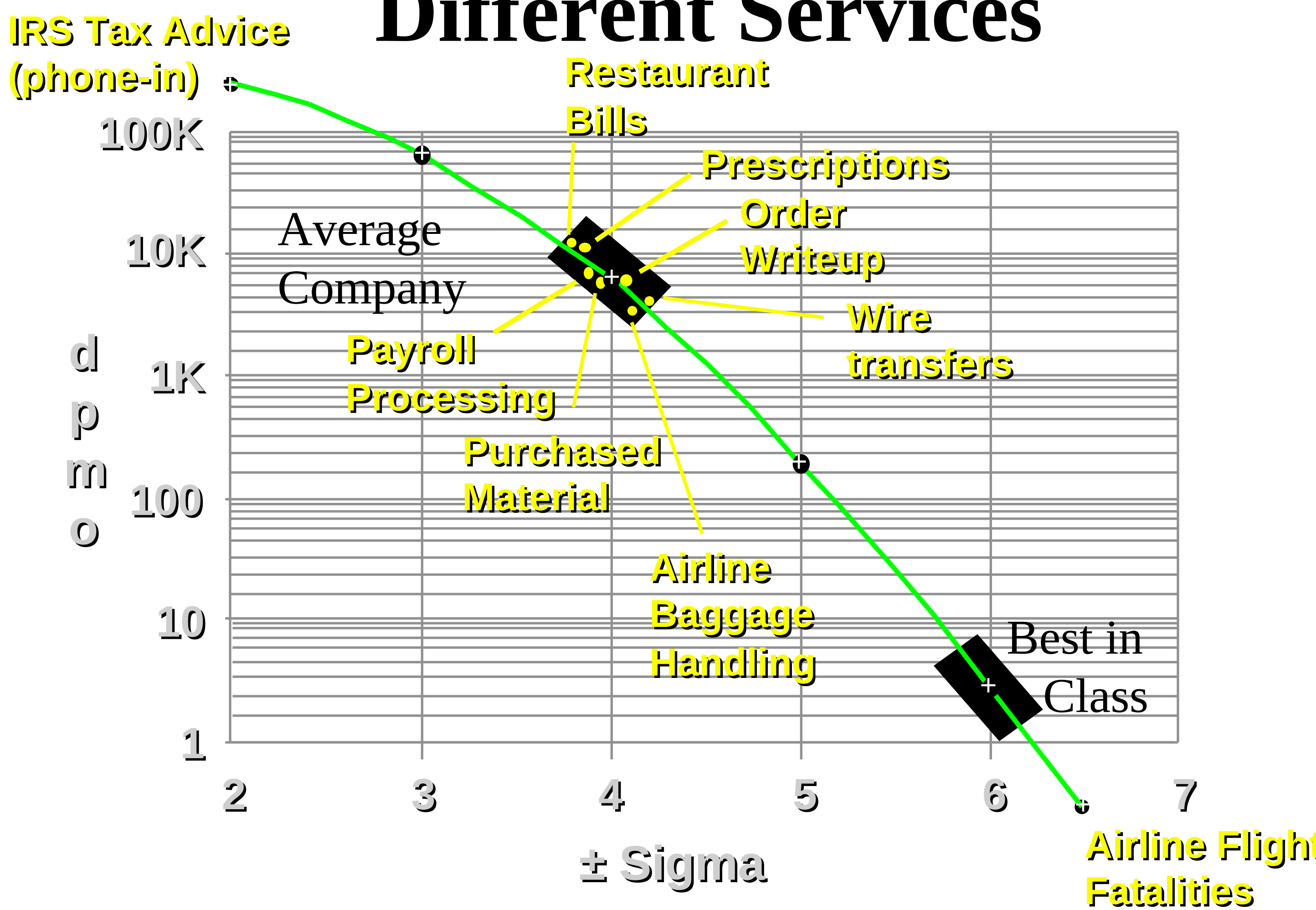
Benchmarking Different Products



Why Six Sigma?

- A Six Sigma manufacturing program will spend 1% or less of each dollar on the cost of non-conformance.
- A Four Sigma manufacturing program will spend as much as 25%
- A Four Sigma program cannot compete with a Six Sigma program.
- We believe program survival depends on achieving Six Sigma.

Benchmarking Different Services

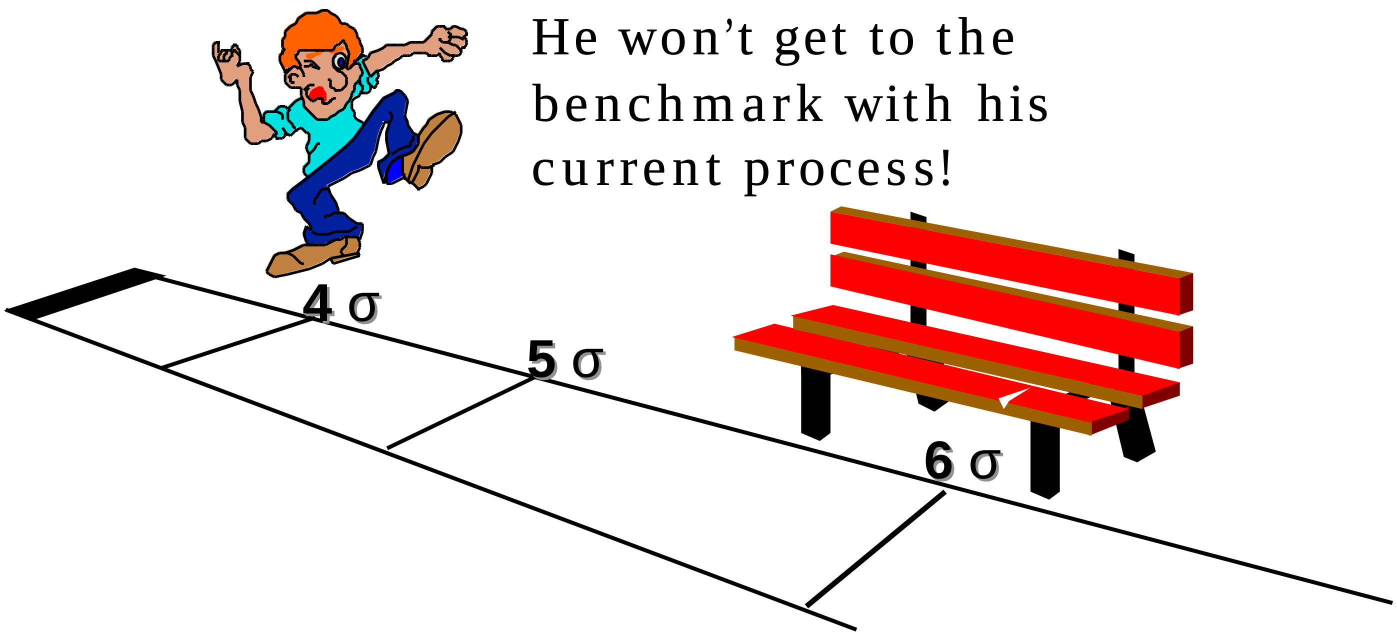


Acknowledgement: Motorola

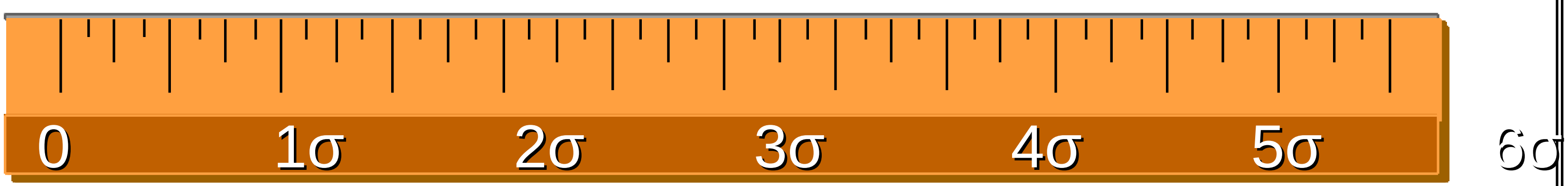
A Stretch Goal

- **Six Sigma, the metric, quantifies the benchmark: “world class” quality**
- **Six Sigma, the method, is a set of principles to get to “world class”**

He won’t get to the benchmark with his current process!



Six Sigma -
A Common Yardstick for Quality



Six Sigma and the Product Life Cycle

Concept (6.1, 6.2) → Tech Transfer (6.3) → Production

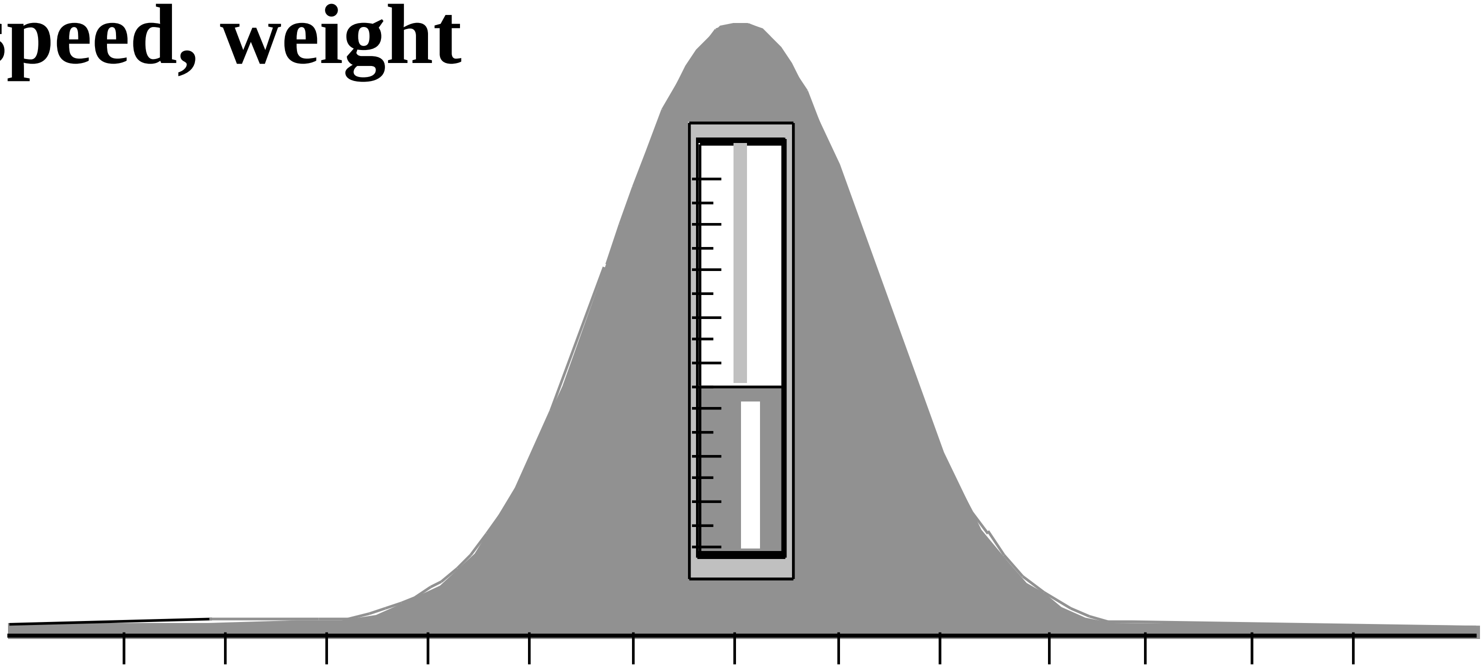
Six Sigma and
Cost Risk Management
in S&T

Six Sigma for
Intellectual Activities

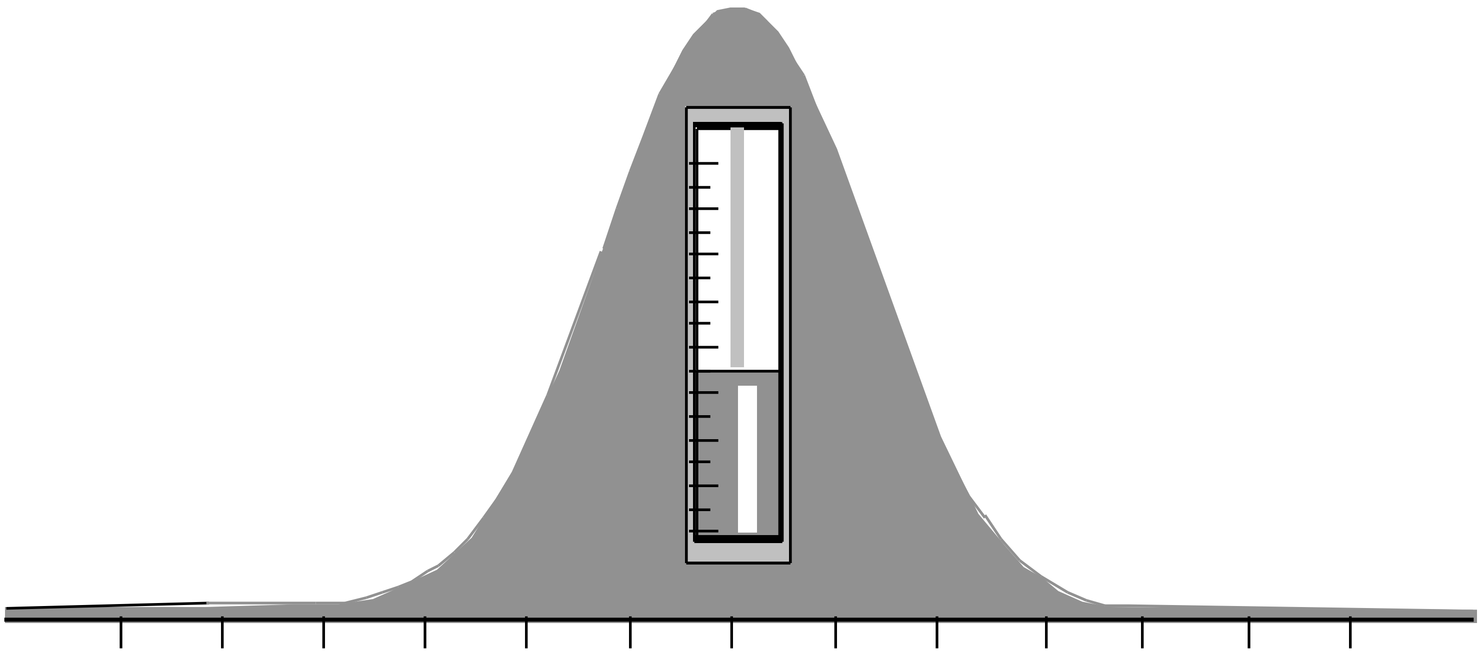
Design for
Six Sigma Manufacturability

Variables

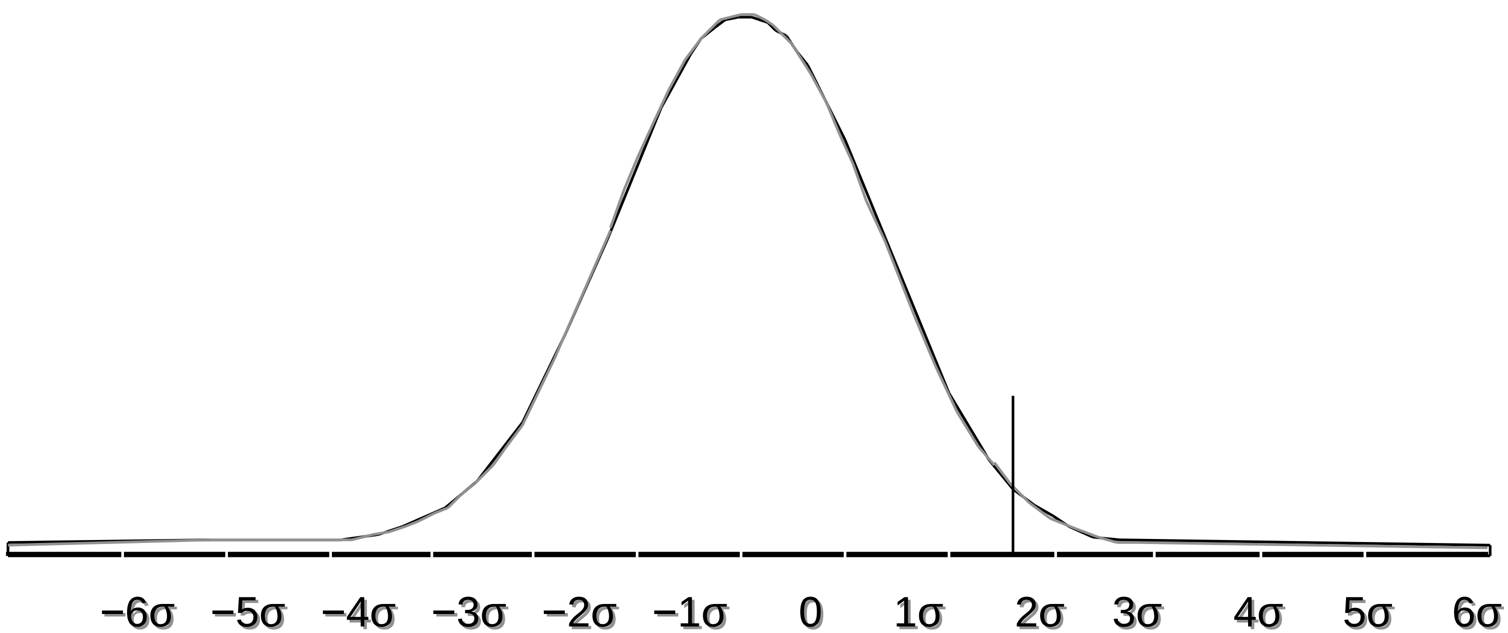
are things measured on a continuous scale. Examples: temperature, volts, feet, speed, weight



Many product/process variables are distributed in ways that resemble the Normal distribution.

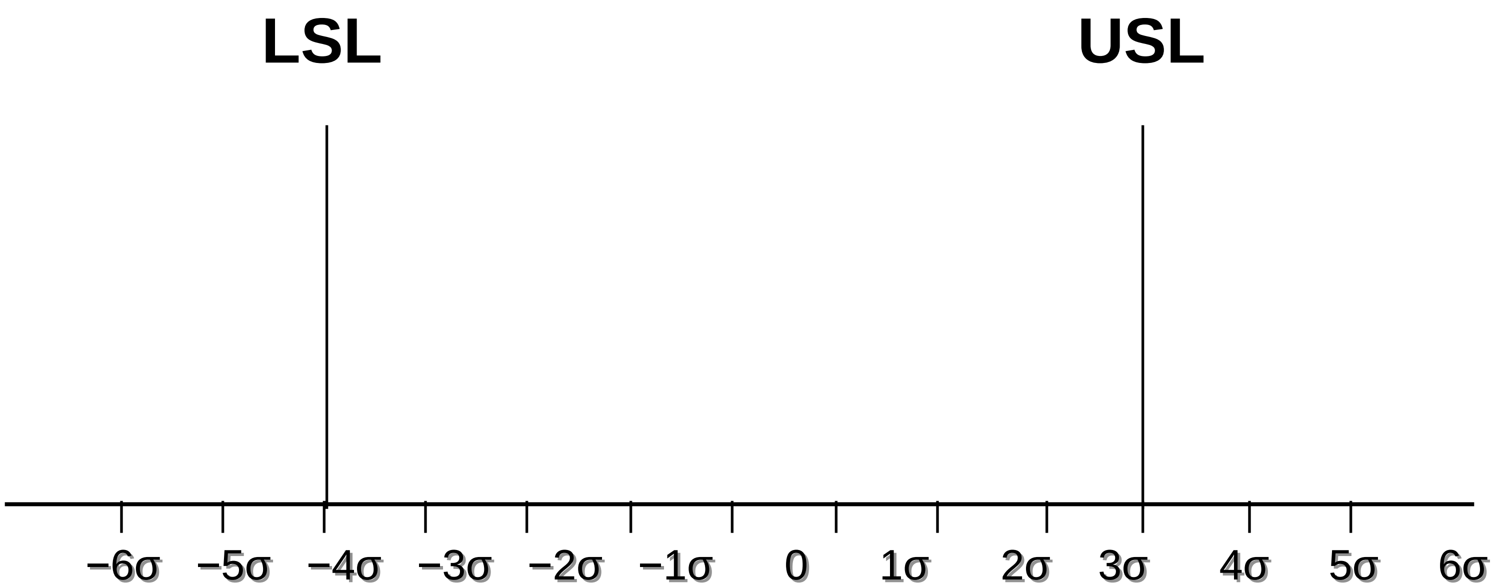


The normal distribution is used to estimate the probability of exceeding a value.



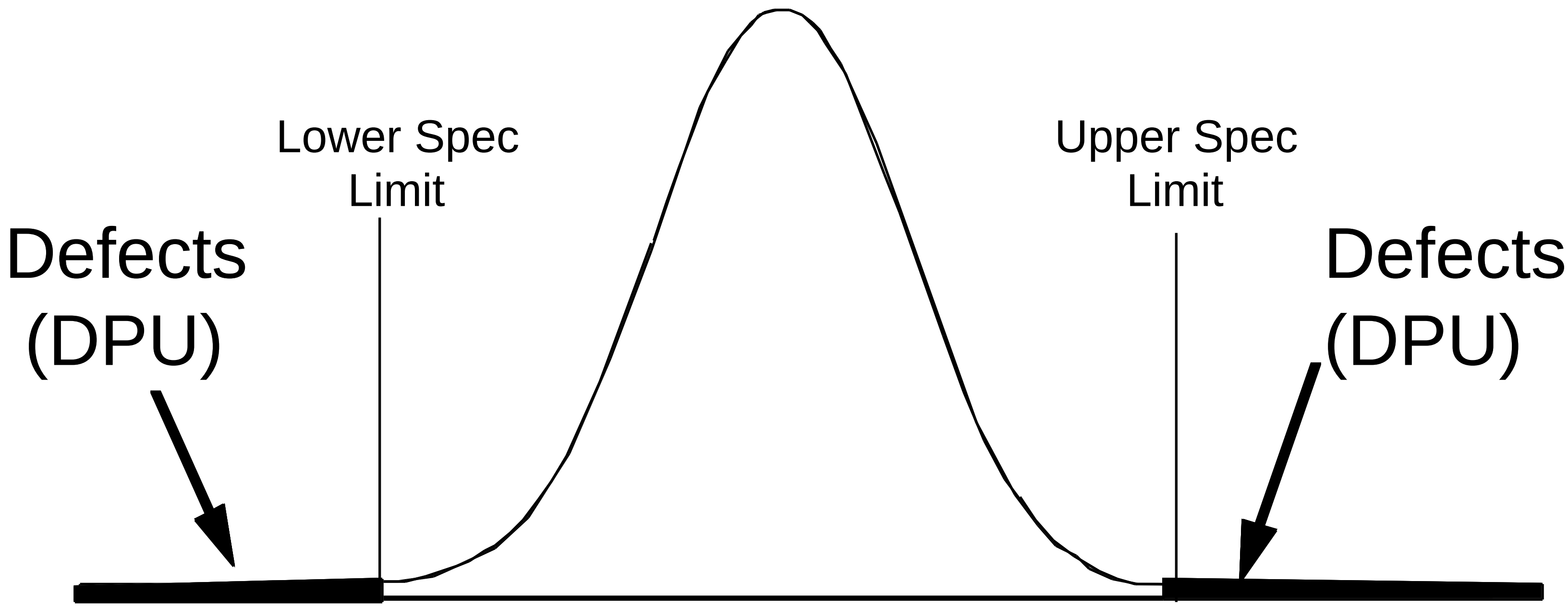
Probabilities for the normal distribution are found in Z tables.

Specification Limits

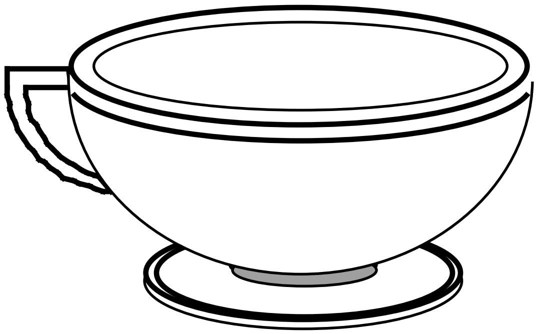


What Causes Defects ?

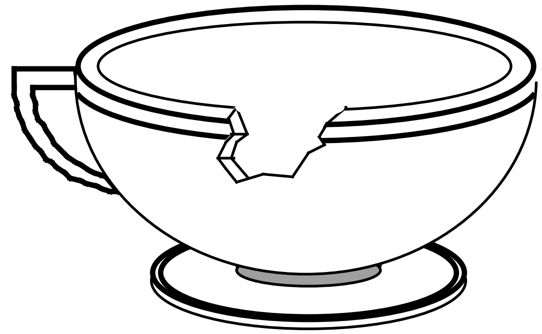
The Capability does not meet the Requirement !



Attributes

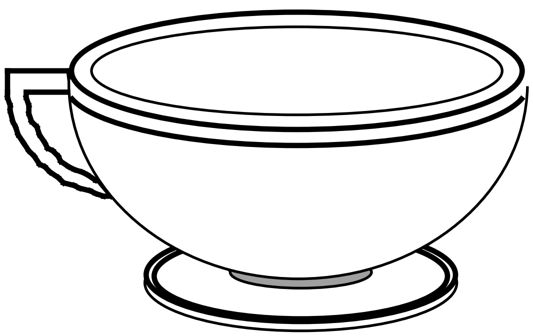


No Defect

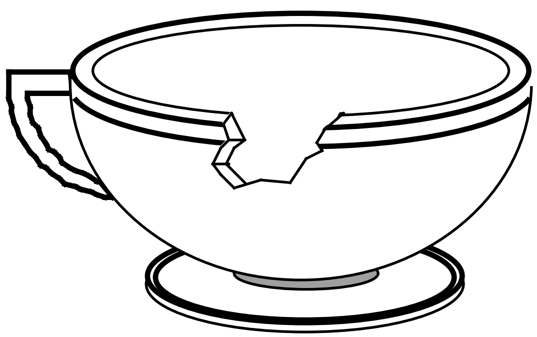


Defect

Attributes
What causes defects?
The capabilities do not meet the requirements.

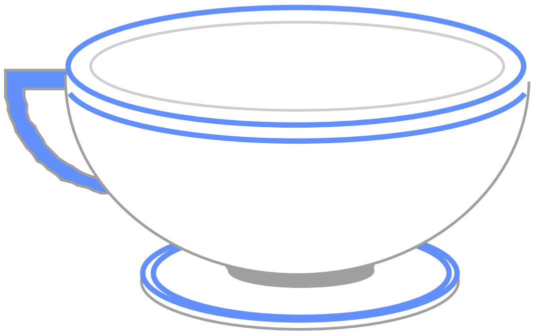


No Defect

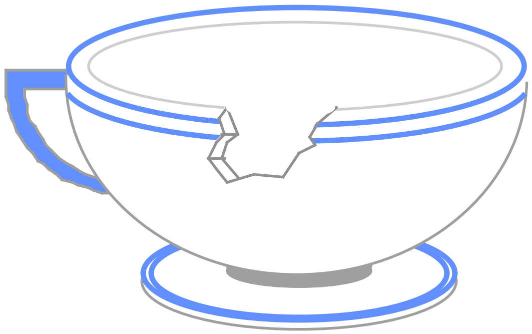


Defect

Attributes Data



No Defect



Defect

$$\text{DPU} = \frac{\text{\# defects found}}{\text{\# units inspected}} = \frac{1}{200} = .005$$

The probabilities are additive

- The defects (risk) that are estimated from product variables, and...
- the defects (risk) that are estimated from product attributes...
- can be added together...
- to form a metric.
- Defects per Unit (DPU)

Metrics Cascade

Customer

Defects (Risk)

Unit

Defects per Unit (DPU)

Opportunities/Unit

For Benchmarking

dpmo

Sigma Level

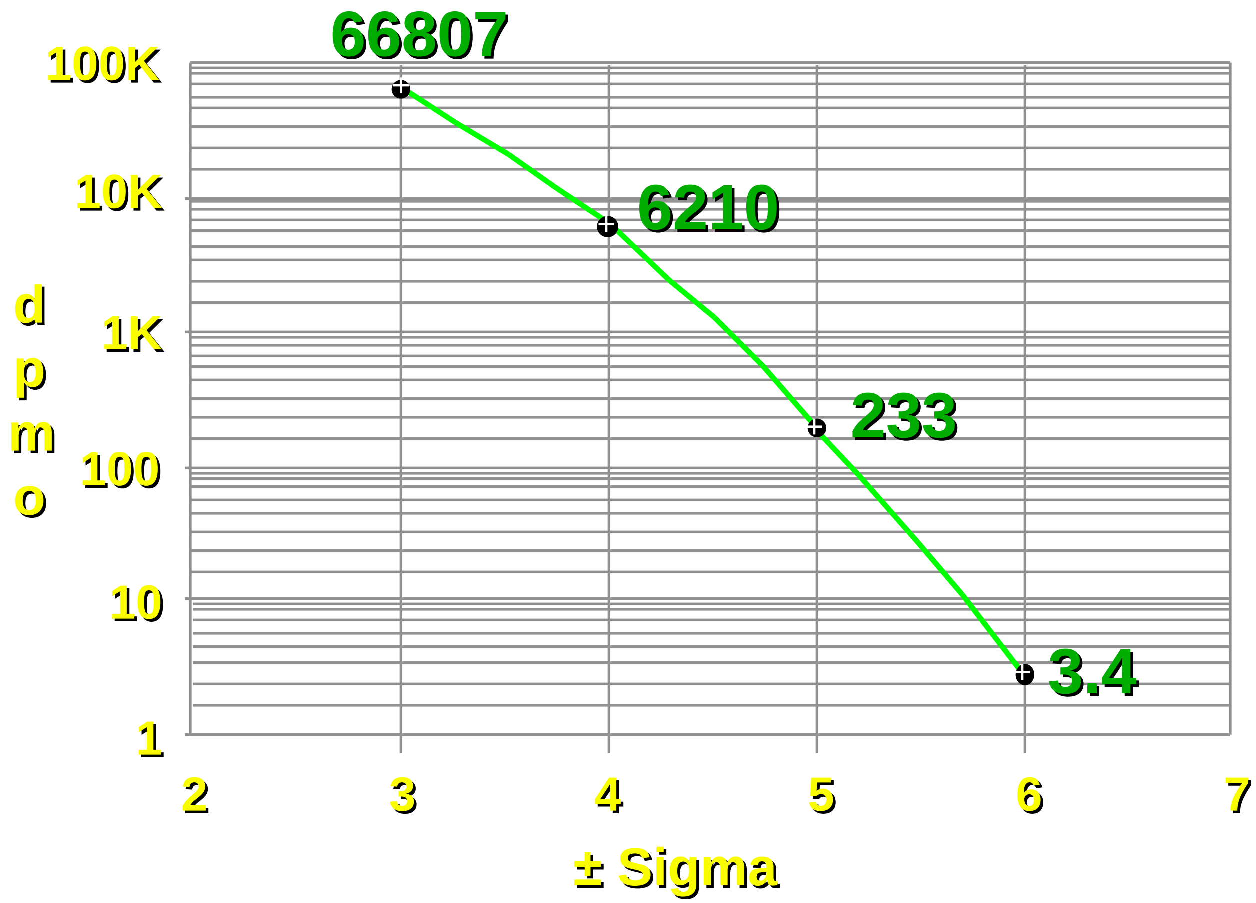
Defintion
Opportunities per Unit

- For rational comparison of quality, the complexity must be considered.
- Opportunites are a measure of complexity.
- “Opportunities” are the number of things that must be right for the unit to meet all the requirements.
- Examples: features, characteristics, number of components, square meters, etc.

Defects per million opportunities

$$\text{dpmo} = \frac{\text{DPU}}{\text{opportunities per unit}} \times 10^{6}$$

dpmo to Sigma Relationship



Six Sigma Product Design

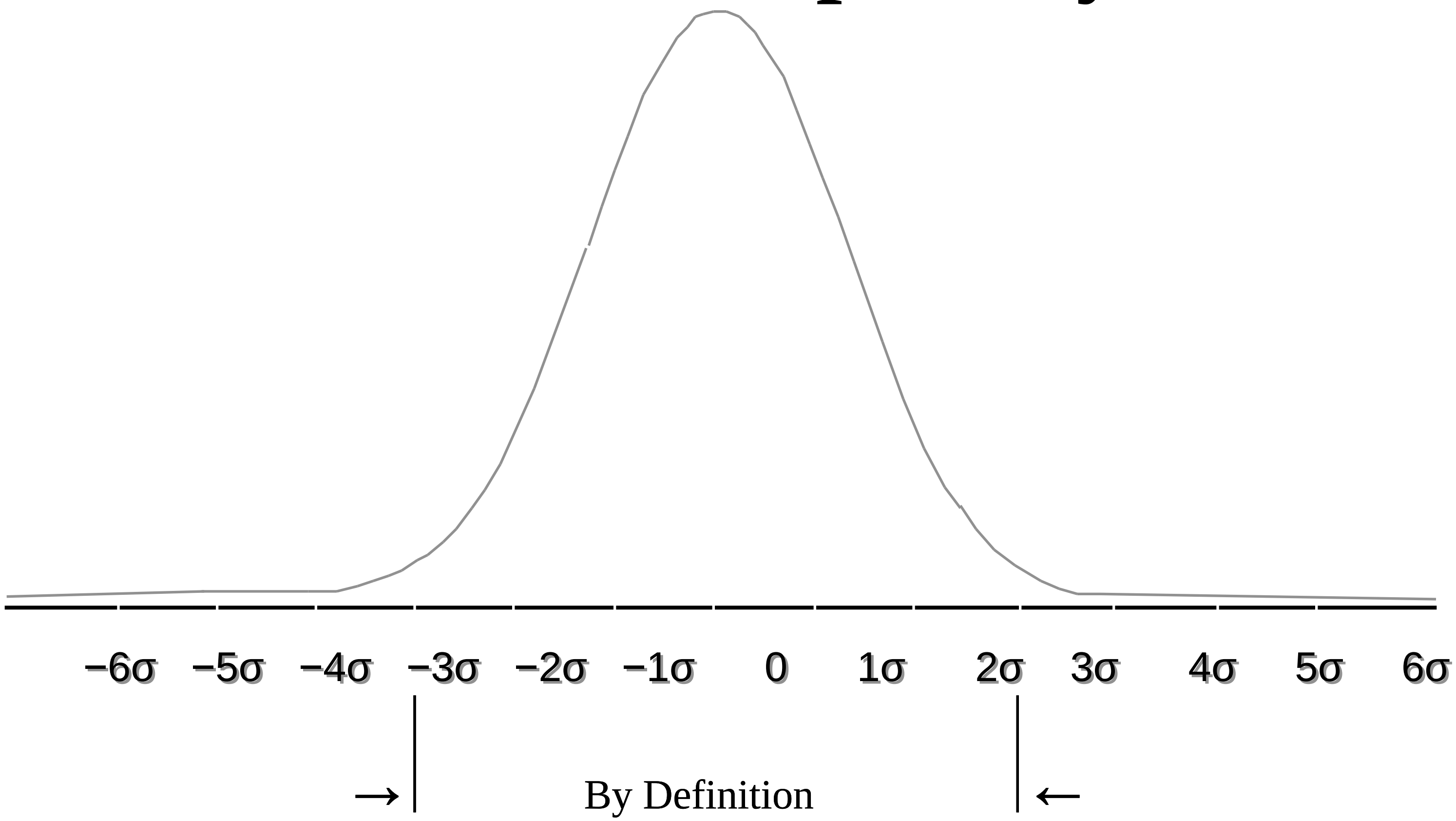
Six Sigma design is the application of statistical techniques to analyze and optimize the inherent system design margins. The objective is a design which can be built error-free.

Rich Karm
Ron Randall

Six Steps
For Integrated Product/Process Development Teams

1. Identify the customer's physical and functional requirements.
2. Determine the product characteristics critical to each requirement.
3. Determine if the characteristic is controlled by the part, the process, or both.
4. Determine the target nominal and maximum tolerance allowable for each characteristic.
5. Determine the process capability for each critical characteristic.
6. If Cp< 2 OR Cpk< 1.5, redesign the product or process as required.

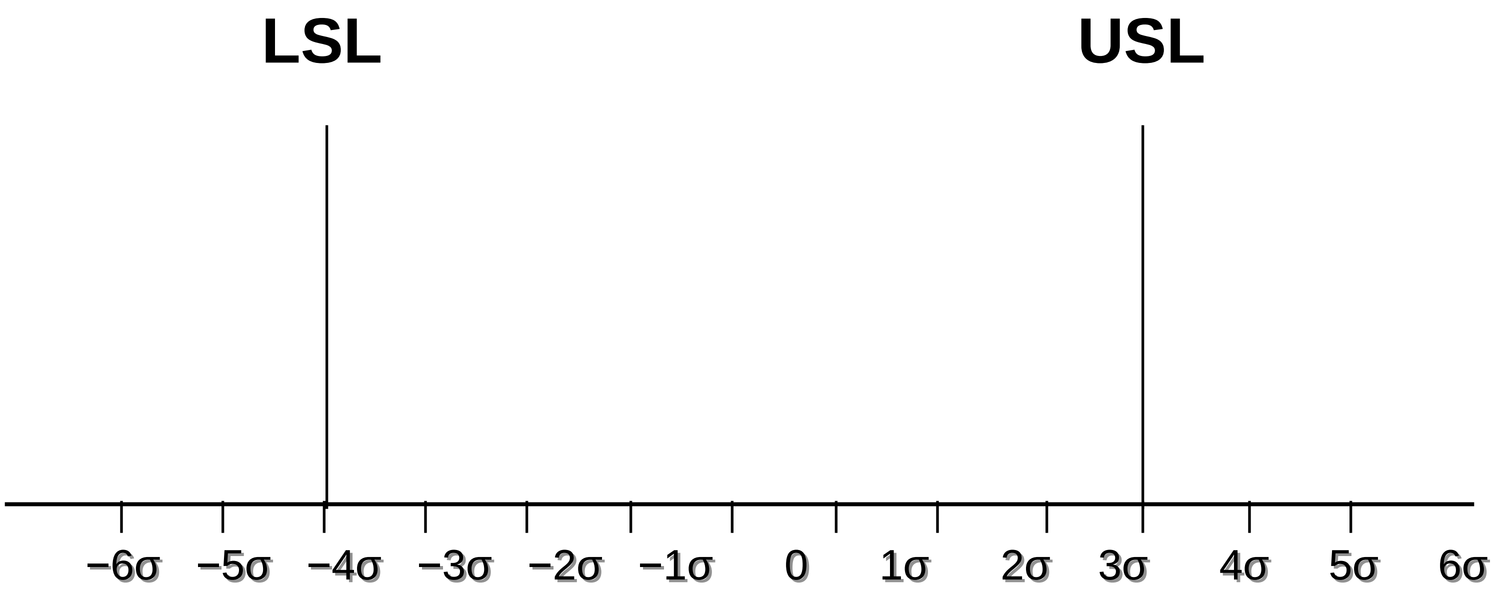
Process Capability



± 3 σ

99.73%

Specification Limits



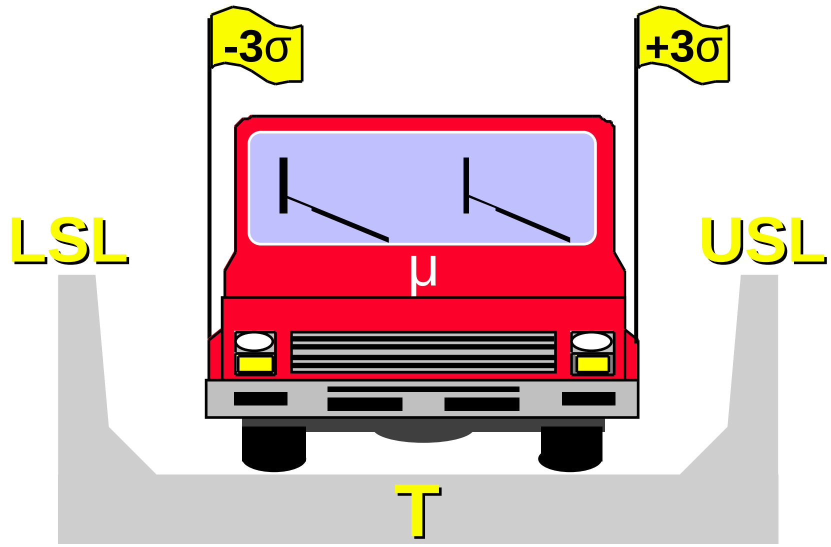
Process Capability Index
Cp
By Definition:

$$C_p = \frac{\text{Spec Width (road)}}{\text{Mfg Capability (car)}} = \frac{\text{USL - LSL}}{\pm 3\sigma}$$

Concurrent Engineering Index

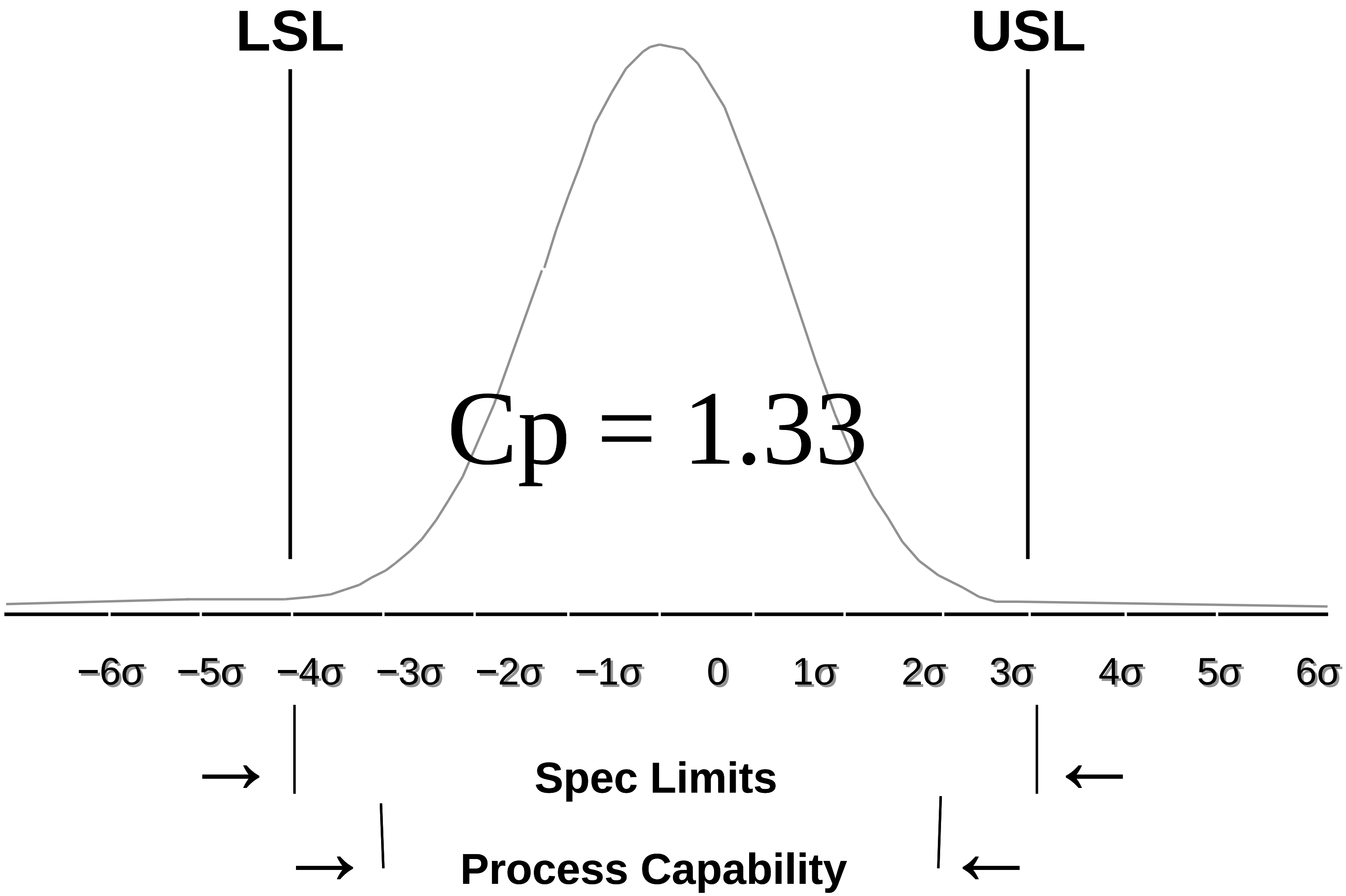
Design / Manufacturing

Capability Index



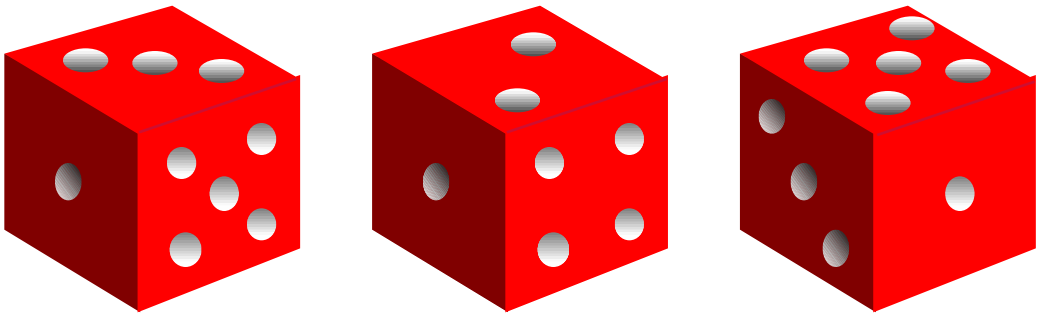
$$C_p = \frac{\text{Spec Width (road)}}{\text{Mfg Capability (car)}} = \frac{\text{USL - LSL}}{\pm\, 3\sigma}$$

Capability Index at ± 4 Sigma



Combined Probability of Independent Events

Probability of not throwing a 1 on any of 3 die:

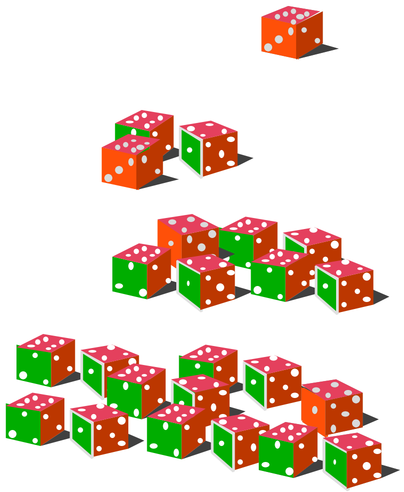


$$\frac{5}{6} \times \frac{5}{6} \times \frac{5}{6} =$$

57.87% =

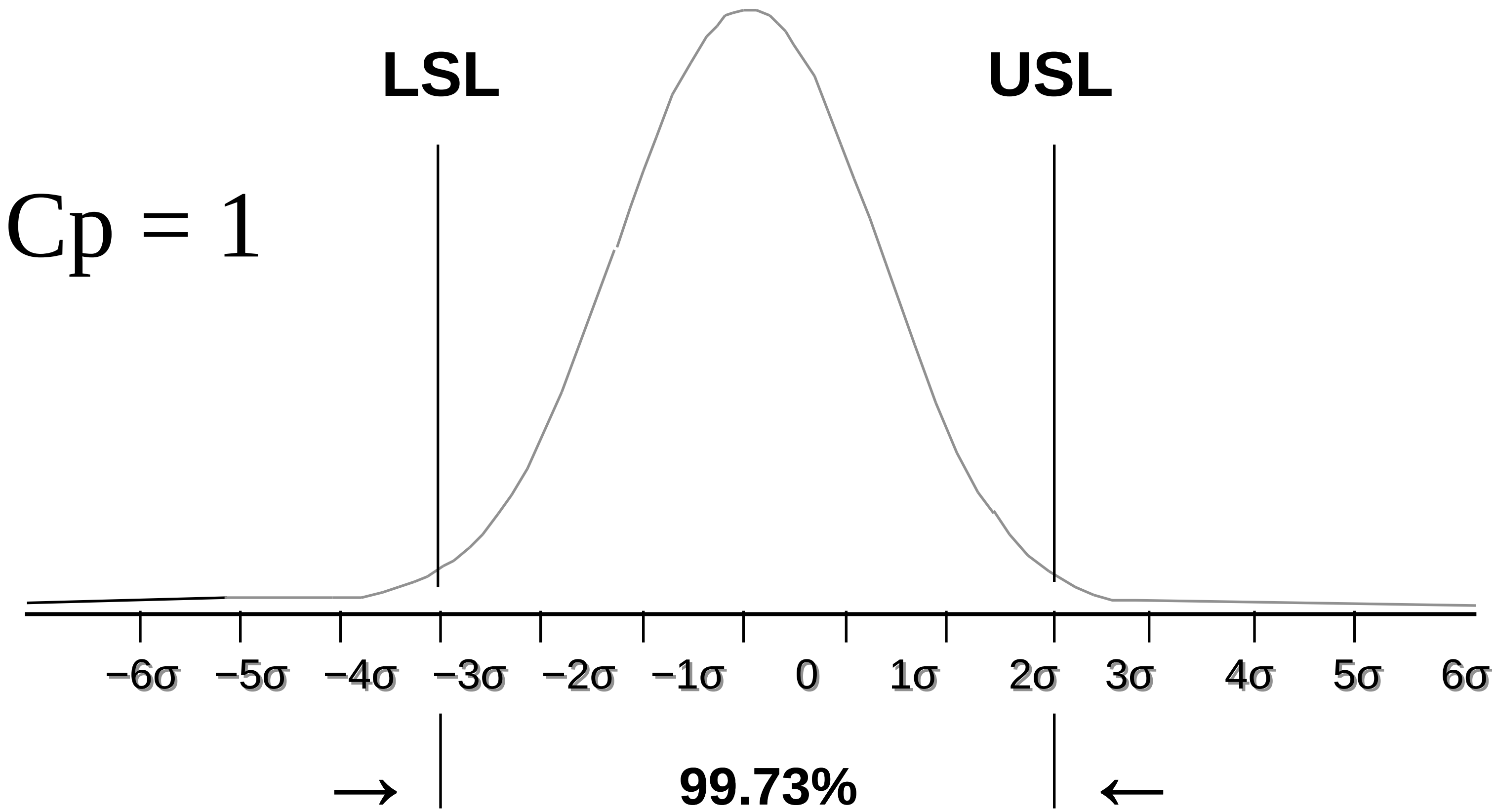
Rolled Yield

Probability of Not Rolling a One



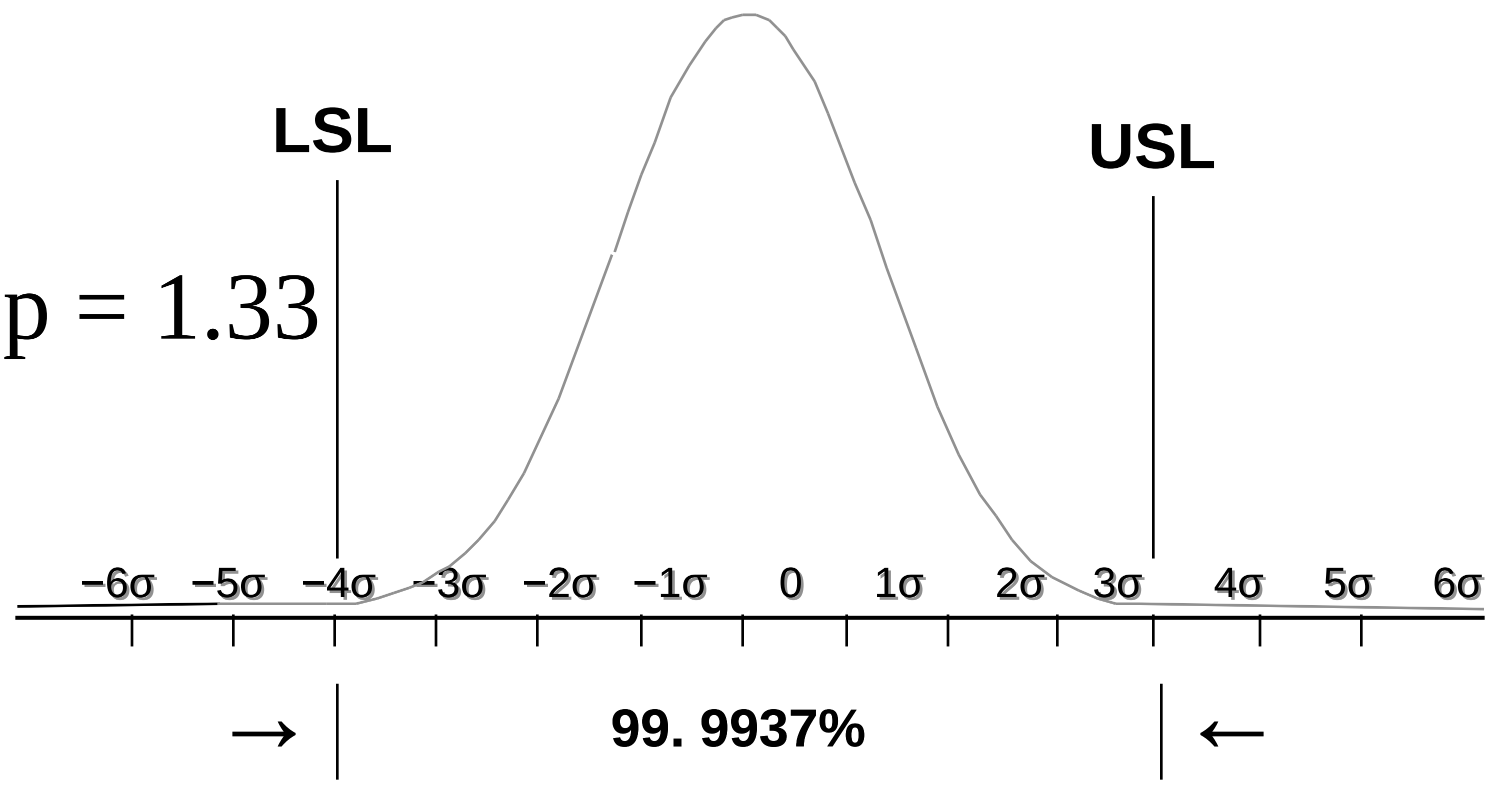
# of dice (x)	$RY = Y_1^x$
1	83.33%
3	57.87%
10	16.15%
30	.42%
50	.01%
100	--

Probability of Success with ± 3 Sigma Spec Limits



Probability of Success with ± 4 Sigma Spec Limits

Cp = 1.33



Spec Limit Effect on Yields

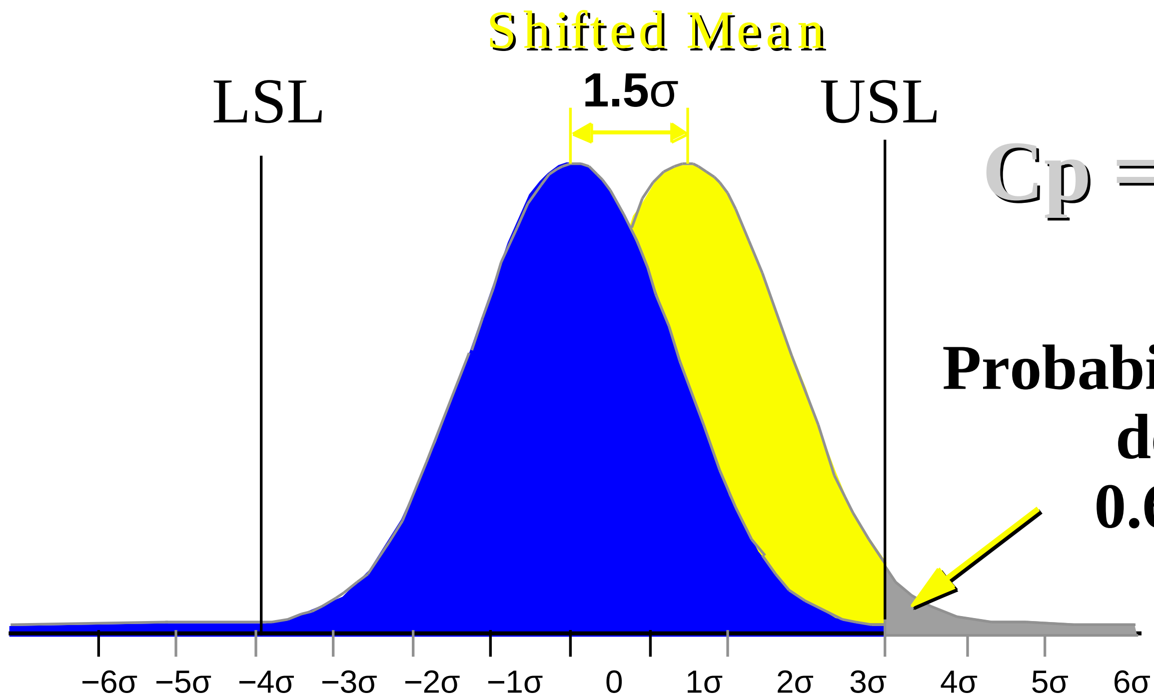
(If distribution is always centered)

# of parts or steps (x)	Spec Limits at ± 3σ	± 4σ
1	99.73%	99.9937%
10	97.33	99.94
30	92.21	99.81
50	87.36	99.68
100	76.31	99.37
150	66.66	99.06
200	58.23	98.74
300	44.44	98.12
400	33.91	97.50
500	25.88	96.89

$$RY = Y_1^{x}$$

Reality

Processes are not always in the center



Cp = 1.33

Probability of a defect 0.621%

Cpk

Process capability adjusted for centering

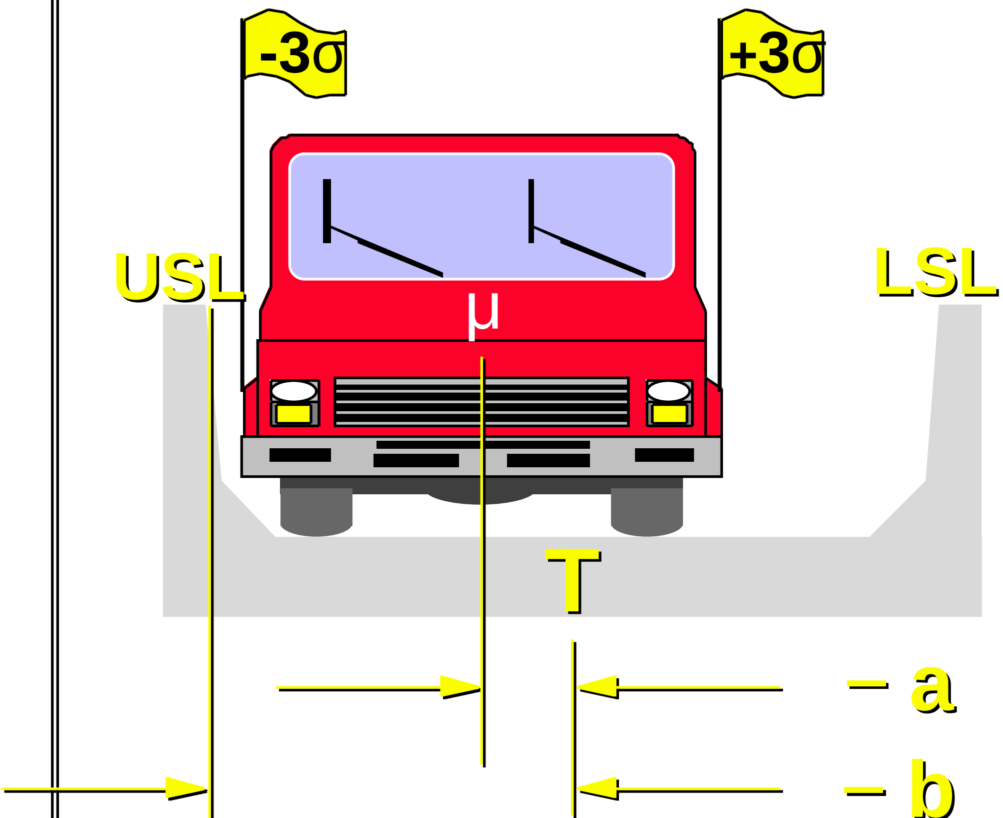
By Definition:

Cpk = Cp(1-k)

k = amount of shift / 1/2(USL-LSL)

k is always positive

Capability Index
Adjusted for Shifted Mean



$$C_{pk} = C_p (1\text{-}k)$$

where $k = \dfrac{-a}{-b}$

k is always positive

± 4 Sigma Spec Width

Shifted Mean

Cp = 1.33

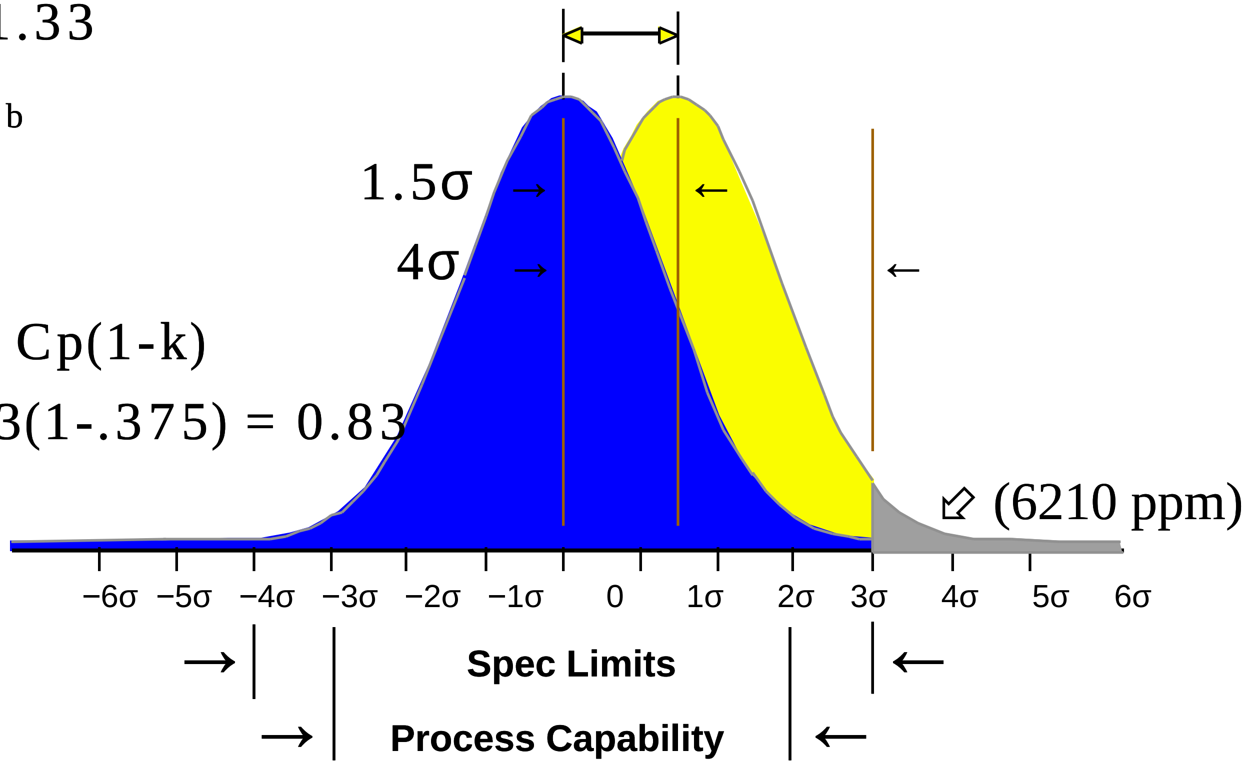
k = $^{a}/_{b}$

a =

b =

Cpk = Cp(1-k)

= 1.33(1-.375) = 0.83



± 6 Sigma Spec Width

Shifted Mean

$Cp = 2$

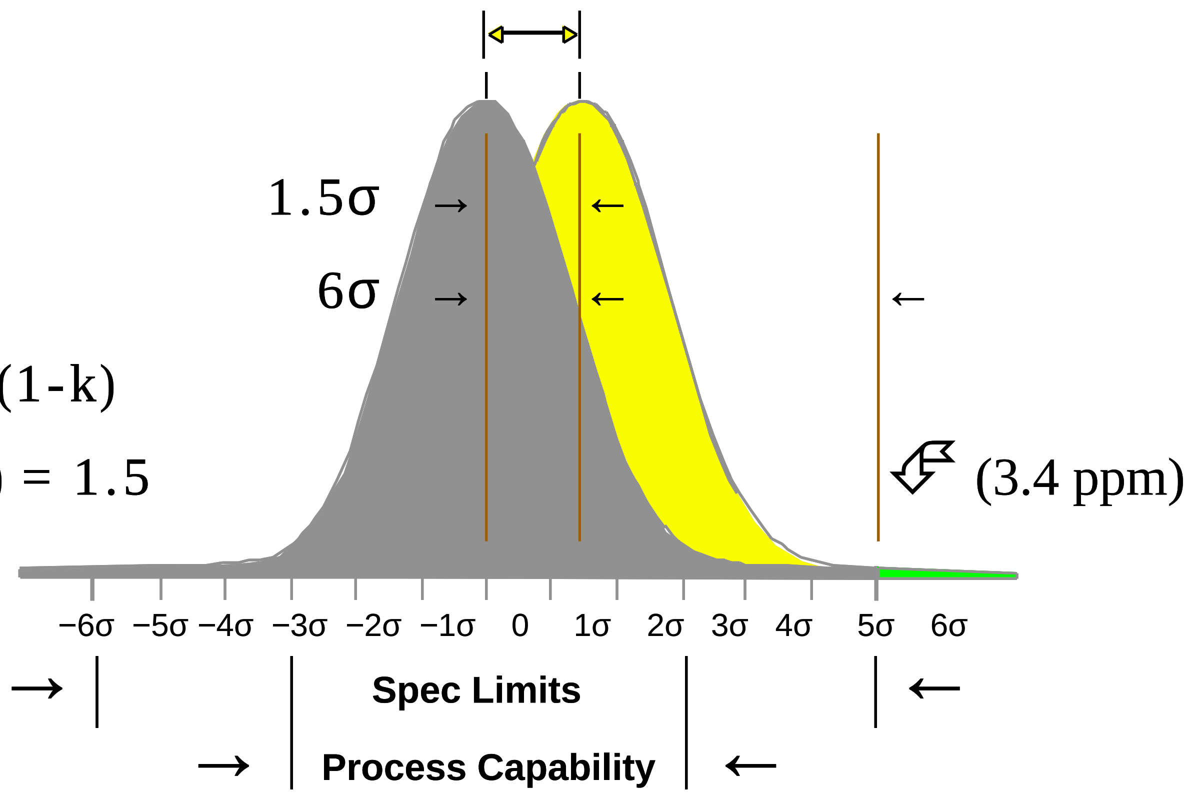
$k = {}^{a}/_{b}$

$a = 1.5\sigma$

$b = 6\sigma$

$Cpk = Cp(1-k)$

$= 2(1-.25) = 1.5$



Yields thru Multiple Steps/Parts

Distribution Shifted +/- 1.5σ

$RY = Y_1^x$

x # of parts or steps	± 3σ	± 4σ	± 5σ	± 6σ
1	93.32%	99.379%	99.9767%	99.99966%
10	50.08	93.96	99.768	99.9966
30	12.57	82.95	99.30	99.99
50	---	73.24	98.84	99.98
100	---	53.64	97.70	99.966
150	---	39.38	96.61	99.949
200	---	28.77	95.45	99.932
300	---	15.43	93.26	99.898
400	---	8.28	91.11	99.864
500	---	4.44	89.02	99.830
800	---	00.69	83.02	99.729
1200	---	00.06	75.88	99.593

The Technical Feasibility of Unobservium

An Exercise in Cp and Cpk

Cp and Cpk Exercise

- Your mission is to develop a practical invisible aircraft using a new material.
- Introducing - Unobservium!
- Unobservium is an electroluminescent material with the strength to weight characteristics which make it ideal for aircraft structural use.
- Your job is to evaluate the critical characteristics of laboratory samples of unobservium statistically, and recommend where research money should be invested to reduce the risk of transition to production.

Cp and Cpk Exercise

- Unobservium responds to the application of electrical current by absorbing or emitting electromagnetic radiation throughout the visible and much of the invisible electromagnetic spectrum, including the infrared and microwave spectrums.

Cp and Cpk Exercise

- This allows an object covered with unobservium to change the light absorption and reflection of its surface, rendering it invisible to optical, laser, and radar tracking devices.
- This is accomplished through the use of a set of classified sensors and electronic stimulators controlled by very fast microprocessors running a sophisticated algorithm nicknamed “chameleon”.

Cp and Cpk Exercise

- Research has found that there are three critical characteristics of the material:
  1. Reflectivity
  2. Yield strength
  3. Hardness

Cp and Cpk Exercise

- All specifications are double sided. Each has a high and a low spec limit.

  1. Reflectivity: Too much and the aircraft becomes visible because it is shiny. Too little and it appears dark against the background.

  2. Yield strength: Too much and metal fatigue problems become pronounced. Too little and the material tears.

Cp and Cpk Exercise

3. Hardness: Too much and the material cannot be economically machined and formed. Too little and the material abrades in flight causing the reflectivity to change.

Cp and Cpk Exercise

- The class will divide into teams.
- Each team will gather data on one of the critical characteristics from laboratory samples.
- Each team will then compare its data against the functional spec limits for that material characteristic.

Cp and Cpk Exercise
Hardness

This exercise simulates gathering hardness data from 40 samples of unobservium from the laboratory.

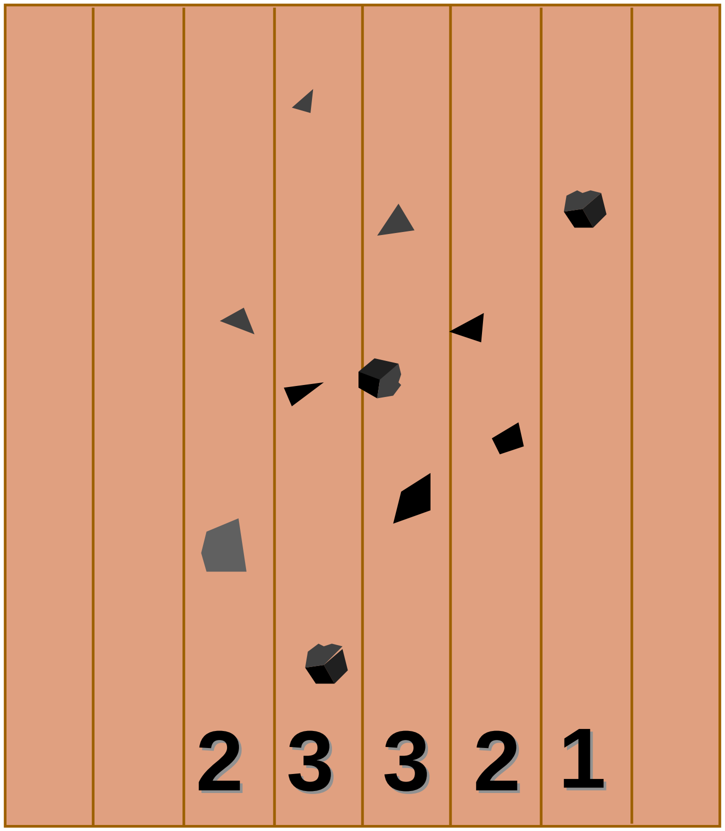
- Throw a pencil at a flip chart.
- The target is a vertical line in the middle of the chart.
- The throwers must stand 10 ft. (3 meters) away from the target.
- The team must record at least 40 throws. Each throw represents a sample hardness reading.

Cp and Cpk Exercise
Hardness

- Count the number of pencil hits (marks) up to one inch to the right of the target, one inch to the left of the target, between one and two inches from the target on each side, between two and three inches from the target on each side, etc.

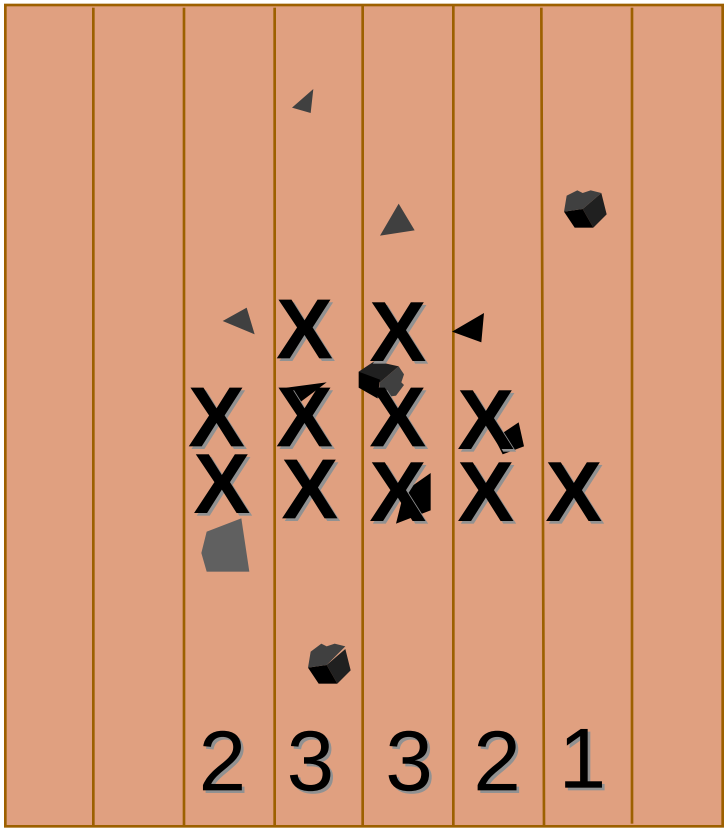
Cp and Cpk Exercise Hardness

- Write the total number of hits in each column at the bottom of each column.
- A column is the area between the lines.



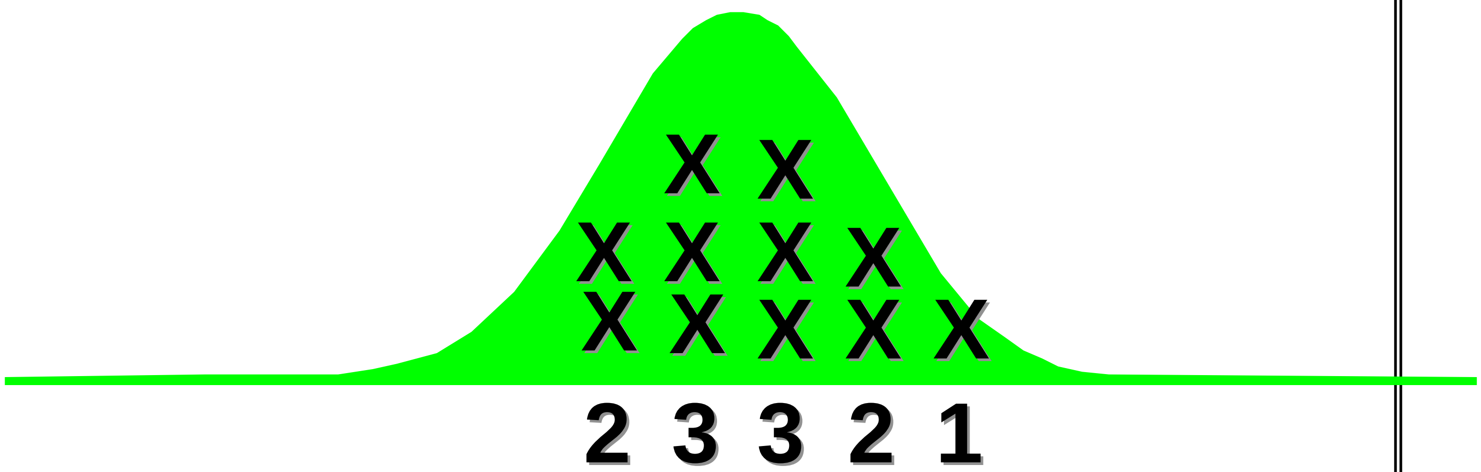
Cp and Cpk Exercise
Hardness

- Create a histogram using the number of hits in each column.



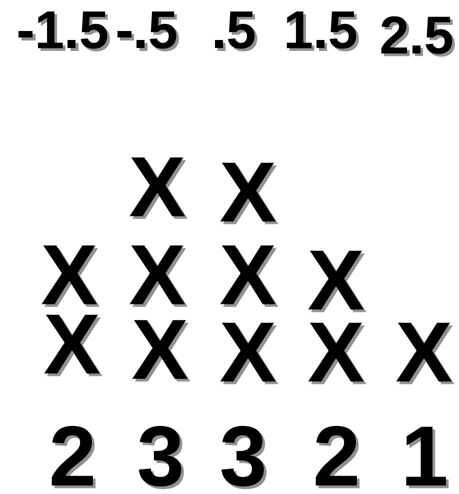
Cp and Cpk Exercise Hardness

- Calculate the mean and standard deviation for the samples.



Cp and Cpk Exercise
Hardness

- Use mid-range values for each column to simplify the calculations.
- Example: 2 hits at -1.5”
  3 hits at -0.5”
  3 hits at 0.5”
  2 hits at 1.5”
  1 hit at 2.5”



Cp and Cpk Exercise
Hardness

- For a target with a width of +/- 2 inches (+/- 5 cm.) centered on the target line, what is the Cp and Cpk?

$$Cp = \frac{\text{Spec Width}}{6x(\text{Std. Dev.})}$$

Cp and Cpk Exercise
Hardness

$$Cpk = Cp\,(1-k)$$

$$k = \frac{|\,\text{Mean} - \text{Target}\,|}{1/2 \text{ Spec Width}}$$

Cp and Cpk Exercise

- Some Useful Formulas -

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n} - \bar{x}^2}$$

Cp and Cpk Exercise Discussion

- Which characteristic has the lowest Cp and Cpk?

- Which characteristic is the most likely to have problems?

- Where should we devote our attention and research dollars?

Cp and Cpk Exercise
Summary

- **Cp and Cpk can point out areas of design risk.**
- **By focusing our technical resources on the potential problem areas we can avoid future problems and costly surprises.**
- **By using six sigma techniques to identify critical variables and control them, we can reduce the risk associated with transitioning advanced technology into production.**

Malcolm Baldrige

National Quality Award

1992 Winner

Texas Instruments

Defense Systems & Electronics Group