



# **THE SIX SIGMA BLACK BELT PRIMER**

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**Quality Council of Indiana  
602 West Paris Avenue  
West Terre Haute, IN 47885  
TEL: 800-660-4215  
FAX: 812-533-4216  
qci@qualitycouncil.com  
<http://www.qualitycouncil.com>**



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**III. PROCESS MANAGEMENT**  
**BUSINESS MEASURES/PERFORMANCE MEASURES**

**II.C.1**

## **Business Level Metrics**

**Business level metrics are typically financial (external) and operational (internal) summaries for shareholders and management.**

**Business (executive) level metrics comprise summaries of detailed operations and financial results reported monthly, quarterly, or annually.**



**III. PROCESS MANAGEMENT  
BUSINESS MEASURES/PERFORMANCE MEASURES**

**II.C.1**

## **Operations Level Metrics**

**Six sigma provides new metrics for managing complex operations. Business effectiveness measures track how well products are meeting customer needs (external focus). Breyfogle indicates that they should have a longer-term perspective and reflect the total variation that the customer sees.**

**Operational efficiency measures relate to the cost and time required to produce the products. They provide key linkages between detailed process measures and summary business results, and help identify important relationships and root causes.**



V. DEFINE  
VOICE OF THE CUSTOMER/IDENTIFICATION

IV.A.1

## **External Customer Segmentation (Cont'd)**

The consumer customer market differs from the business market as follows:

- The consumer market has a large number of customers
- The majority of consumer purchases are small in actual dollar amounts
- The transaction is usually a simple purchase
- Most consumers are not very knowledgeable about the product
- The supplier does not share proprietary information with the consumer



**V. DEFINE  
VOICE OF THE CUSTOMER/IDENTIFICATION**

**IV.A.1**

## **External Customer Segmentation (Cont'd)**

**In contrast, the business customer acts in the following manner:**

- **There are a very small number of business customers**
- **The amount purchased per transaction is quite large**
- **The purchase is handled through specialized personnel**
- **The customer may know more about the requirements than the producer**
- **The supplier may allow the customer access to all sorts of information**

**It is also important to look at the market for the next two to five years and estimate how it will change and grow.**



V. DEFINE  
VOICE OF THE CUSTOMER/IDENTIFICATION

IV.A.1

## **Customer Service**

**The customer driven company is beginning to emerge in America. The public demands and expects better quality products and service. One sample program follows:**

- **Listen to the customer and determine needs**
- **Define a service strategy**
- **Set standards of performance**
- **Select and train the right employees**
- **Recognize and reward accomplishment**

**There is the need to listen to the customer, provide a vision, provide training, improve the process, find or develop response metrics, and measure the results. About 70% of customers who leave a company do so because of service quality.**



V. DEFINE  
VOICE OF THE CUSTOMER/IDENTIFICATION

IV.A.1

## **Customer Retention**

**Most organizations spend the bulk of their resources on attaining new customers and smaller amounts on retaining customers. High customer satisfaction numbers do not necessarily mean the company has good customer retention and good customer loyalty. It has been found that current customers are worth as much as five times more than new customers. The cost of retaining a current customer is only one-fourth the cost of acquiring a new customer.**

**Another study showed that companies will boost profits by about 100% by just retaining 5% more of their customers.**





V. DEFINE  
VOICE OF THE CUSTOMER/IDENTIFICATION

IV.A.1

## **Customer Retention (Continued)**

**Furlong lists some techniques for getting to know customers better:**

- **Don't use your own instincts as data**
- **See the world from the customer's side**
- **People high in the organization are out of touch**
- **Get customers to talk**
- **90% of unhappy customers won't complain**
- **Do research to retain customers**
- **Determine how satisfied customers are**
- **Conduct research on customer expectations**
- **Develop a customer profile**
- **Share the results of customer research studies**
- **Don't go overboard on the details and measurement**
- **Coordinate and use research efforts**
- **Understand that sometimes research does not help**



V. DEFINE  
VOICE OF THE CUSTOMER/IDENTIFICATION

IV.A.1

## **Customer Loyalty**

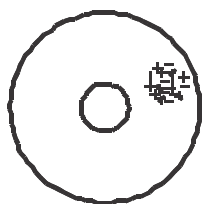
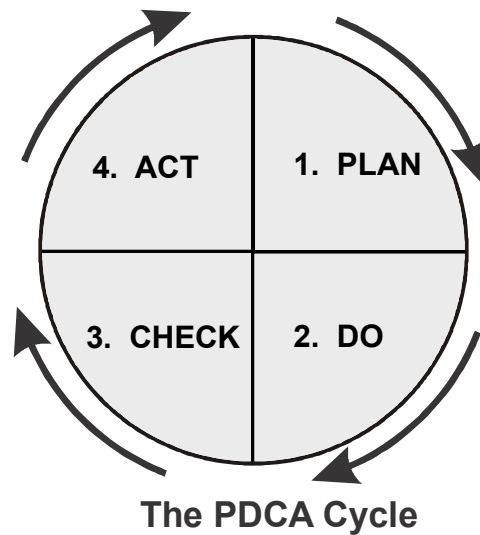
**The value of a loyal customer is not measured on the basis of one gigantic purchase, but rather on his/her lifetime worth. Loyal customers account for a high proportion of sales and profit growth. Customer retention generates repeat sales, and it is cheaper to retain customers. Customer loyalty is something that must be demonstrated through an act of execution, trust, or delightful service. Customers become partners.**



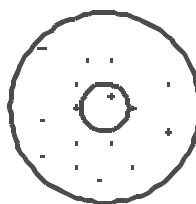
VI. MEASURE - DATA  
PROCESS CHARACTERISTICS/ANALYSIS TOOLS

V.A.2

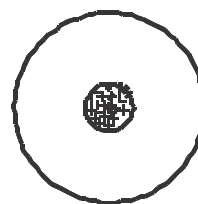
## Circle Diagrams (Continued)



Precise, but Biased



Unbiased, but not Precise



Unbiased and Precise

### Bias and Precision Distinction

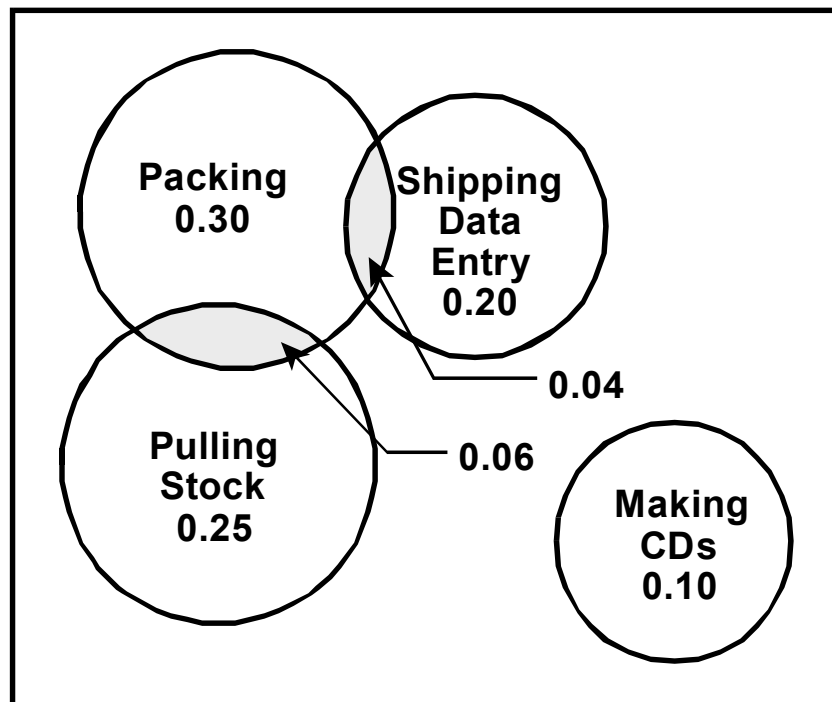


VI. MEASURE - DATA  
PROCESS CHARACTERISTICS/ANALYSIS TOOLS

V.A.2

## Circle Diagrams

On occasion, a circle diagram can help conceptualize the relationship between work elements in order to optimize work activities. Shown below is a hypothetical analysis of the work load for a shipping employee using a Venn (or circle) diagram.





VII. MEASURE - STATISTICS  
PROBABILITY/OTHER DISTRIBUTIONS

V.E.2

## Hypergeometric Distribution (Continued)

From a group of 20 products, 10 are selected at random for testing. What is the probability that the 10 selected contain the 5 best units?

$$N = 20, n = 10, d = 5, (N-d) = 15 \text{ and } r = 5$$

$$P(r) = \frac{C_5^5 C_5^{15}}{C_{10}^{20}} \left( \text{note that } C_r^n = \frac{n!}{r!(n-r)!} \right)$$

$$P(r) = \frac{\left( \frac{5!}{5!10!} \right) \left( \frac{15!}{5!10!} \right)}{\left( \frac{20!}{10!10!} \right)} = \left( \frac{15!}{5!10!} \right) \left( \frac{10!10!}{20!} \right) = 0.0163 = 1.63\%$$

The mean and the variance of the hypergeometric distribution are:

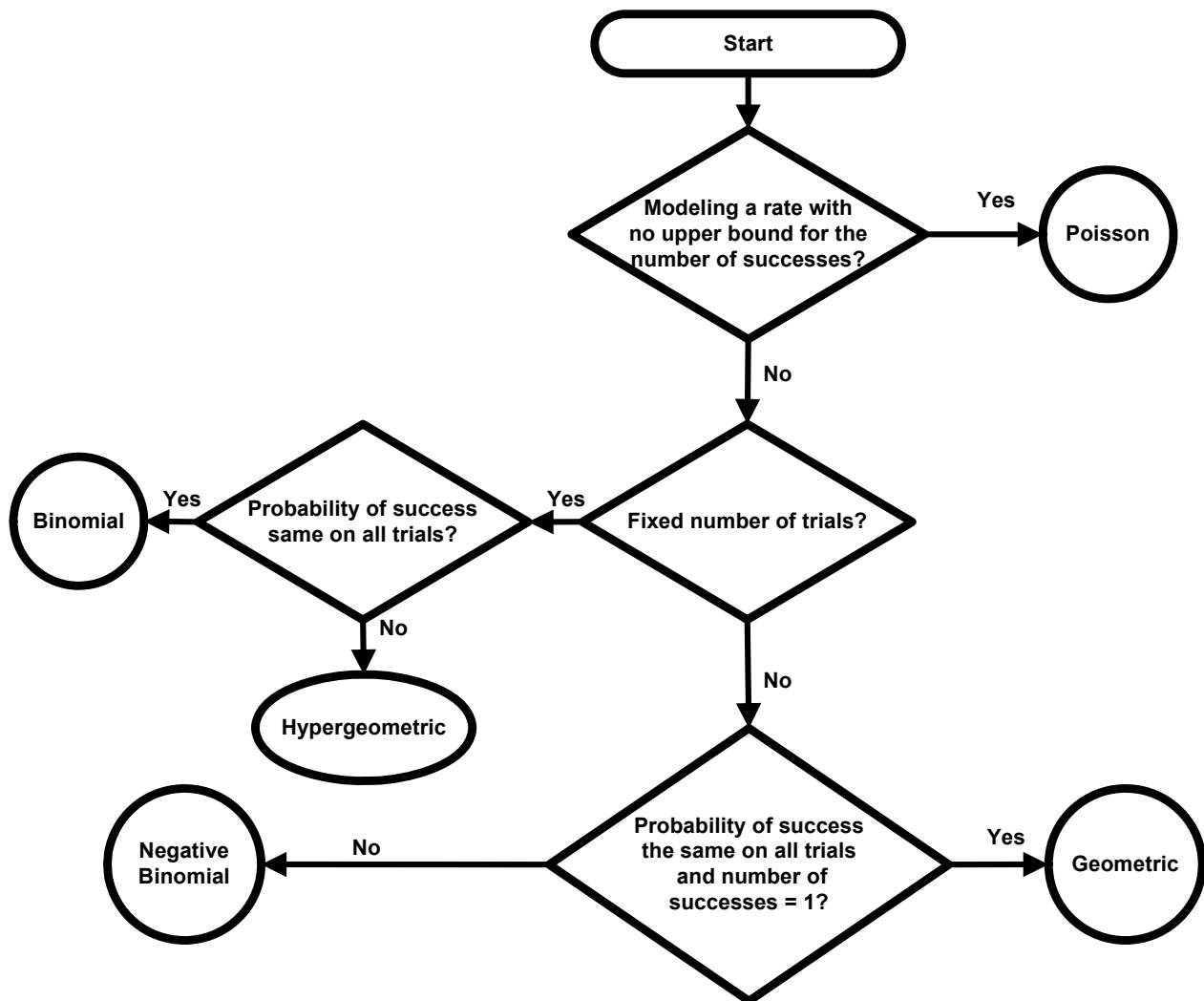
$$\mu = \frac{nm}{N} \quad \sigma = \left( \frac{nm}{N} \right) \left( 1 - \frac{m}{N} \right) \left( \frac{N-n}{N-1} \right)$$



VII. MEASURE - STATISTICS  
PROBABILITY/OTHER DISTRIBUTIONS

V.E.2

# Choosing A Discrete Distribution



VII. MEASURE - STATISTICS  
PROBABILITY/OTHER DISTRIBUTIONS

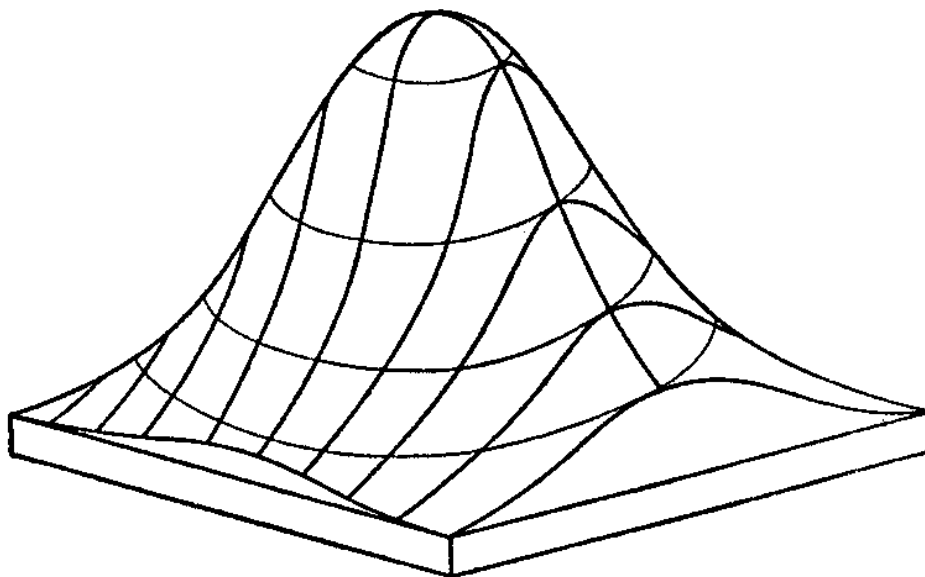
V.E.2

## Bivariate Normal Distribution

The joint distribution of two variables is called a bivariate distribution. Bivariate distributions may be discrete or continuous.

The graphical representation of a bivariate distribution is a three dimensional plot, with the x and y-axis representing the independent variables and the z-axis representing the frequency for discrete data or the probability for continuous data.

A special case of the bivariate distribution is the bivariate normal distribution shown below:





**VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES**

**V.F.3**

## **Identifying Characteristics**

**The identification of characteristics to be measured in a process capability study should meet the following requirements:**

- **The characteristic should be indicative of a key factor in the quality of the product or process**
- **It should be possible to adjust the value of the characteristic**
- **The operating conditions that affect the measured characteristic should be defined and controlled**

**Selecting one, or possibly two, key dimensions provides a manageable method of evaluating the process capability. The characteristic selected may also be determined by the history of the part and the parameter that has been the most difficult to control.**

**Customer purchase order requirements or industry standards may also determine the characteristics that are required to be measured.**





VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES

V.F.3

## Identifying Specifications/Tolerances

The process specifications or tolerances are determined either by customer requirements, industry standards, or the organization's engineering department.

## Developing Sampling Plans

The appropriate sampling plan for conducting process capability studies depends upon the purpose and whether there are customer or standards requirements for the study.

If the process is currently running and is in control, control chart data may be used to calculate the process capability indices. If the process fits a normal distribution and is in statistical control, then the standard deviation can be estimated from:

$$\sigma_R \approx \frac{\bar{R}}{d_2}$$

For new processes a pilot run may be used to estimate the process capability. A design of experiments can be used to determine the optimum values of the process variables which yield the lowest process variation.

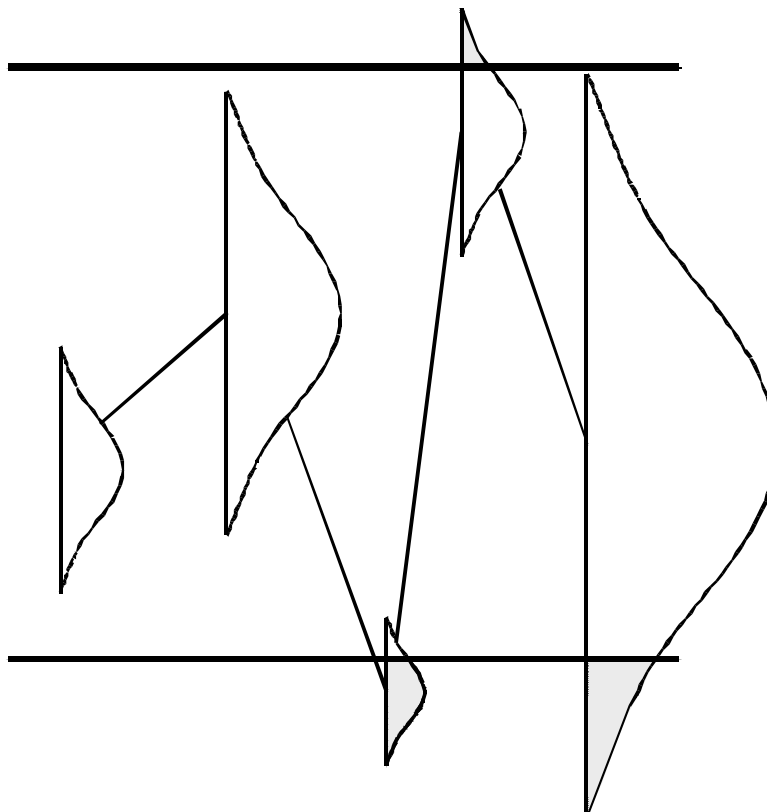
VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES

V.F.3

## Verifying Stability and Normality

If only common causes of variation are present in a process, then the output of the process forms a distribution that is stable over time and is predictable. If special causes of variation are present, the process output is not stable over time.

The Figure below depicts an unstable process with both process average and variation out-of-control. The process may also be unstable if either the process average or variation is out-of-control.





**VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES**

**V.F.3**

## **Verifying Stability and Normality (Cont'd)**

The validity of the normality assumption may be tested using the chi square hypothesis test. To perform this test, the data is partitioned into data ranges. The number of data points in each range is then compared with the number predicted from a normal distribution.

Continuous data may be tested using a variety of goodness-of-fit tests.

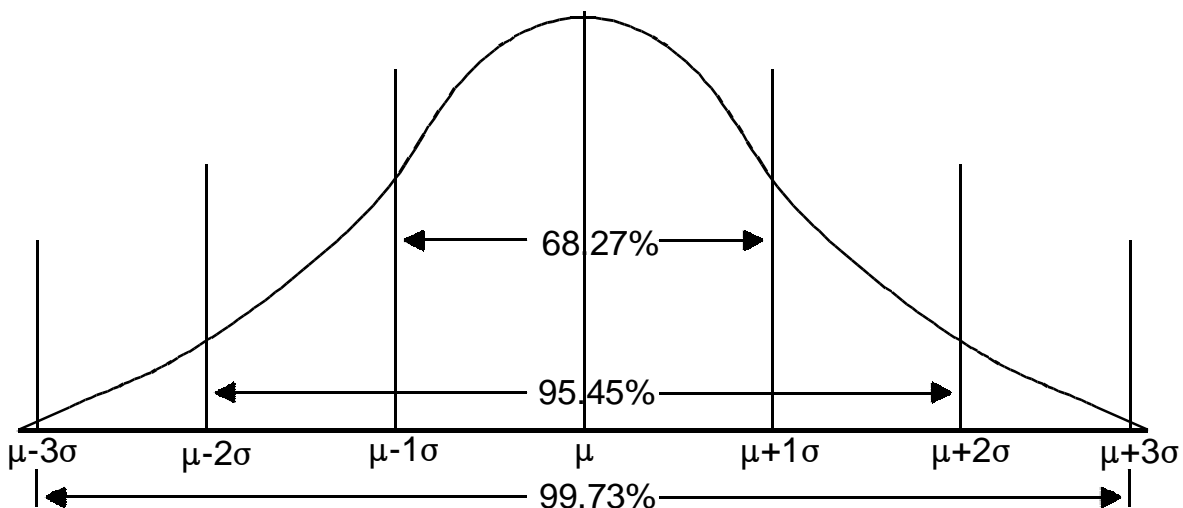


VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES

V.F.3

## The Normal Distribution

When all special causes of variation are eliminated, many variable data processes, when sampled and plotted, produce a bell-shaped distribution. If the base of the histogram is divided into six (6) equal lengths (three on each side of the average), the amount of data in each interval exhibits the following percentages:





VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES

V.F.3

## The Z Value

The area outside of specification for a normal curve can be determined by a Z value.

$$Z_{\text{LOWER}} = \frac{\bar{X} - \text{LSL}}{S}$$

$$Z_{\text{UPPER}} = \frac{\text{USL} - \bar{X}}{S}$$

The Z transformation formula is:

$$Z = \frac{X - \mu}{\sigma}$$

This transformation will convert the original values to the number of standard deviations away from the mean. The result allows one to use a single standard normal table to describe areas under the curve (probability of occurrence).

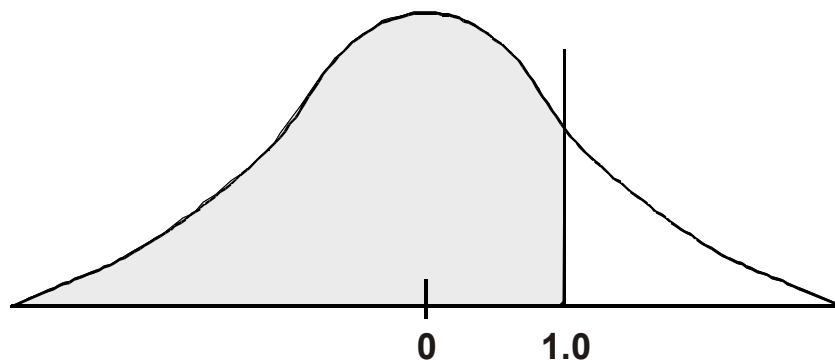
VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES

V.F.3

## Z Value (Continued)

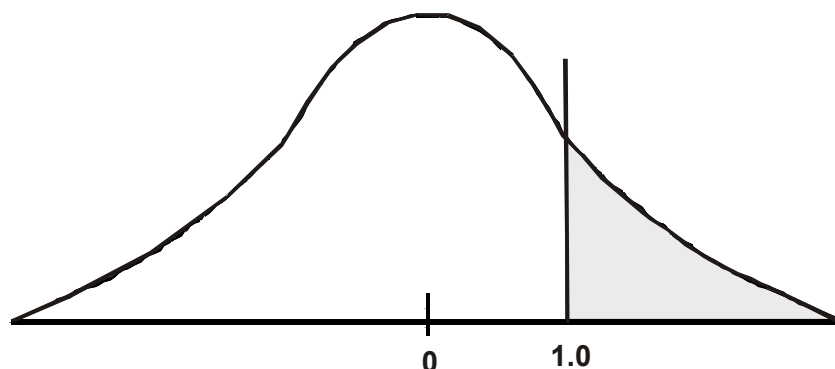
There are several ways to display the normal (standardized) distribution:

1. As a number under the curve, up to the Z value.



$$P(Z = -\infty \text{ to } 1) = 0.8413$$

2. As a number beyond the Z value.



$$P(Z = 1 \text{ to } +\infty) = 0.1587$$

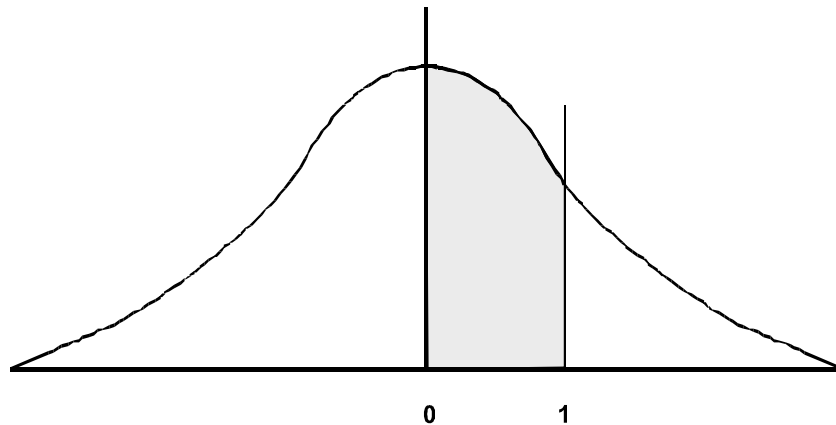


VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES

V.F.3

## Z Value (Continued)

3. As a number under the curve, and at a distance from the mean.



$$P(Z = 0 \text{ to } 1) = 0.3413$$

The standard normal table in this Primer uses the second method of calculating the probability of occurrence.

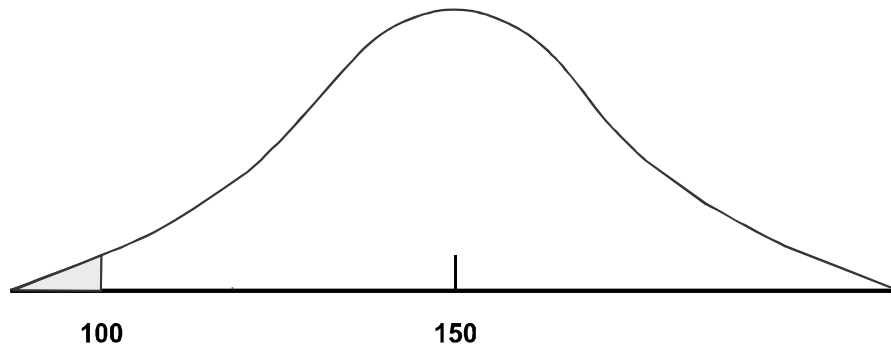


VII. MEASURE - STATISTICS  
PROCESS CAPABILITY/CAPABILITY STUDIES

V.F.3

## Z Value Example

Tenth grade students weights follow a normal distribution with a mean  $\mu = 150$  lb and a standard deviation of 20 lb. What is the probability of a student weighing less than 100 lb?



$$\mu = 150$$

$$x = 100$$

$$\sigma = 20$$

$$Z = \frac{X - \mu}{\sigma}$$

$$Z = \frac{100 - 150}{20} = -\frac{50}{20} = -2.5$$

Since the normal table has values about the mean, a Z value of - 2.5 can be treated as 2.5.

$P(Z = -\infty \text{ to } -2.5) = 0.0062$ . That is, 0.62% of the students will weigh less than 100 lb.





VII. MEASURE - STATISTICS  
PROCESS CAPABILITY / CAPABILITY INDICES

V.F.1

## Capability Index Failure Rates

There is a direct link between the calculated  $C_p$  (and  $P_p$  values) with the standard normal (Z value) table. A  $C_p$  of 1.0 is the loss suffered at a Z value of 3.0 (doubled, since the table is one sided). Refer to the Table below.

<b>Cp</b>	<b>Z value</b>	<b>ppm</b>
<b>0.33</b>	<b>1.00</b>	<b>317,311</b>
<b>0.67</b>	<b>2.00</b>	<b>45,500</b>
<b>1.00</b>	<b>3.00</b>	<b>2,700</b>
<b>1.10</b>	<b>3.30</b>	<b>967</b>
<b>1.20</b>	<b>3.60</b>	<b>318</b>
<b>1.30</b>	<b>3.90</b>	<b>96</b>
<b>1.33</b>	<b>4.00</b>	<b>63</b>
<b>1.40</b>	<b>4.20</b>	<b>27</b>
<b>1.50</b>	<b>4.50</b>	<b>6.8</b>
<b>1.60</b>	<b>4.80</b>	<b>1.6</b>
<b>1.67</b>	<b>5.00</b>	<b>0.57</b>
<b>1.80</b>	<b>5.40</b>	<b>0.067</b>
<b>2.00</b>	<b>6.00</b>	<b>0.002</b>



VII. MEASURE - STATISTICS  
PROCESS CAPABILITY / CAPABILITY INDICES

V.F.1

## Index Failure Rates (Continued)

In the prior Table, ppm equals parts per million of nonconformance (or failure) when the process:

- Is centered on  $\bar{X}$
- Has a two-tailed specification
- Is normally distributed
- Has no significant shifts in average or dispersion

When the  $C_p$ ,  $C_{pk}$ ,  $P_p$ , and  $P_{pk}$  values are 1.0 or less, Z values and the standard normal table can be used to determine failure rates. With the drive for increasingly dependable products, there is a need for failure rates in the  $C_p$  range of 1.5 to 2.0.



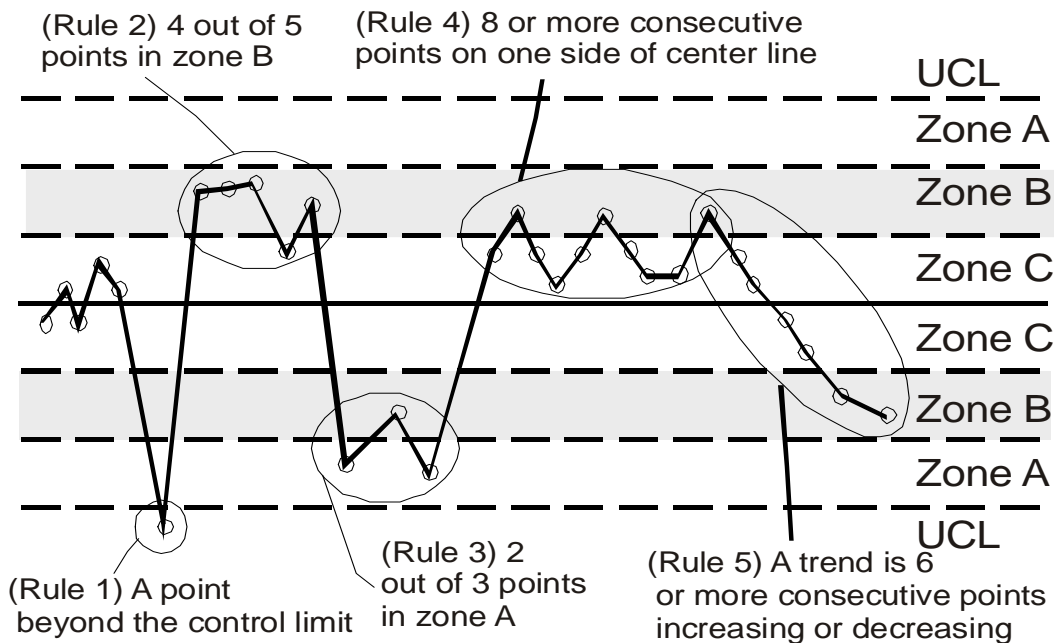


**X. CONTROL  
SPC/CONTROL CHART ANALYSIS**

**VIII.A.6**

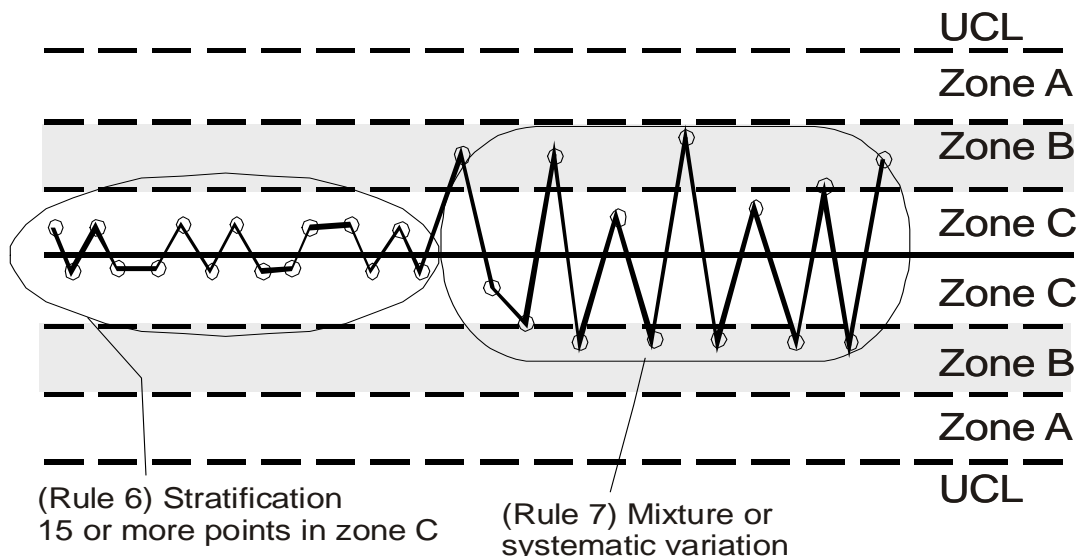
# Control Chart Interpretation

## Five Common Rules



Comment: Some authorities say 7 or more consecutive points for both Rules 4 and 5.

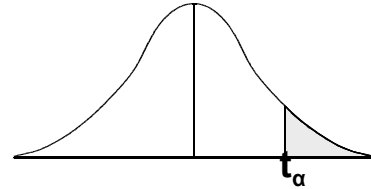
## Other Unusual Patterns





XII. APPENDIX

**Table V - t Distribution**



d.f.	t <sub>.100</sub>	t <sub>.050</sub> *	t <sub>.025</sub> **	t <sub>.010</sub>	t <sub>.005</sub>	d.f.
1	3.078	6.314	12.706	31.821	63.657	1
2	1.886	2.920	4.303	6.965	9.925	2
3	1.638	2.353	3.182	4.541	5.841	3
4	1.533	2.132	2.776	3.747	4.604	4
5	1.476	2.015	2.571	3.365	4.032	5
6	1.440	1.943	2.447	3.143	3.707	6
7	1.415	1.895	2.365	2.998	3.499	7
8	1.397	1.860	2.306	2.896	3.355	8
9	1.383	1.833	2.262	2.821	3.250	9
10	1.372	1.812	2.228	2.764	3.169	10
11	1.363	1.796	2.201	2.718	3.106	11
12	1.356	1.782	2.179	2.681	3.055	12
13	1.350	1.771	2.160	2.650	3.012	13
14	1.345	1.761	2.145	2.624	2.977	14
15	1.341	1.753	2.131	2.602	2.947	15
16	1.337	1.746	2.120	2.583	2.921	16
17	1.333	1.740	2.110	2.567	2.898	17
18	1.330	1.734	2.101	2.552	2.878	18
19	1.328	1.729	2.093	2.539	2.861	19
20	1.325	1.725	2.086	2.528	2.845	20
21	1.323	1.721	2.080	2.518	2.831	21
22	1.321	1.717	2.074	2.508	2.819	22
23	1.319	1.714	2.069	2.500	2.807	23
24	1.318	1.711	2.064	2.492	2.797	24
25	1.316	1.708	2.060	2.485	2.787	25
26	1.315	1.706	2.056	2.479	2.779	26
27	1.314	1.703	2.052	2.473	2.771	27
28	1.313	1.701	2.048	2.467	2.763	28
29	1.311	1.699	2.045	2.462	2.756	29
inf.	1.282	1.645	1.960	2.326	2.576	inf.

\* one tail 5%  $\alpha$  risk

\*\* two tail 5%  $\alpha$  risk



XII. APPENDIX

**Table IX - Control Chart Factors**

Sample Observations	CHART FOR AVERAGES		CHART FOR STANDARD DEVIATIONS			CHART FOR RANGES		
	Control limit Factors		Center Line Factors	Control Limit Factors		Center Line Factors	Control Limit Factors	
n	A <sub>2</sub>	A <sub>3</sub>	c <sub>4</sub>	B <sub>3</sub>	B <sub>4</sub>	d <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>
2	1.880	2.659	0.7979	0	3.267	1.128	0	3.267
3	1.023	1.954	0.8862	0	2.568	1.693	0	2.574
4	0.729	1.628	0.9213	0	2.266	2.059	0	2.282
5	0.577	1.427	0.9400	0	2.089	2.326	0	2.114
6	0.483	1.287	0.9515	0.030	1.970	2.534	0	2.004
7	0.419	1.182	0.9594	0.118	1.882	2.704	0.076	1.924
8	0.373	1.099	0.9650	0.185	1.815	2.847	0.136	1.864
9	0.337	1.032	0.9693	0.239	1.761	2.970	0.184	1.816
10	0.308	0.975	0.9727	0.284	1.716	3.078	0.223	1.777
15	0.223	0.789	0.9823	0.428	1.572	3.472	0.347	1.653
20	0.180	0.680	0.9869	0.510	1.490	3.735	0.415	1.585
25	0.153	0.606	0.9896	0.565	1.435	3.931	0.459	1.541

$\bar{X} - R$  Charts

$$CL_{\bar{x}} = \bar{\bar{x}} \pm A_2 \bar{R}$$

$$UCL_R = D_4 \bar{R}$$

$$LCL_R = D_3 \bar{R}$$

Approximate capability

$$\hat{\sigma} = \frac{\bar{R}}{d_2}$$

$\bar{X} - S$  Charts

$$CL_{\bar{x}} = \bar{\bar{x}} \pm A_3 \bar{S}$$

$$UCL_R = B_4 \bar{S}$$

$$LCL_R = B_3 \bar{S}$$

Approximate capability

$$\hat{\sigma} = \frac{\bar{S}}{c_4}$$