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# Statistical Process Control and Software System Development

Tutorial

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# Topics

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- Purpose
- SPC Fundamentals
- Choosing a Chart
- SPC uses
- Continuous Process Improvement
- CMMI perspective
- Conclusion

# Purpose

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- Gather statistical basics into one place
- Separate statistics theory from its use in process improvement
- State my opinions, up front.

# SPC Fundamentals

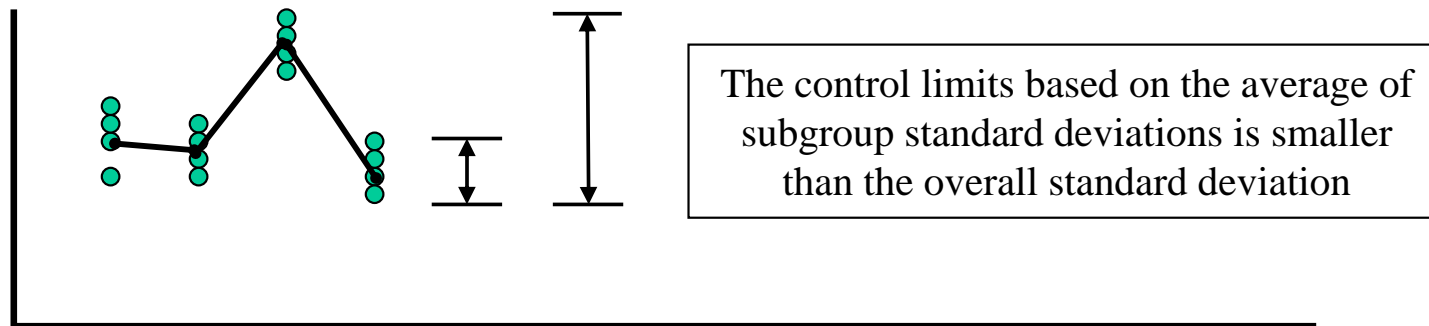
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- Invented by Walter Shewhart ~ 1925, while studying factors affecting the manufacture of telephones at the Bell System.
- His first book, “Economic Control of Quality of Manufactured Product” was published in 1931 His second book, “Statistical Method from the Viewpoint of Quality Control” was published in 1939.
- All process behavior charts are time ordered or ordered on attributes not related to the data values.
- Behavior charts are used to gain insight and understanding, not numbers.
- U chart – based on a Poisson distribution, requires estimating one parameter, process mean,  $\lambda$ . Standard deviation =  $\sqrt{\lambda}$ .
- XmR chart – based on a Normal distribution, requires estimating two parameters, process mean,  $\mu$  and standard deviation,  $\sigma$

# Average Sigma of Rational Subgroups

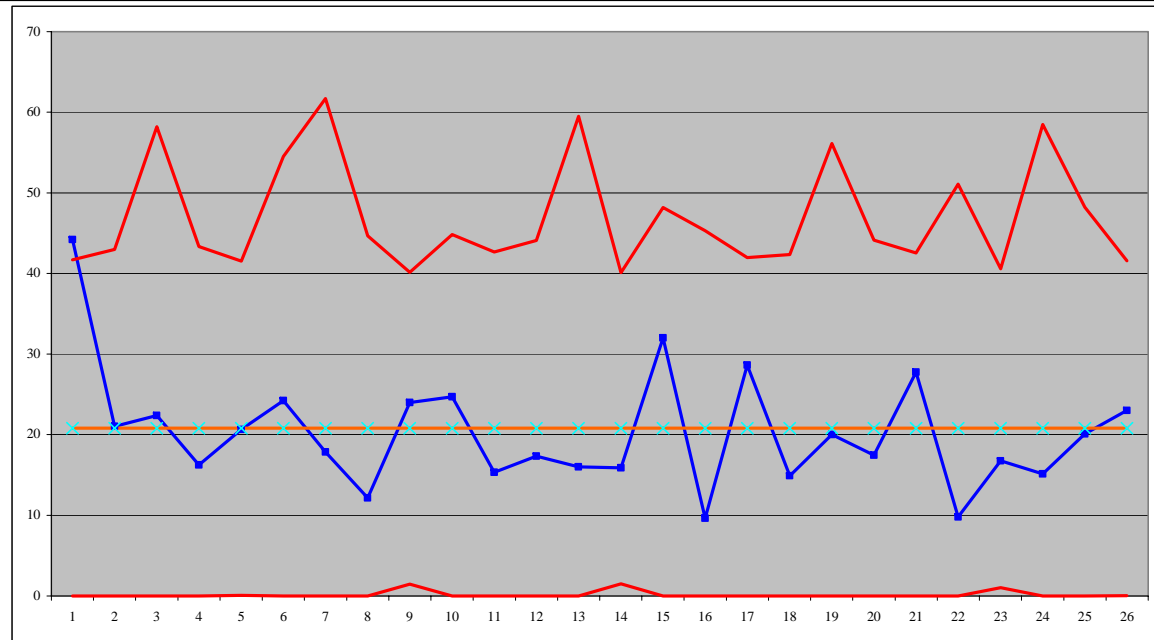
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- Data are sampled using rational subgroups, e.g., samples of 4 or 5 observations
- Each sample is assumed to be homogeneous.
- An average of the subgroup standard deviations is a better estimate of the process standard deviation than the overall “ensemble” standard deviation, if the process “shifts” in the middle.
- If the process produces homogeneous output at all times the two methods produce the same standard deviation.
- Shewhart asked the question, “What if the output of a process is not homogeneous?”



# U-Chart Definition

Module Number	Number of Defects	Module Size (KSLOC)	Defect per KSLOC
1	19	0.43	44.2
2	8	0.38	21.1
3	3	0.13	22.4
4	6	0.37	16.3
5	9	0.44	20.6
6	4	0.17	24.2
7	2	0.11	17.9
8	4	0.33	12.2
9	12	0.50	24.0
10	8	0.32	24.7
11	6	0.39	15.3
12	6	0.35	17.3
13	2	0.13	16.0
14	8	0.50	15.9
15	8	0.25	32.0
16	3	0.31	9.6
17	12	0.42	28.6
18	6	0.40	14.9
19	3	0.15	20.0
20	6	0.34	17.4
21	11	0.40	27.8
22	2	0.20	9.8
23	8	0.48	16.7
24	2	0.13	15.2
25	5	0.25	20.1
26	10	0.44	23.0
<b>Sum</b>	<b>173</b>	<b>8.32</b>	



$$U_I = \# \text{ defects }_I / \text{size }_I$$

$$\blacktriangleright \text{Ubar} = \text{sum all defects} / \text{sum all sizes} = 173/8.32 = 20.8$$

$$\blacktriangleright \sigma_I = \text{sqrt}(\text{Ubar}/\text{size}_I)$$

$$\blacktriangleright \text{Lcl}_I = \text{Ubar} - 3 * \sigma_I$$

$$\blacktriangleright \text{Ucl}_I = \text{Ubar} + 3 * \sigma_I$$

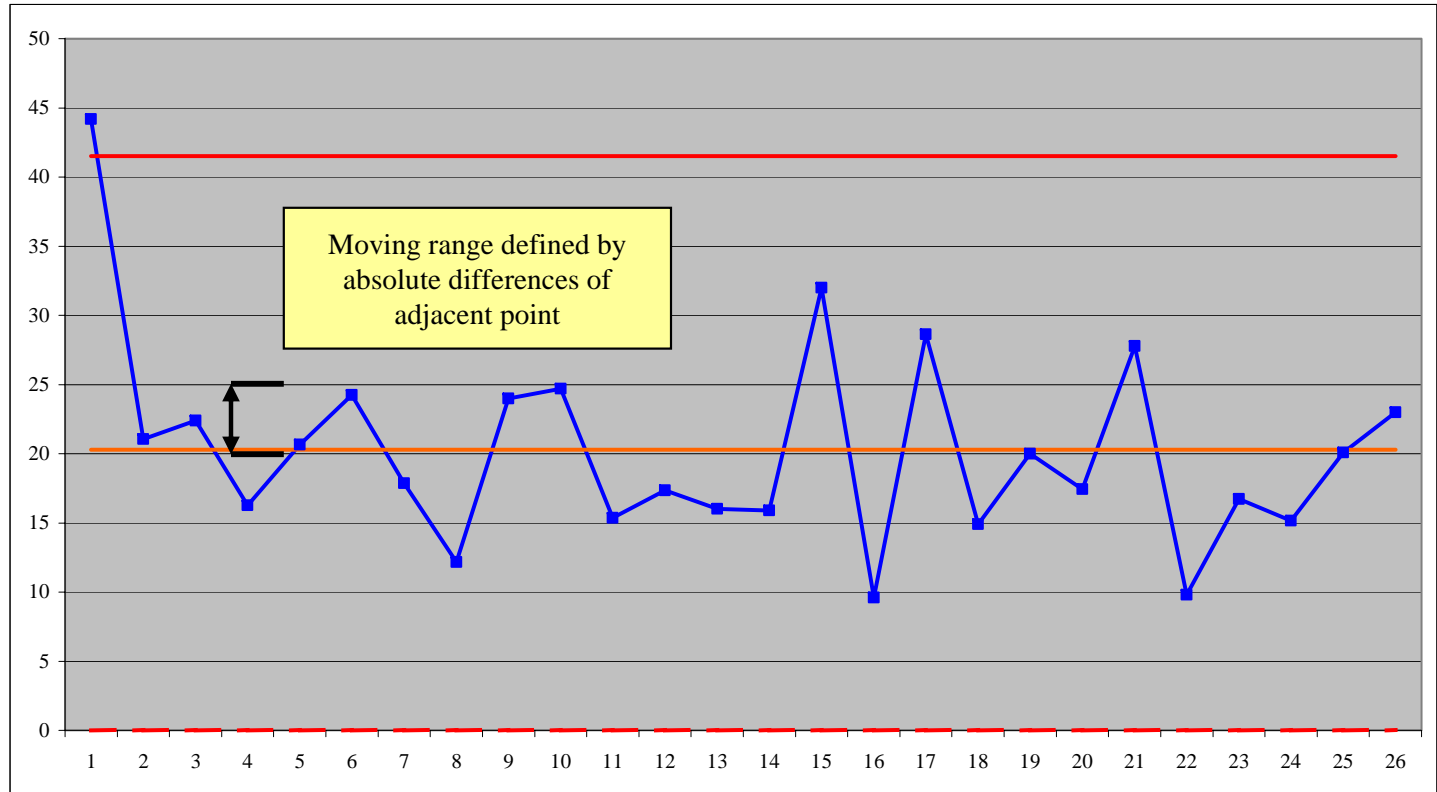
$$Z_I = (U_I - \text{Ubar}) / \sigma_I$$

Four equations  
define process  
center line and  
process limits.

Example from Practical Software Measurements,  
Florac, Park, Carleton, SEI/CMU-97-HB-003, Figure 5-22.

# XmR Chart Definition

Module Number	Defect per KSLOC	mR
1	44.2	
2	21.1	23.1
3	22.4	1.3
4	16.3	6.1
5	20.6	4.4
6	24.2	3.6
7	17.9	6.4
8	12.2	5.7
9	24.0	11.8
10	24.7	0.7
11	15.3	9.3
12	17.3	2.0
13	16.0	1.3
14	15.9	0.1
15	32.0	16.1
16	9.6	22.4
17	28.6	19.0
18	14.9	13.8
19	20.0	5.1
20	17.4	2.6
21	27.8	10.3
22	9.8	18.0
23	16.7	6.9
24	15.2	1.6
25	20.1	4.9
26	23.0	2.9



➤  $\bar{X} = \text{average}(X_I) = 20.3$

➤  $\sigma = \text{average}(mR_I) / 1.128$

➤  $LNL = \bar{X} - 3\sigma$

➤  $UNL = \bar{X} + 3\sigma$

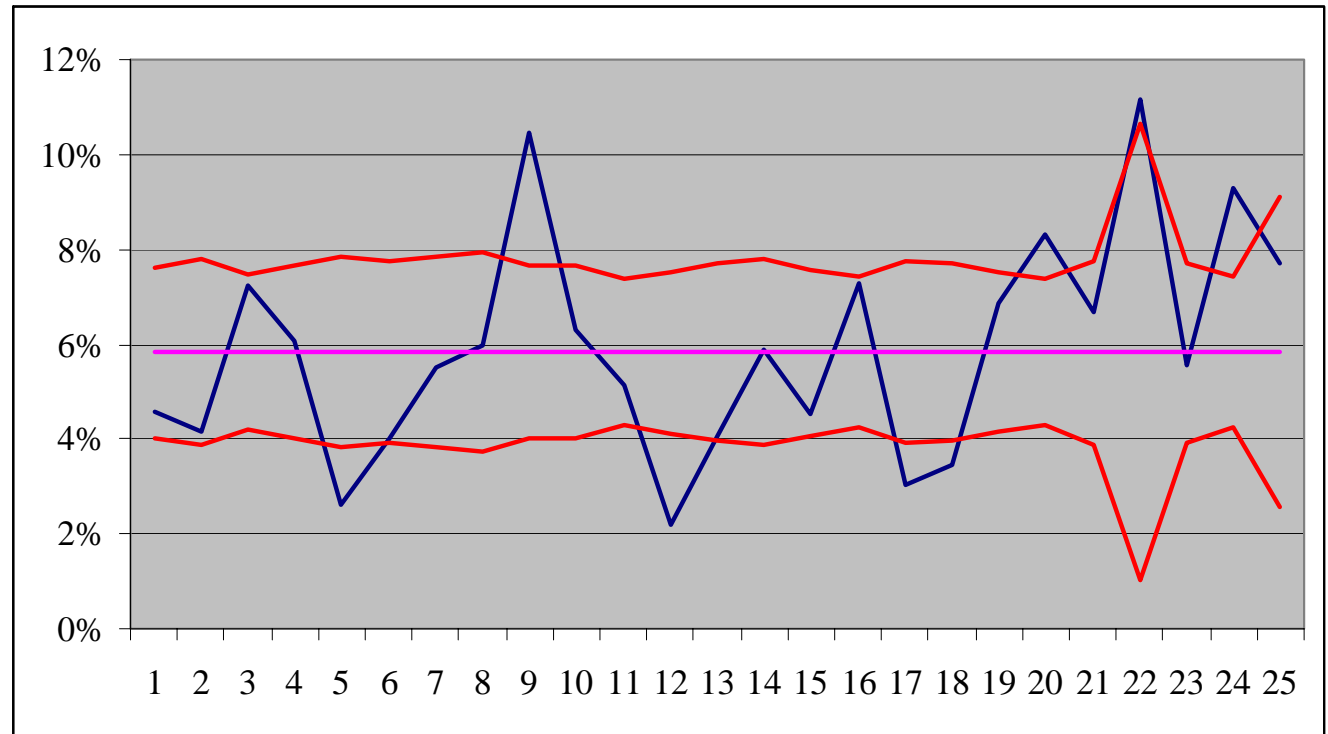
$Z_I = (X_I - \bar{X}) / \sigma$

Note:  $2.66 = 3/1.128$ , so  $UNL = \bar{X} + 2.66 * \text{average}(mR)$

Four equations define process center line and process limits.

# P-Chart Definition

Number in Sample	Number Defective	% Defective
1524	70	4.59%
1275	53	4.16%
1821	132	7.25%
1496	91	6.08%
1213	32	2.64%
1371	55	4.01%
1248	69	5.53%
1123	67	5.97%
1517	159	10.48%
1488	94	6.32%
2052	105	5.12%
1696	37	2.18%
1427	58	4.06%
1277	75	5.87%
1613	73	4.53%
1987	145	7.30%
1360	41	3.01%
1439	50	3.47%
1723	118	6.85%
2035	169	8.30%
1314	88	6.70%
215	24	11.16%
1384	77	5.56%
1995	185	9.27%
467	36	7.71%
<b>36060</b>	<b>2103</b>	



$$p_I = \# \text{ defects }_I / \text{Number in sample }_I$$

$$\text{pbar} = \text{sum all defects} / \text{sum all sizes} = 2103/36060 = .058$$

$$\sigma_I = \text{sqrt}(p*(1-p)/\text{size}_I)$$

$$Lcl_I = \text{pbar} - 3*\sigma_I$$

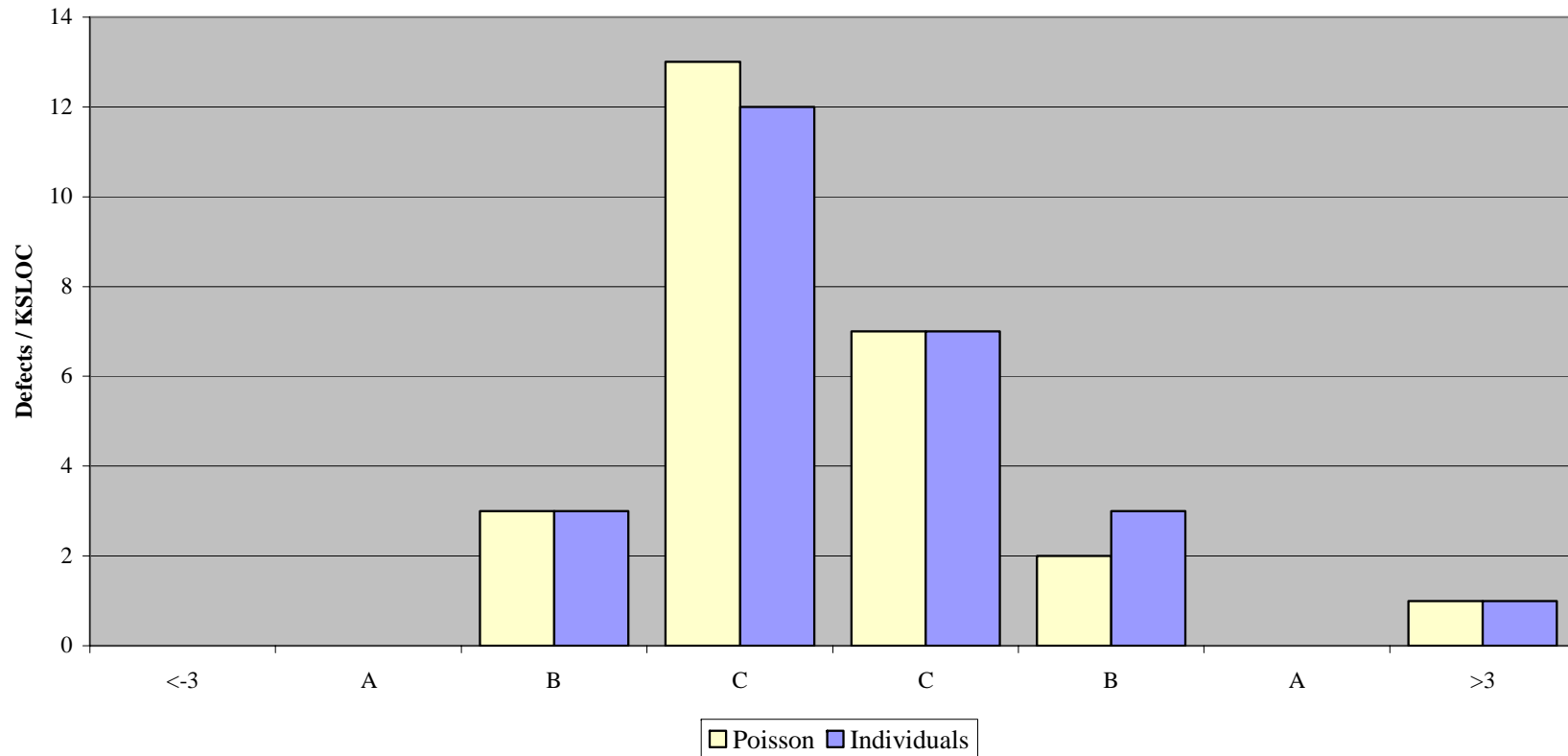
$$Ucl_I = \text{pbar} + 3*\sigma_I$$

$$Z_I = (p_I - \text{pbar}) / \sigma_I$$

Four equations  
define process  
center line and  
process limits.

# Choosing Between Poisson and XmR

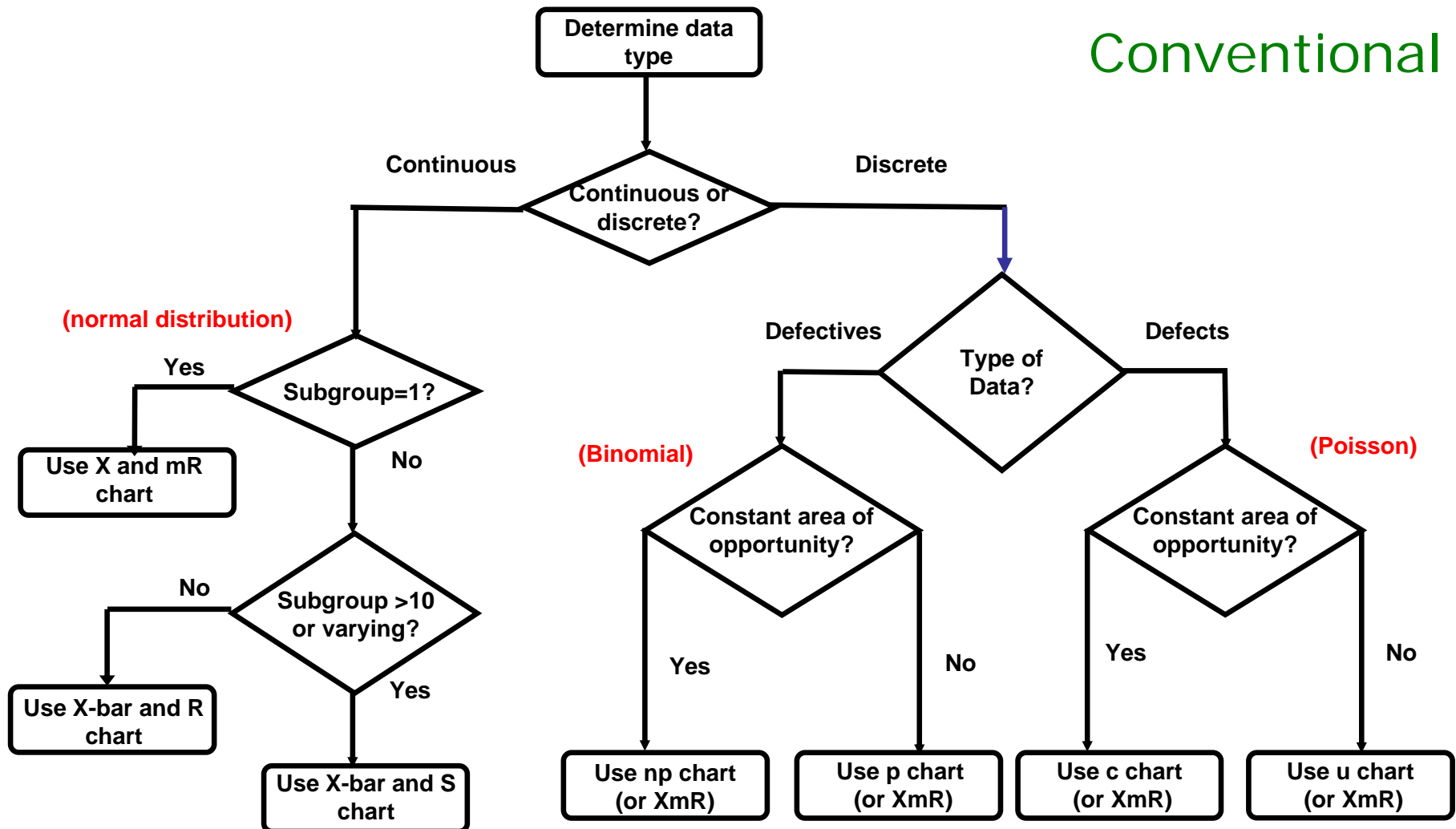
Distribution Histograms



- **Shape:** In this case, it doesn't matter; in other cases, the shape doesn't "look like" the expected Poisson or Normal distribution
- **S:** Calculate the standard deviation of the data (7.1), Approximately equal to the sqrt[of the mean] (4.56) -> Poisson, else Normal.

# Selecting a Process Behavior Chart (1 of 2)

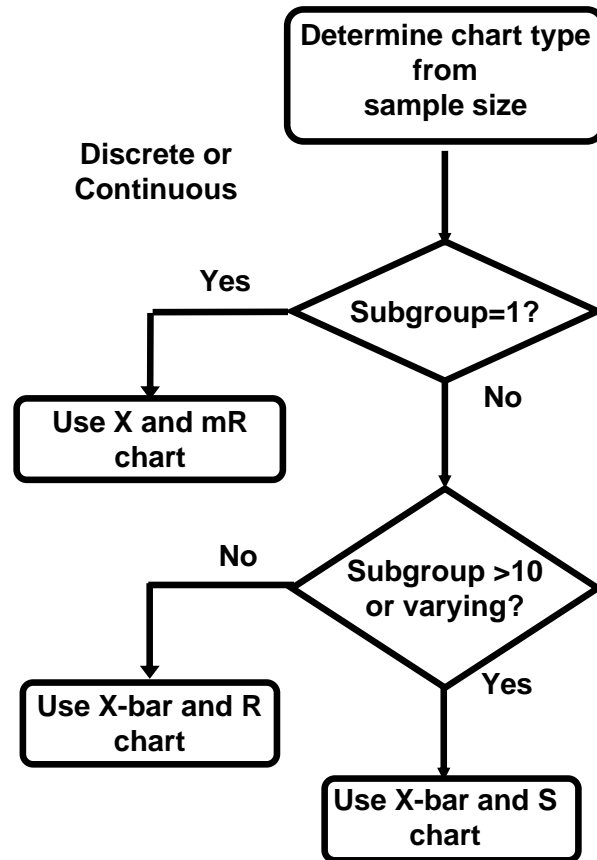
Conventional



# Selecting a Process Behavior Chart (2 of 2)

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Simplified



# Five Uses for Control Charts (1 of 2)

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Report Card	May be used for information about how things are going, not used in real time for operating or improving the processes and systems present.
Process Adjustment	Some product characteristics may be plotted on a control chart and used in a feedback loop for making process adjustments.
Process Trial	Analyze the data from simple experiments performed upon the process. This usage is often found in conjunction with the next category.
Extended Monitoring	Next slide
Continual Improvement	Next slide

Adapted from “Five Ways to Use Shewhart’s Charts” by Donald J. Wheeler, Ph.D.

# Five Uses for Control Charts (2 of 2)

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<p>Extended Monitoring</p>	<p>Use of multiple control charts to simultaneously track several related characteristics in order to discover just which charts provide the best predictors of process or product performance. It is one of the preliminary steps for both the effective utilization of control charts and the effective use of process experiments.</p>
<p>Continual Improvement</p>	<p>In many cases, progress to this last category comes only after extended monitoring and, possibly, process trials run. The control chart becomes a powerful tool for continual improvement only as those involved with the process learn how to use the chart to identify and remove assignable causes of uncontrolled variation. Every out-of-control point is an opportunity. But these opportunities can be utilized only by those who have prepared themselves in advance.</p>

# Comment on Uses

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- If you don't use the control charts to make remove anomalies or to stimulate process change, you are actually using the charts in report card mode **not** process improvement mode.
- Process Trial → Extended Monitoring → Continual Improvement is a normal progression.
- Explaining out of limit points is not sufficient, you must take action to prevent reoccurrence.
- Automatically generating charts once per reporting period can lead to wall charts (a form of report card use). This is particularly dangerous because well intentioned management may overvalue consistency and regularity.
- A measurement analyst must be an experimenter. “What if” examinations should be the norm not the exception. Comparing two types of charts, two histograms or first half of the data versus second half of the data are signs that insight is being sought.

# Three Interpretations of Continuous Process Improvement

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1. Constant churn, process discussions and no progress. Never happy with what exists.
2. Incorporate process changes at the initiation of a new contract, then “lock down” the process and perform
3. Always be on the “look out” for the need to modify something. Look for anomalies that need removing before considering a process change.

The third interpretation is a disciplined, systematic approach that does not churn or have the inflexibility of a lock down mindset.

# CMMI and Process Improvement

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Level 4 QPM	Remove measurement and process anomalies to stabilize processes. Ensure process is performed as specified and as expected to be performed. Use SPC in trial, extending monitoring and / or process improvement mode.
Level 5 OID	Change the process to move process center and/or variation. Stabilized processes and measurements are the basis for specifying new versions of processes.

# Conclusion

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- Shewhart decided that  $\pm 3$  sigma limits about the mean identified about the right number of problems to investigate while making economic sense. Eighty years later, we still concur.
- Sigma is determined as the average of rational subgroup standard deviations.
- Control charts are straightforward and simple to produce with Excel.
- Control charts are not process improvement and possibly not the most important consideration.
- Control charts are extremely valuable when they apply and they are used properly.

# References

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- Economic Control of Quality of Manufactured Product, Walter A. Shewhart, D. Van Nostrand Company Inc., 1931
- Statistical Method from the Viewpoint of Quality Control, Walter A. Shewhart, Dover Publications Inc., 1939.
- Understanding Variation: The Key to Managing Chaos, Donald J.Wheeler, SPC Press, 1993
- Understanding Statistical Process Control, Donald J.Wheeler and David S.Chambers, SPC Press, 1992
- Making Sense of Data: SPC for the Service Industry, Donald J.Wheeler, SPC Press, 2003
- Normality and the Process Behavior Chart, Donald J.Wheeler, SPC Press, 2000
- Statistical Quality Control Handbook, Western Electric, 1956
- Practical Software Measurement: Measuring for Process Management and Improvement, CMU/SEI-97-HB-003, 1997