Control Chart Rules and Interpretation

March 2016

Control charts are a valuable tool for monitoring process performance. However, you have to be able to interpret the control chart for it to be of any value to you. Is communication important in your life? Of course it is – both at work and at home. Here is the key to effectively using control charts – the control chart is the way the process communicates with you. Through the control chart, the process will let you know if everything is "under control" or if there is a problem present. Potential problems include large or small shifts, upward or downward trends, points alternating up or down over time and the presence of mixtures.

This month's publication examines 8 rules that you can use to help you interpret what your control chart is communicating to you. These rules help you identify when the variation on your control chart is no longer random, but forms a pattern that is described by one or more of these eight rules. These patterns give you insights into what may be causing the "special causes" – the problem in your process.

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You may download a pdf copy of this publication at **this link (https://www.spcforexcel.com/publications/control-chart-rules/index.html)**. You may also leave a comment at the end of the publication.

VARIATION REVIEW

We have covered variation in **11 publications (/spc-for-excel-publications-category#variation)** over the years. Here is an excerpt from one:

"I used to, now and then, spill a glass of milk when I was young. Our table slanted toward where my mother sat. So, the milk always headed in her direction. And she usually had some choice words when this happened. Of course, I was at fault. I needed to be more careful. Or was that really true? If you understand variation, you will realize that most of the problems you face are not due to individual people, but to the process -- the way it was designed and the way it is managed on a day-to-day basis.

Variation comes from two sources, common and special causes. Think about how long it takes you to get to work in the morning. Maybe it takes you 30 minutes on average. Some days it may take a little longer, some days a little shorter. But as long as you are within a certain range, you are not concerned. The range may be from 25 to 35 minutes. This variation represents common cause variation --- it is the variation that is always present in the process. And this type of variation is consistent and predictable. You don't know how long it will take to get to work tomorrow, but you know that it will be between 25 and 35 minutes as long as the process remains the same.

Now, suppose you have a flat tire when driving to work. How long will it take you to get to work? Definitely longer than the 25 to 35 minutes in your "normal" variation. Maybe it takes you an hour longer. This is a special cause of variation. Something is different. Something happened that was not supposed to happen. It is not part of the normal process. Special causes are not predictable and are sporadic in nature.

Why is it important to know the type of variation present in your process? Because the action you take to improve your process depends on the type of variation present. If special causes are present, you must find the cause of the problem and then eliminate it from ever coming back, if possible. This is usually the responsibility of the person closest to the process. If only common causes are present, you must FUNDAMENTALLY change the process. The key word is fundamentally -- a major change in the process is required to reduce common causes of variation. And management is responsible for changing the process.

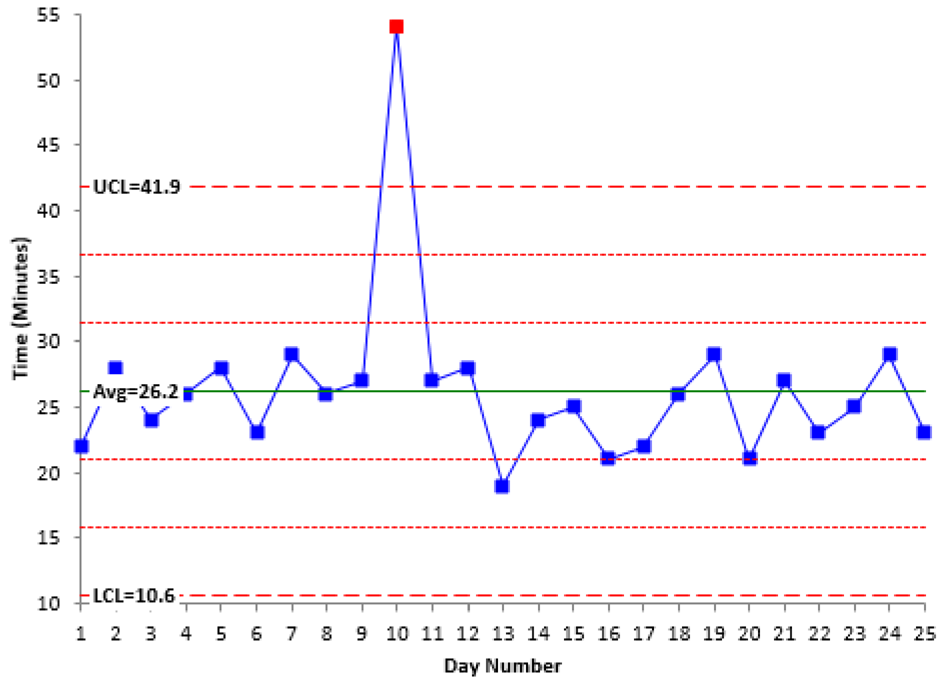
It has been estimated that 94% of the problems a company faces are due to common causes. Only 6% are due to special causes (that may or may not be people related). So, if you always blame problems on people, you will be wrong at least 85% of the time. It is the process most of the time that needs to be changed. Management must set up the system to allow the processes to be changed."

CONTROL CHART REVIEW

The only effective way to separate common causes from special causes of variation is through the use of control charts. A control chart monitors a process variable over time – e.g., the time to get to work. The average is calculated after you have sufficient data. The control limits are calculated – an upper control limit (UCL) and a lower control limit (LCL). The UCL is the largest value you would expect from a process with just common causes of variation present. The LCL is the smallest value you would expect with just common cause of variation present.   As long as the all the points are within the limits and there are no patterns, only common causes of variation are present. The process is said to be "in control."

Figure 1 is an example of a control chart using the driving to work example. Each day the time to get to work is measured. The data are then plotted on the control chart. The average is calculated. The average is 26.2 – which means it takes on average each day 26.2 minutes to get to work. The control limits are then calculated. The UCL is 41.9 minutes. This is the maximum time it will take to get to work when only common causes are present. The LCL is 10.6 minutes. This is the minimum time it will take to get to work when only common causes are present. As long as all the points are within the control limits and there are no patterns, then process is in statistical control.

Figure 1: Control Chart Example

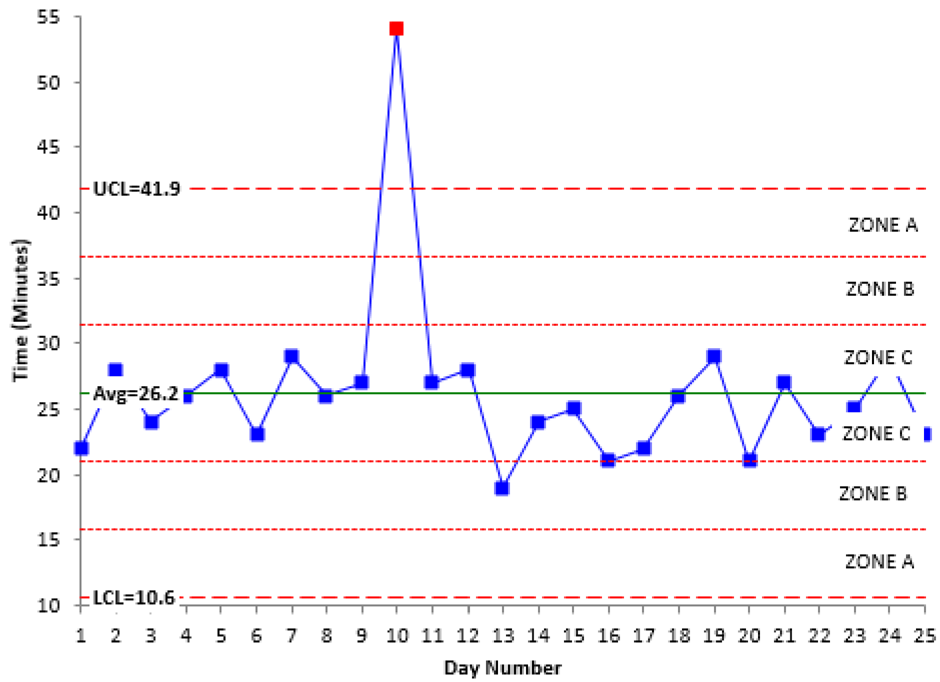


There is one point beyond the UCL in Figure 1. This is the first pattern that signifies an out of control point – a special cause of variation. One possible cause is the flat tire. There are many other possible causes as well – car break down, bad weather, etc.

Special causes of variation are detected on control charts by noticing certain types of patterns that appear on the control chart. The point beyond the control limits is one such pattern. You might see a pattern of 7 consecutive points above the average. This pattern indicates that something has happened to cause your process average go up – a special cause is present. Recognizing patterns – and what they mean in your process – is one key to finding the reason for special causes. All of the control chart rules are patterns that form on your control chart to indicate special causes of variation are present.

Some of these patterns depend on “zones” in a control chart. To see if these patterns exits, a control chart is divided into three equal zones above and below the average. This is shown in Figure 2.

Figure 2: Control Chart Divided into Zones



Zone C is the zone closest to the average. It represents the area from the average to one sigma above the average. There is a corresponding zone C below the average. Zone B is the zone from one sigma to two sigma above the average. Again, there is a corresponding Zone B below the average. Zone A is the zone from two sigma to three sigma above the average – as well as below the average.

THE 8 CONTROL CHART RULES

If a process is in statistical control, most of the points will be near the average, some will be closer to the control limits and no points will be beyond the control limits. The 8 control chart rules listed in Table 1 give you indications that there are special causes of variation present. Again, these represent patterns.

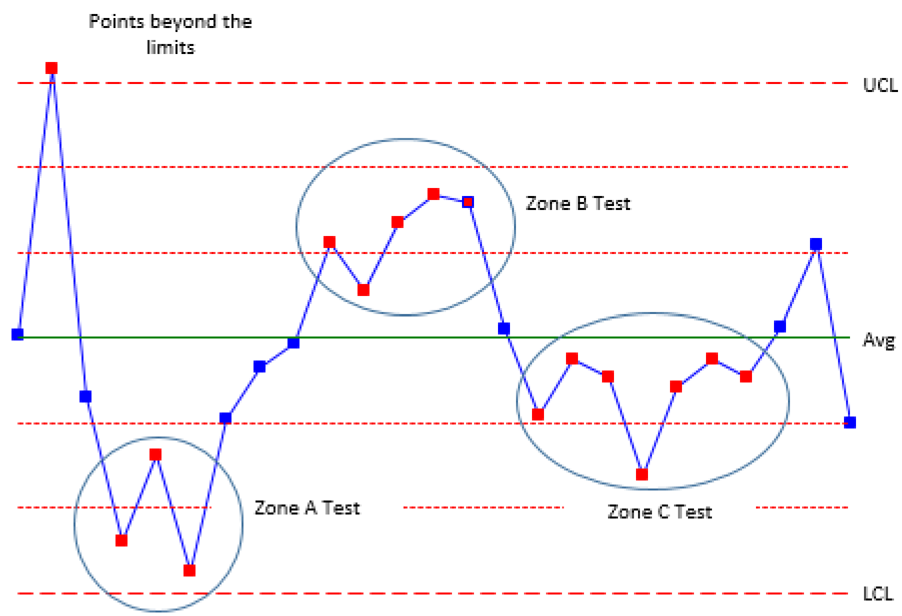
Table 1: Control Chart Rules

Rule	Rule Name	Pattern

1	Beyond Limits	One or more points beyond the control limits
2	Zone A	2 out of 3 consecutive points in Zone A or beyond
3	Zone B	4 out of 5 consecutive points in Zone B or beyond
4	Zone C	7 or more consecutive points on one side of the average (in Zone C or beyond)
5	Trend	7 consecutive points trending up or trending down
6	Mixture	8 consecutive points with no points in Zone C
7	Stratification	15 consecutive points in Zone C
8	Over-control	14 consecutive points alternating up and down

It should be noted that the numbers can be different depending upon the source. For example, some sources will use 8 consecutive points on one side of the average (Zone C test) instead of the 7 shown in the table above. But they are all very similar. Figures 3 through 5 illustrate the patterns. Figure 3 shows the patterns for Rules 1 to 4.

Figure 3: Zone Tests (Rules 1 to 4)



Rules 1 (points beyond the control limits) and 2 (zone A test) represent sudden, large shifts from the average. These are often fleeting – a one-time occurrence of a special cause – like the flat tire when driving to work.

Rules 3 (zone B) and 4 (Zone C) represent smaller shifts that are maintained over time. A change in raw material could cause these smaller shifts. The key is that the shifts are maintained over time – at least over a longer time frame than Rules 1 and 2.

Figure 4 shows Rules 5 and 6. Rule 5 (trending up or trending down) represents a process that is trending in one direction. For example, tool wearing could cause this type of trend. Rule 6 (mixture) occurs when you have more than one process present and are sampling each process by itself. Hence the mixture term. For example, you might be taking data from four different shifts. Shifts 1 and 2 operate at a different average than shifts 3 and 4. The control chart could have shifts 1 and 2 in zone B or beyond above the average and shifts 3 and 4 in zone B below the average – with nothing in zone C.

Figure 4: Rules 5 and 6

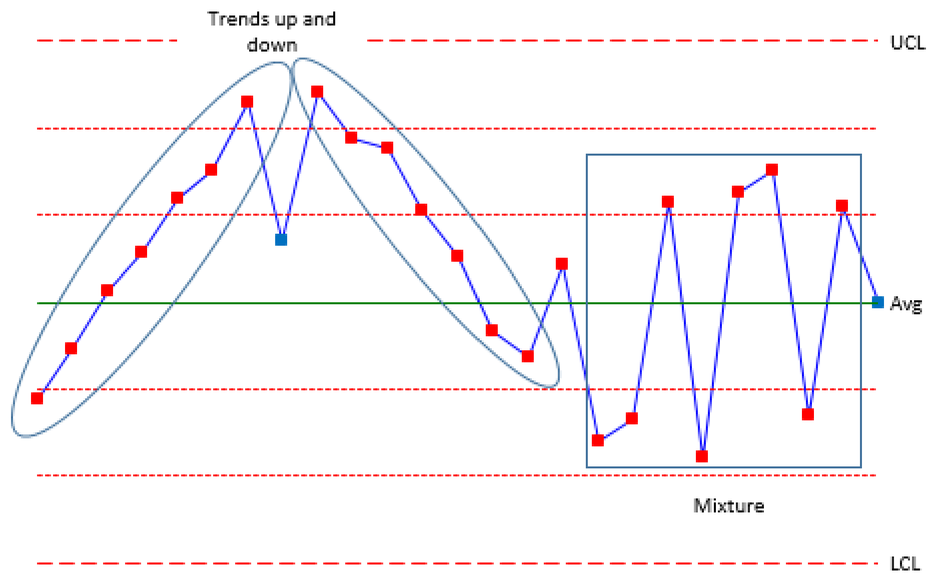
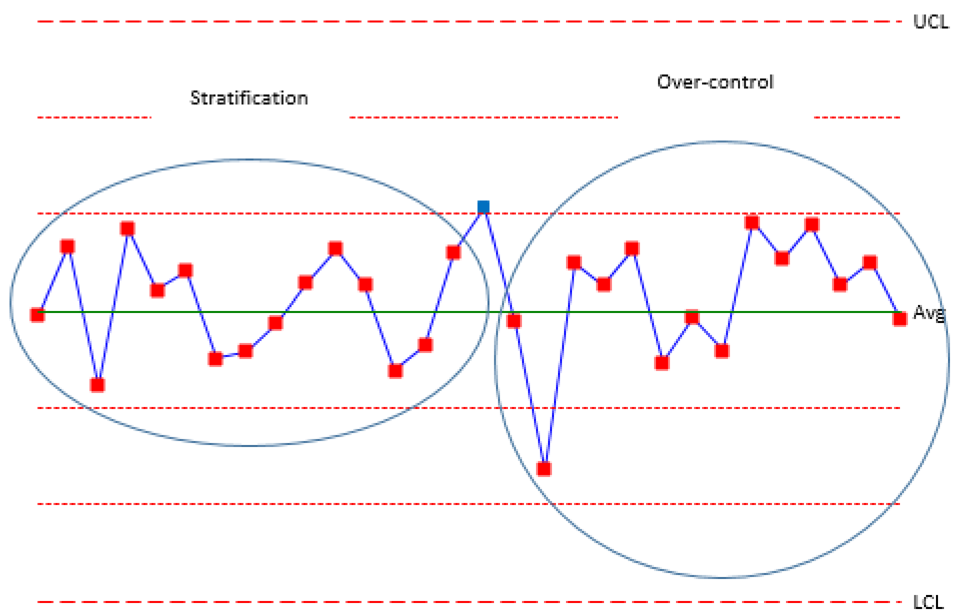


Figure 5 shows rules 7 and 8. Rule 7 (stratification) also occurs when you have multiple processes but you are including all the processes in a subgroup. This can lead to the data "hugging" the average – all the points in zone C with no points beyond zone C. Rule 8 (over-control) is often due to over adjustment. This is often called "tampering" with the process. Adjusting a process that is in statistical control actually increases the process variation. For example, an operator is trying to hit a certain value. If the result is above that value, the operator makes an adjustment to lower the value. If the result is below that value, the operator makes an adjust to raise the value. This results in a saw-tooth pattern.

Figure 5: Rules 7 and 8



Rules 6 and 7, in particular, often occur because of the way the data are subgrouped. Rational subgrouping is an important part of setting up an effective control chart. A **previous publication (/knowledge/rational-subgrouping/spc-and-rational-subgrouping)** demonstrates how mixture and stratification can occur based on the subgrouping selected.

These rules represent different situations – patterns = on a control chart. It should be noted that not all rules apply to all types of control charts. Table 2 summaries the rules by the type of pattern.

Table 2: Rules by Type of Pattern

Pattern Description	Rules
Large shifts from the average	1, 2
Small shifts from the average	3, 4
Trends	5
Mixtures	6

Stratifications	7
Over-control	8

POSSIBLE CAUSES BY PATTERN

It is difficult to list possible causes for each pattern because special causes (just like common causes) are very dependent on the type of process. Manufacturing processes have different issues that service processes. Different types of control chart look at different sources of variation. Still, it is helpful to show some possible causes by pattern description. Table 3 attempts to do this based on the type of pattern.

Table 3: Possible Causes by Pattern

Pattern Description	Rules	Possible Causes
Large shifts from the average	1, 2	New person doing the job Wrong setup Measurement error Process step skipped Process step not completed Power failure Equipment breakdown
Small shifts from the average	3, 4	Raw material change Change in work instruction Different measurement device/calibration Different shift Person gains greater skills in doing the job Change in maintenance program Change in setup procedure
Trends	5	Tooling wear Temperature effects (cooling, heating)
Mixtures	6	More than one process present (e.g. shifts, machines, raw material.)

Stratifications	7	More than one process present (e.g. shifts, machines, raw materials)
Over-control	8	Tampering by operator Alternating raw materials

Table 3 provides some guidance on what you should be thinking about as you try to find the reasons for special causes. For example, if Rule 1 or Rule 2 is violated, you should be asking "what in this process could cause a large shift from the average?". Or if Rule 6 occurs, you should be asking "what in this process could cause there to be more than one process present?" These type of questions can help guide brainstorming sessions to find the reasons for the special cause of variation. The type of pattern can guide your analysis of the out of control point.

SUMMARY

This publication took a look at the 8 control chart rules for identifying the presence of a special cause of variation. The rules describe certain patterns of variation that will give you insights on where to look for the special cause of variation. No one table can give you the reasons for out of control points in your process. You have to use your own knowledge (and that of those closest to the process) to discover the reason.

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Thanks so much for reading our publication. We hope you find it informative and useful. Happy charting and may the data always support your position.

Sincerely,

Dr. Bill McNeese
BPI Consulting, LLC

(https://www.linkedin.com/in/billmcneese)

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Jason S. Kong **reply (/comment/reply/444/6269)**

Hi! Your page has been significantly helpful. Can you tell me how these rules would apply for an individuals-moving range chart? Can these zones still be created? Thanks in advance!

Oct 12, 2016

Bill McNeese **reply (/comment/reply/444/6270)**

The zones test can be applied to the individuals chart; not the moving range chart. I probably need to do an article of what rules apply to which charts. But all apply the individuals chart. On the moving range, points beyond the limits, a run below or above the average (twice as long as individuals chart since each data point is reused in the moving range, overcontrol, an seven trending up or down.

Oct 12, 2016

SPC_Mark

reply (/comment/reply/444/6319)

Hi Bill - useful stuff. However, I'm struggling to understand which Control Chart rules I should apply. For example, do I use Westgard, Nelson, WECO etc. - none of which seem to be the rules you've listed above. Are you able to shed any light on which rules to use on an individuals chart? Thanks.

Jan 04, 2017

Bill McNeese

reply (/comment/reply/444/6320)

Of course, points beyond the control limits always apply. With the X chart for individuals, you apply all the rules listed in the article. However, with the moving range chart, you only use points beyond the control limts, and long runs above or below the average range or trending up or down. This is because you are reusing the data. I will do the next publication on which tests apply to which charts. Software, like SPC for Excel, will automatically select the appropraite tests for the control chart although you can change those options.

Jan 04, 2017

SPC_Mark

reply (/comment/reply/444/6322)

Sorry...I suppose what I was really trying to say is that there are slight variations to the available sets of rules. As I'm only just entering the world of SPC charts, my understanding is that WECO is the original set of rules (pretty much a cornerstone for all rule sets) and since then, newer iterations such as Nelson and Westgard have been developed. Therefore, I'm confused on which set of rules I should use. In Rule 5 above, you state the need to observe at least 7 consecutive points whereas Nelson rules (rule 3) state the requirement to observe at least 6. Is there a "correct" choice, or does it come down to how long you wish to observe a trend for before determining it to be out of control? Thanks.

Jan 04, 2017

Bill McNeese

reply (/comment/reply/444/6324)

Yes, there are slight variations in the rules. Some have 7, others 6, others 8. There is not a correct choice as such. You are correct - it is how "sure" you want to be that there is signal. Suppose we were tossing a coin and you paid me a dollar each time it was heads and I paid you a dollar each times it was tails. If I got six heads in a row, you would start wondering about the coin. 7 times in a row you would wonder even more. By 8 times, I am sure you think the coin is not a true coin.

For example, consider a run above the average. What is the probablity of getting 6 points in a row above the average? It is 1.56% (simply .5^6). For 7 points, it is 0.78%. For 8 points it is 0.39%. It is really your choice. The probability of getting a point beyond the control limits for a true normal distribution (doesn't exist) is 0.27%. So, picking something around there for the other tests is a good way to approach this - so 7 or 8 points looks good to me.

Jan 04, 2017

John Pinds

reply (/comment/reply/444/6333)

Hi Bill,Thanks for your page. It is indeed very useful. Tell me, when is it possible for a control chart which is in control to be actually out of control? Regards, John

Jan 27, 2017

Bill McNeese

reply (/comment/reply/444/6334)

Thanks John. Not sure I fully understand your question. There is no way to assign a probability to a point being a special cause or not. A point beyond the control limits could just be common cause of variation. And just because a point is within the control limits does notmean there is a not a special cause of variation present. The rules simply give a way of reacting to certain conditions that most likely are out of control points.

Jan 27, 2017

Kris Miller

reply (/comment/reply/444/6377)

Your explanation in this article is really quite good, with one exception. Nowwhere in the article do you mention that the rules you are applying are intended only for use with *averages*; usually of n=2 to 5 individual points. This is vitally important. Grouped means (histograms) are always **normal** distributions, whereas grouped individuals are totally unpredictable. They can result in a wide variety of distributions, usually not normally distributed. The makes control charting of individuals very risky, because the distribution is not normal, most of the time. The Shewart control chart was derived soley for averages, because they are always normal distributions, therebye predictable.

May 22, 2017

Juliana Vianna

reply (/comment/reply/444/6402)

Hi! I work with pharmaceutical compressing process to create tablets, and I have some doubts about our chart crontol. From time to time we take some tablets samples and we analize some parameters like weight. The problem is: my samples have 30 tablets each, and I can't take the individual tablets in the exactly moment they leave the machine. So, how can I analize some events like shifts if I don't have the time precision of wich tablet? I'm from Brazil and we don't have here enought information about the topic. I really could use some help. =) Could you contact me? Kind Regrats!

Jul 26, 2017

hamza saad

reply (/comment/reply/444/6431)

thanks for great explain, would u help to Calculate the probability that an in-control process will yield the “Simplified” Runs Rule violation of having 2 consecutive points at 1.5sigma or beyond

Sep 09, 2017

Bill McNeese

reply (/comment/reply/444/6432)

If you have Excel, you can use the NORMSDIST(z) function (or NORM.S.DIST for Excel 2001 and later) to determine this. For example, the probability of getting a point below 1.5 sigma is NORMSDIST(-1.5) = 0.0668 or about 6.68%. The probability of geting two beyond 1.5 sigma on the same side of the average is 0.0668^2 or .0045.

Sep 10, 2017

Casey

reply (/comment/reply/444/6526)

thanks for this article it’s really helpful. I wonder is there a standard to define when a process is back in control? How many points ‘under control’ would we need to observe after a special cause event to think it was back in control. I am trying to develop a simple “in control? Yes/No” indicator to sit along side our SPC charts. I don’t want to be continually alerting that there was a single blip 8 months ago for example. Any advice? Thanks

Mar 24, 2018

Bill McNeese

reply (/comment/reply/444/6527)

It is back in control, in my opinion, if the next point is back within the control limits - if it is a fleeting special cause of variation that comes and goes. But suppose that out of control point stays around. You have a point above the upper control limit. The next point is back within the limits but it is above the upper control limit. If it stays about the average for a run and you can't find out why, then you have re-calculate the control limits or adjust the process to bring it back into control. This link has more details: **https://www.spcforexcel.com/knowledge/control-chart-basics/when-calculat... (https://www.spcforexcel.com/knowledge/control-chart-basics/when-calculate-lock-and-recalculate-control-limits)**

Mar 24, 2018

Nikita

reply (/comment/reply/444/6897)

Dear Bill, thank you for the nice and clear explanation. I have one question, Shewhart control chart can still be created if the data are not normal, right? What about these interpretations, they can only be used if the data are normal? or can some of them be applied in case of non normality of the available whole data for the analysis? Thank you.

Jul 06, 2018

Bill McNeese **reply (/comment/reply/444/6902)**

Thank you. The data does not have to be normally distributed to use a control chart. Most Xbar data is symmetrical assuming the subgroup size is large enough. The zones tests require some symmetry about the average, but basically, you should not worry about normality. You know your process and will know if a control chart is signalling a special case most likely.

Jul 06, 2018

jag **reply (/comment/reply/444/8898)**

the method of calculation and underlying statistical basis for establishing the UCL & LCL is not clear in your article. what are the calculations, and on what are they based?? thanks.

Mar 11, 2019

Bill McNeese **reply (/comment/reply/444/8899)**

Hello,

The calculations vary based on the type of control chart. Please see this link for the various variable control charts:

https://www.spcforexcel.com/spc-for-excel-publications-category#variable (https://www.spcforexcel.com/spc-for-excel-publications-category#variable)

This link explains in genearl were they come from:

https://www.spcforexcel.com/knowledge/control-chart-basics/control-limits (https://www.spcforexcel.com/knowledge/control-chart-basics/control-limits)

Mar 11, 2019

Mike Nguyen **reply (/comment/reply/444/8928)**

Hi Dr. Bill.Your info is really helpful. I just started to work on Control Chart that why have some basic question.We have a #4 trend for almost 2 years. I checked all the samples, Technician, collecting data process and machine are OK. I just keep an eye on it. I have questions:1. If we have to make comment on this trend like " In control " or " Out of Control". Can we say "Our Control chart is IN CONTROL, we need to keep an eye on it and react whenever we got outliner" ?2. If all condition is the same but the trend Is #4 for long time. Do we need to recalculate Control limit? What can I say to convince other ones to recalculate Control limit?Thx Dr. Mike Nguyen

Apr 11, 2019

Bill McNeese

reply (/comment/reply/444/8929)

If you have a long run above the average (or below), it means that something has changed to cause the average to move up or down. It is "out of contorl". If you can't find what happened - and it doesn't bascially change the product, then you can recalculate the control limits starting with the shift changed. And use those for the future.

Apr 12, 2019

John Dominic

reply (/comment/reply/444/9176)

Texts over the years have allowed e.g. 1 in 25 or 2 in ~50 points outside Control Limits w/o stating "out of control." In your experience with data or reference material texts have you encountered any rule re: % of points beyond limits. At times I will deal with >50 or 100 Control Chart points. Thanks...

Jun 27, 2019

Bill McNeese

reply (/comment/reply/444/9178)

A rough rule i have used over the years is that a process is pretty stable if less than 5% of thepoints are out of control. That is close to what you reference.

Jun 28, 2019

Scott A Wagner

reply (/comment/reply/444/9193)

Is there a hirearchy for these rules? In other words, how would they be ranked in order of statictical significance?

Jul 23, 2019

Bill McNeese

reply (/comment/reply/444/9194)

You can theortically put a statistical probability to each rule assuming a normal distribution - they are all about the same probability. In practical terms, start with the points beyond the control limits, then add the test for zone C later and then zone A and B after that. This approach seems to work well.

Jul 24, 2019

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