Process Capability

User Agreement and Copyright Information

Process Capability

- In this session, we will discuss:
  - The purpose of process capability analysis
  - Brief review of data types
    - Attribute Data
    - Variables Data
  - Measures of capability for attribute data
    - FPY, RTY, dpu, dpmo, sigma capability
  - Measures of capability for variables data
    - Sigma level, Cp, Cpk, dpm, sigma capability
  - Using SPC XL software for process capability analysis

- A list of supplemental material and additional practice/review questions for this session are provided at the end of this presentation
- You can download the pdf of this presentation, along with any supporting data files, on the site where you are accessing this course

Purpose of Process Capability Analysis

- Lean Six Sigma and Design for Six Sigma are both customer-focused
- It is critical we understand **who** is our customer, and **what** they require
- Requirements may come from
  - End (external) customers (in the form of specification limits)
    - Example: the length of a part must be between 10 +/- 1 cm
  - Internal customers (often internally generated goals from management, engineering, etc.)
    - Example: the cycle time for a machine changeover should not exceed 30 minutes
- Process capability analysis helps us answer the question: "How is the process or product performing, in terms of meeting the customer requirements?"

"If you cannot measure it, you cannot improve it."

Lord Kelvin
(1821 – 1907)

Specification Limits (Customer Requirements)

- Specification limits are numerical values or standards that are imposed by the customer

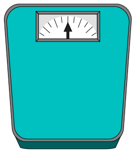
- There may be:
  - One Limit (an upper spec limit (USL) or a lower spec limit (LSL))
    - Example: The gap must be no greater than 0.25 inches
    - Example: The tensile strength for a fiber must be at least 200 psi
  - Two Limits (both a USL and LSL)

- Some specifications may be subjective or visual standards, such as "no noticeable blemishes"

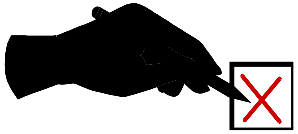
- Results falling outside of the specification limits, or not meeting the customer requirements, are referred to as "defective"

2 Basic Data Types: Brief Review

- **Variables** Data
  - Also called continuous or measurement data
  - Actual measured values are recorded
  - Data can assume a range of values on a continuous scale
  - Examples:
    - Dimension in thousandths of an inch
    - Distance in feet
    - Operating temperature in degrees Celsius



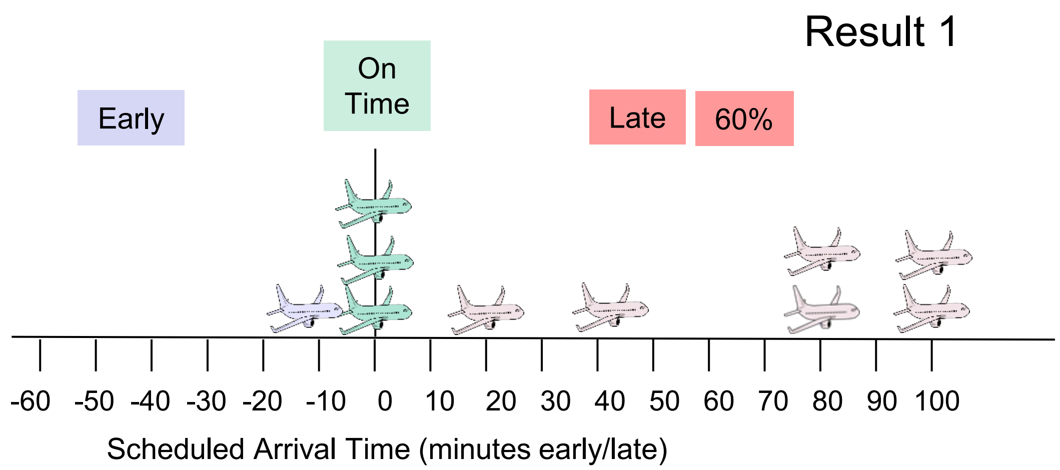
- **Attribute** Data
  - No direct measurement is made
  - The presence or absence of something is recorded (countable)
  - We may classify or count a feature or characteristic of the product or process
  - Examples:
    - Test results (pass/fail, good/bad)
    - Presence or absence of a data code stamp
    - Number of non-conforming articles
    - Invoice errors per week

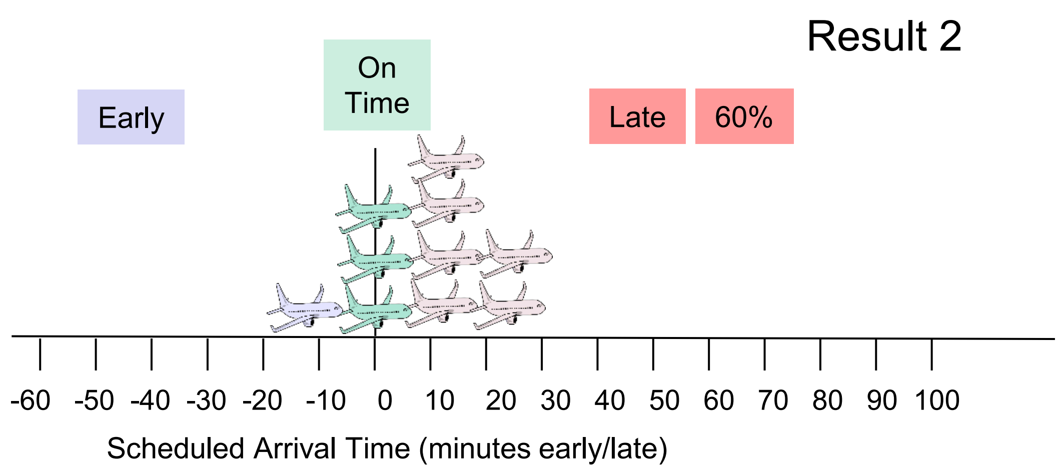


- We will look at measures of process capability for both types of data; but given a choice, which type of data might we prefer to have?

Variables vs. Attribute Data

- Consider a certain Thursday evening flight that you take regularly.
- Of most interest to you, the customer, is arriving on time (or early). Arriving late increases your chances of missing a connection, missing a ride, or simply adding to your frustration level!
- Using attribute data alone (late vs. not late), can you tell the difference in the results?
- Variables data contains more information!

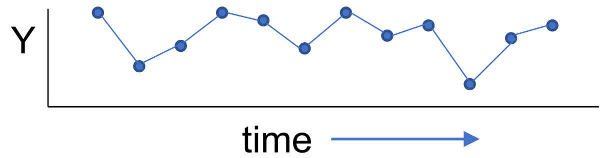




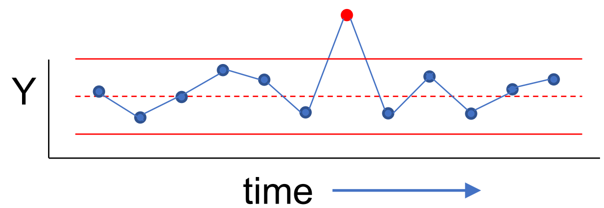
Reminder: "A Picture is Worth a Thousand Words"

- Although the focus of this session is on capability **measures**, process capability analysis should always include a graphical summary of the data

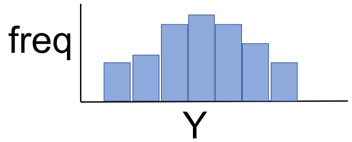
- Helpful charts include:
  - Run charts



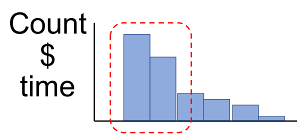
  - Control charts



  - Histograms



  - Pareto charts



For video instruction on generating graphical summaries (run charts, control charts, etc.), go to: https://airacad.com/our-insights/training-videos/spc-xl/

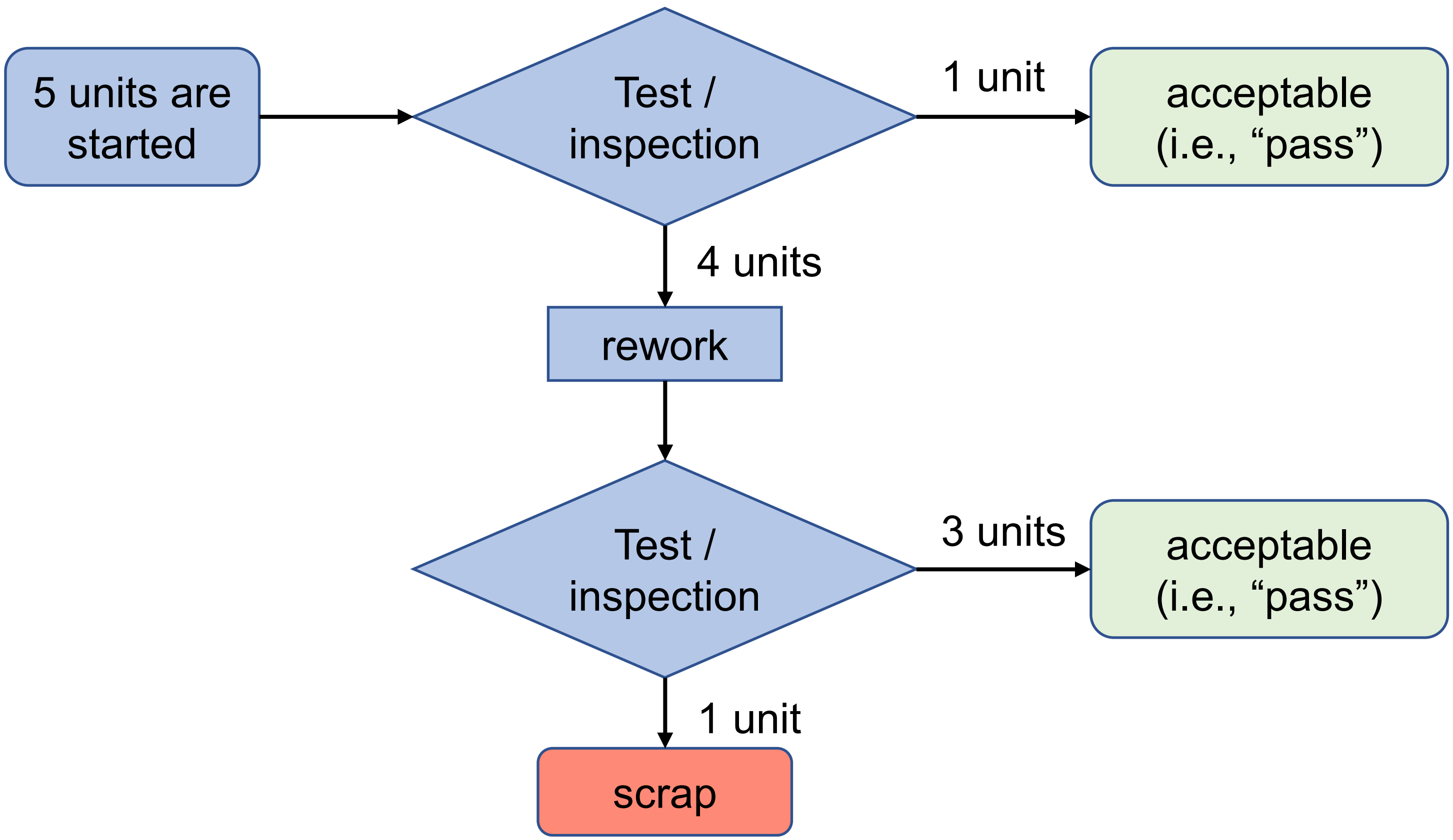
Process Capability Measures for Attribute Data

- First Pass Yield (FPY)
- Rolled Throughput Yield (RTY)
- Defects Per Unit (dpu)
- Defects Per Million Opportunities (dpmo)
- Sigma Capability

Measures of Quality (Attribute Data)

- The yield of process (or step) is a metric often used for assessing quality, however there are sometimes different definitions of yield

- What is the yield of the process below?

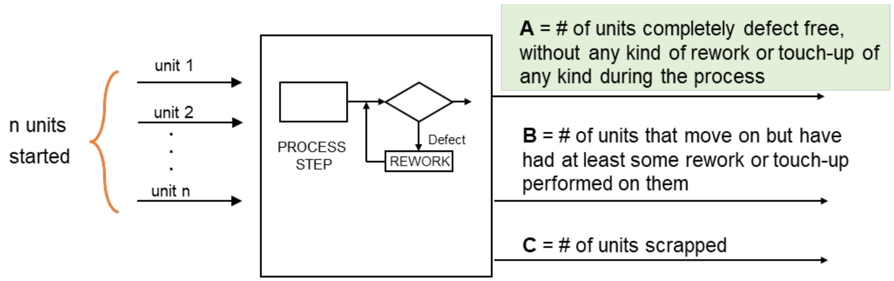


First Pass Yield (FPY) and Rolled Throughput Yield (RTY)

- Unit: any part, item, product, service or transaction for which a quality/performance measure is desired

First pass yield (FPY) =

$$\frac{\text{the number of units completely defect free (i.e., no rework or repair)}}{\text{the number of units started (n)}}$$

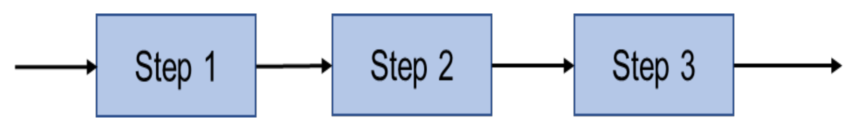


$$FPY = \frac{A}{n}$$

Rolled Throughput Yield (RTY) is the first pass yield of an <u>entire</u> process, from start to finish, across multiple process steps

- It is the proportion of units completing an entire process, or sequence of steps, without ever having to be reworked or repaired

$$RTY = (FPY_{step\ 1}) \times (FPY_{step\ 2}) \times \cdots \times (FPY_{step\ n})$$



FPY = 90% FPY = 99% FPY = 90%

RTY = 80.19%
(0.90 x 0.99 x 0.90)

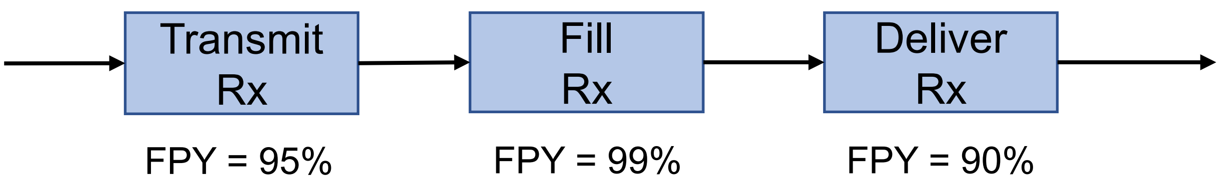
Data file: sigma capability calculator and capability measures.xlsx
(FPY RTY tab)

First Pass Yield (FPY) and Rolled Throughput Yield (RTY) (Practice)

In a prescription delivery process, there are 3 main steps (transmit, fill, and deliver)

1. When studying the transmittal process over the past month, a total of 12,000 prescriptions were transmitted. 600 of those prescriptions contained errors that were eventually resolved and 11,400 of those were transmitted successfully with no errors or rework needed. What is the first pass yield (FPY) of the transmittal process?

2. Suppose that the first pass yield for each step was gathered as shown below.



What is the overall rolled throughput yield (RTY) of the prescription delivery process?

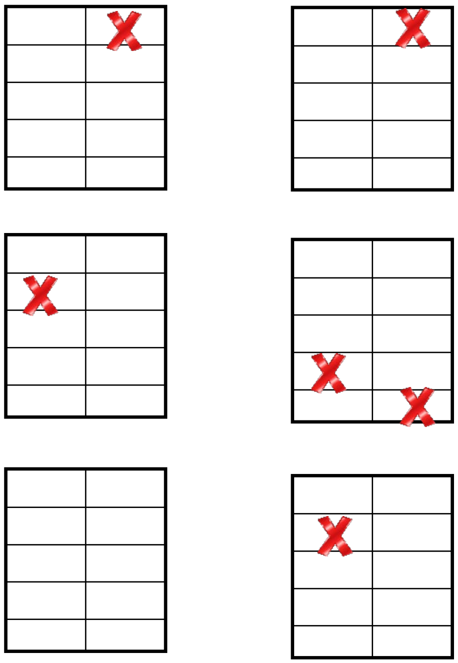
Defects Per Unit (DPU)

- When units can have multiple defects which are recorded, DPU is another measure we can use to measure quality

$$\text{Defects per unit (DPU)} = \frac{\text{Total \# of defects observed from start to finish over all units started}}{\text{the number of units started (n)}}$$

- Example: A document has 10 critical fields of information. Each error is flagged. 6 documents were reviewed for accuracy and a total of 10 defects were observed. (here, a document is the “unit” of work)

DPU = 6 / 6 = 1

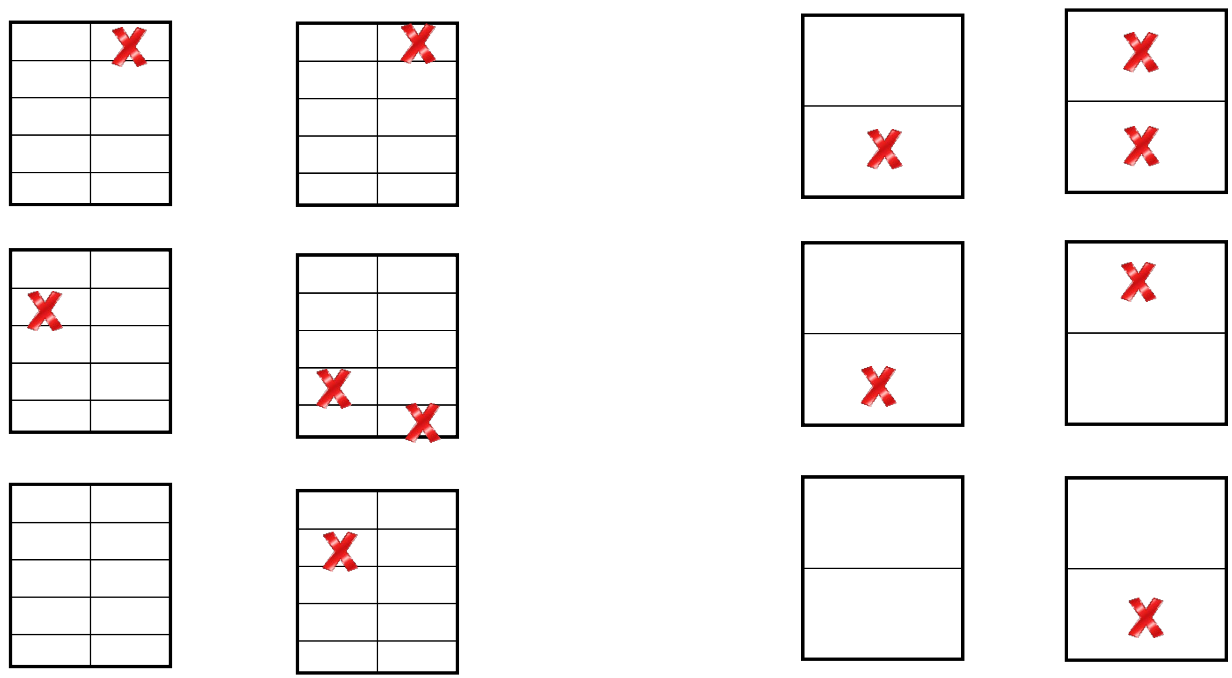


- Since defect cost time and money (reviewing, reworking, etc.), the focus should be on tracking the DPU and working to reduce it!

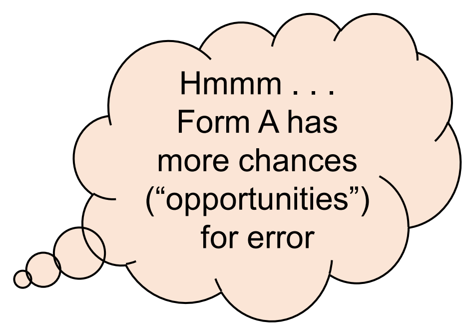
Comparing Two Different Processes (Documents)

- Suppose there are two different types of documents a company produces
- Document A has 10 critical fields of information, while document B is less complex with only 2 critical fields of information

Document Type A Document Type B



DPU = 6 / 6 = <u>1</u> **DPU = 6 / 6 = <u>1</u>**



- Since the DPUs are the same, does this mean the forms have equivalent quality?

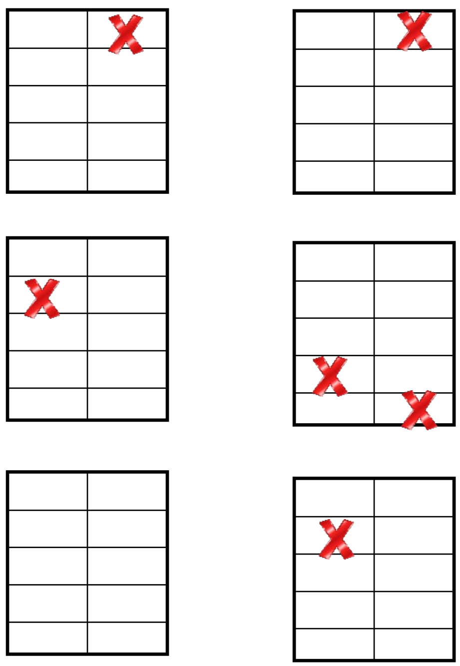
For Comparing DPUs with Different Complexity

- For quality improvement, DPU is the best overall measure to focus on
  - Defects cause us time and money (analyzing, correcting, etc.)
- For the purpose of comparing or benchmarking, DPUs are scaled to account for complexity using “opportunities”
- A DPU for a bicycle vs. a car, or a document vs. a jet engine, could not be fairly compared
- Opportunities are used to level the playing field, so to speak, so that DPUs can be more fairly compared
- Opportunities are the number of value-added entities or features of a part, product or service that must be met or done right (opportunities are “potential” chances for not meeting a customer requirement). Opportunities are a measure of complexity and must be defined precisely (avoid “inflating” the opportunity count)

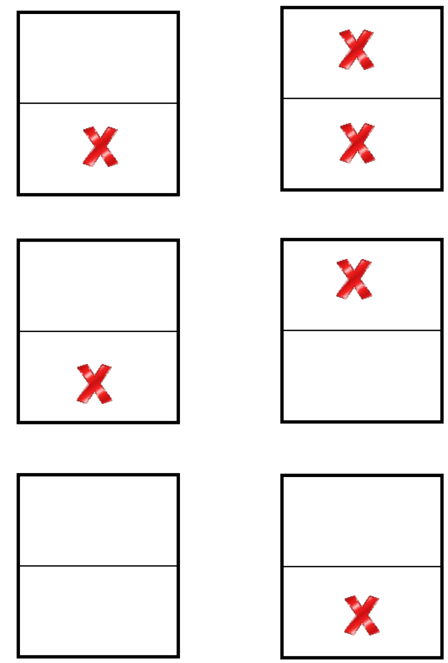
$$\text{DPMO} = \frac{\text{DPU}}{\text{opportunity count per unit}} \times 1{,}000{,}000$$

DPMO for Documents A and B

Document Type A



Document Type B



DPU = 6 / 6 = 1

oppy = 10

DPMO = $^{1}/_{10}$ x 1,000,000

= 100,000

On a "per opportunity" basis, Document A has lower DPMO.

However, from the customer perspective, they don't care how complex the process or product is…the goal is to eliminate or reduce ALL defects!

So track the DPU and work to reduce it.

DPU = 6 / 6 = 1

oppy = 2

DPMO = $^{1}/_{2}$ x 1,000,000

= 500,000

Sigma Capability

- From a quality perspective, "Six Sigma" capability is defined as a process (over the long term) that exhibits no more than 3.4 defects per million opportunities

- Sigma capability can be thought of as a Richter scale for quality, that can be used with both variable and attribute data. It is related to the defect rate and the complexity of a process or product

DPMO-to-Sigma Capability Conversion

(selected values)

↑ sigma capability

↓ defect rate

σ Capability	DPMO	Yield
2	308,537	69.1%
3	66,807	93.3%
4	6,210	99.4%
5	233	99.97%
6	3.4	99.99966%
Sigma Capability	Defects per Million Opportunities	First Pass (rolled throughput) Yield

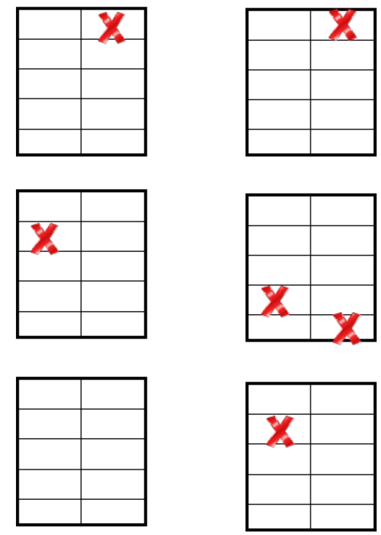
See expanded table in the data file

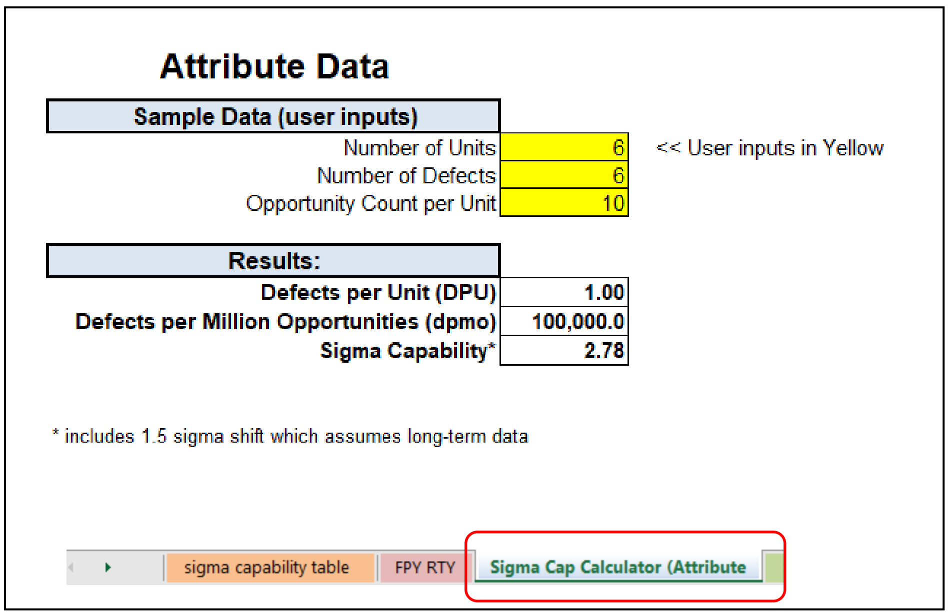
Data file: sigma capability calculator and capability measures.xlsx

DPU, DPMO, and Sigma Capability – Document A

- Let's use the spreadsheet to compute the capability measures for producing Document A
- Recall our data:
  - Total number of units = 6
  - Total number of defects observed = 6
  - Opportunity count per unit = 10

Document Type A





Attribute Data

Sample Data (user inputs)	
Number of Units	6
Number of Defects	6
Opportunity Count per Unit	10

<< User inputs in Yellow

Results:	
Defects per Unit (DPU)	**1.00**
Defects per Million Opportunities (dpmo)	**100,000.0**
Sigma Capability*	**2.78**

* includes 1.5 sigma shift which assumes long-term data

Data file: sigma capability calculator and capability measures.xlsx
(Sigma Cap Calculator (Attribute) tab)

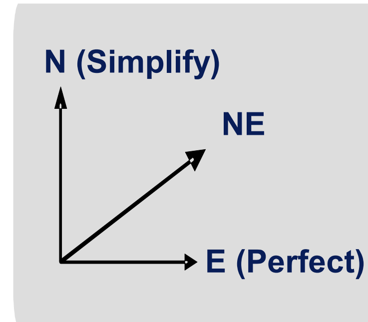
Go NorthEast! (Lean + Six Sigma)

- **Improving** quality (reducing defect rates, improving sigma capability and first pass yield) should be a focus, but **simplifying** a process or product is also important . . . Ideally, focus on both!

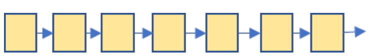
OVERALL YIELD vs SIGMA CAPABILITY
(Distribution Shifted +/- 1.5σ)

# of Parts (Steps)	+/- 3σ	+/- 4σ	+/- 5σ	+/- 6σ
1	93.32%	99.379%	99.9767%	99.99966%
7	61.63	95.733	99.839	99.9976
10	50.08	93.96	99.768	99.9966
20	25.08	88.29	99.536	99.9932
40	6.29	77.94	99.074	99.9864
60	1.58	68.81	98.614	99.9796
80	0.40	60.75	98.156	99.9728
100	0.10	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	99.83
600	- - -	2.38	86.97	99.80
700	- - -	1.28	84.97	99.76
800	- - -	0.69	83.02	99.73
900	- - -	0.37	81.11	99.70
1000	- - -	0.20	79.24	99.66
1200	- - -	0.06	75.88	99.59
3000	- - -	- - -	50.15	98.99
17000	- - -	- - -	1.91	94.38
38000	- - -	- - -	0.01	87.88
70000				78.82
150000				60.00

Adapted From: Six Sigma RESEARCH INSTITUTE
Motorola University Motorola, Inc.



Example: 7 steps
(each with FPY = 93.32%)



RTY = $(0.9332)^7 = 0.6163$

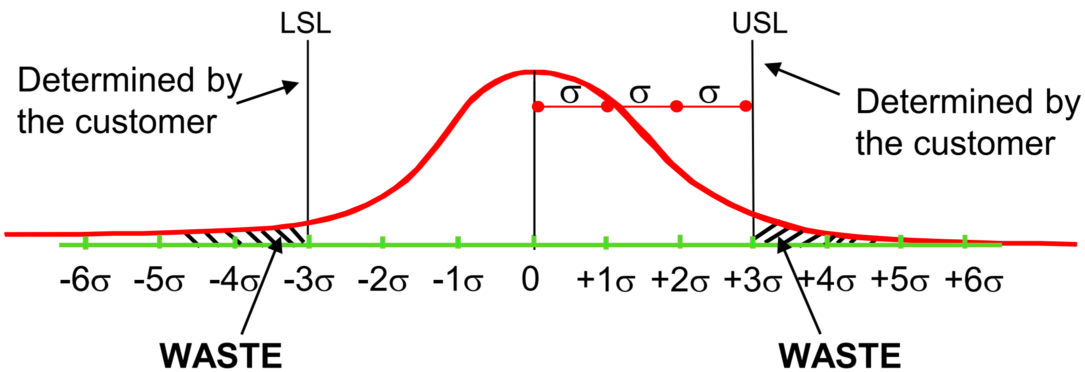
Process Capability Measures for Variables Data

- Sigma level
- Cp and Cpk
- Defects per million (dpm)
- Sigma Capability

Definition of Sigma Level

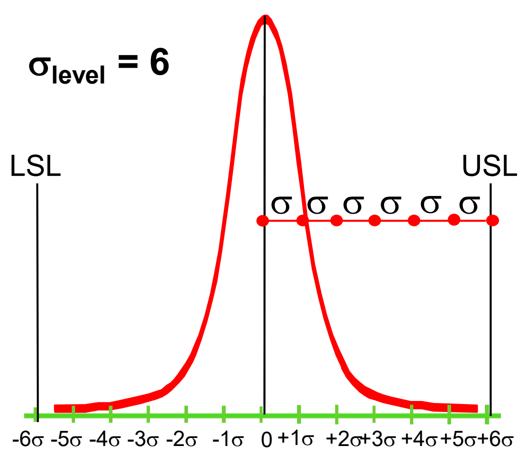
- The sigma level is defined as the number of standard deviations (or σ's) that fit between the center of the process and the **nearest** specification (or requirement) limit

Example 1: $\sigma_{level} = 3$



<u>3σ Process Centered</u>
- Process is WIDER than the specifications, causing waste and cost of poor quality

Example 2: $\sigma_{level} = 6$



↑ sigma level

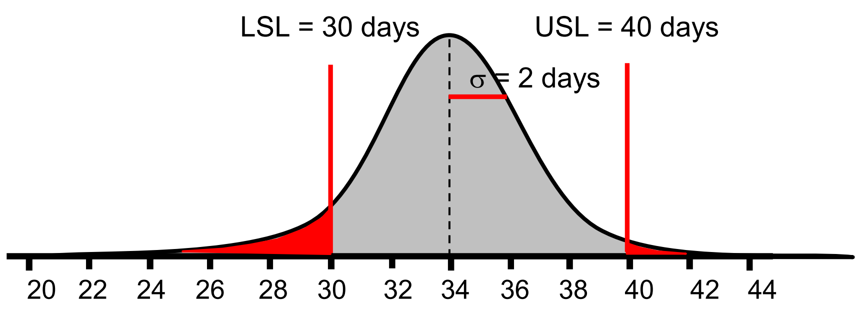
↓ defect rate

<u>6σ Process Centered</u>
- Process FITS well within the specifications, so even if the process shifts, the values fall well within tolerances

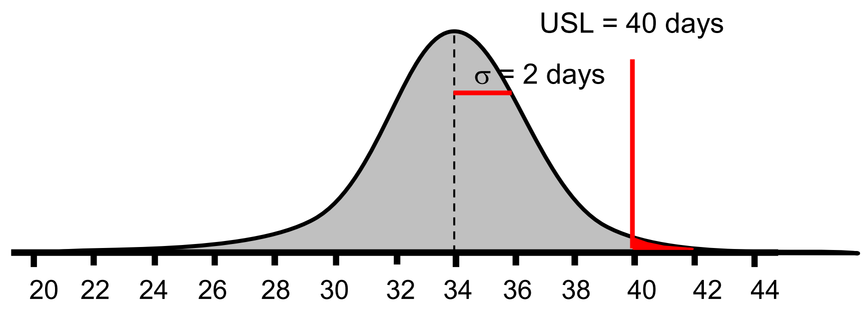
Sigma Level (Practice)

- Using the information shown, determine the sigma level for each process. Which do you expect to the worst?

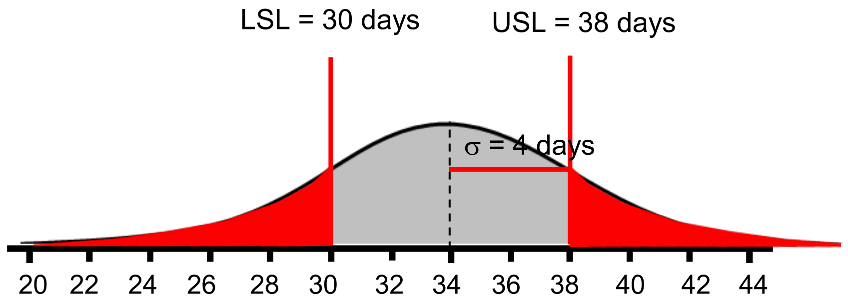
sigma level = _____



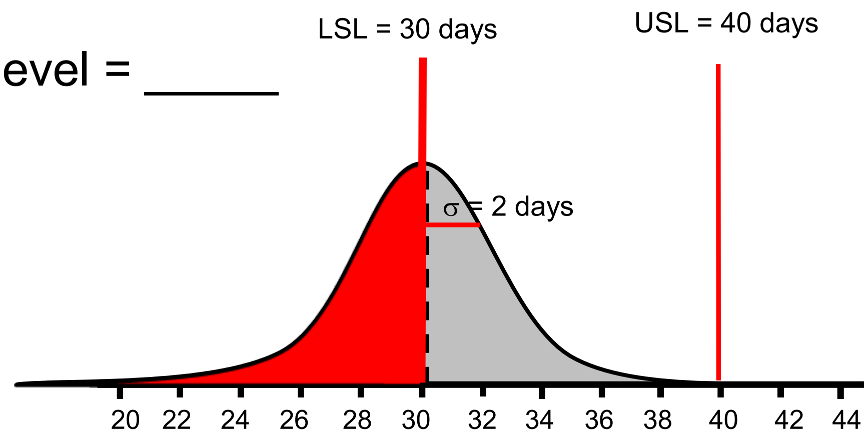
sigma level = _____



sigma level = _____



sigma level = _____

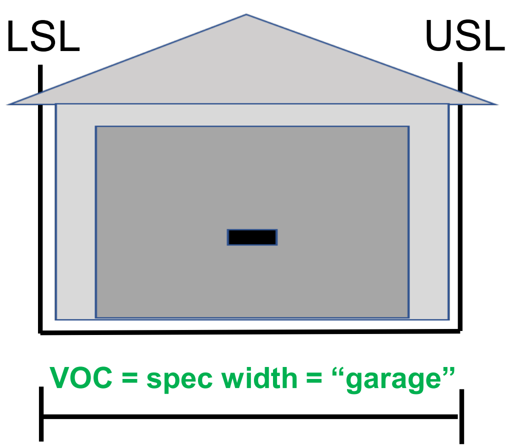


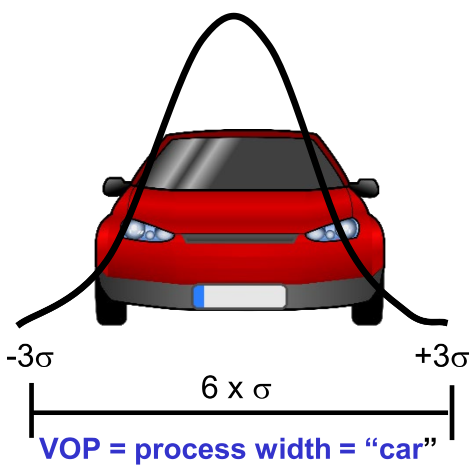
Process Capability Potential (Cp)

- Cp is a measure of capability that compares the **voice of the process** with the **voice of the customer**

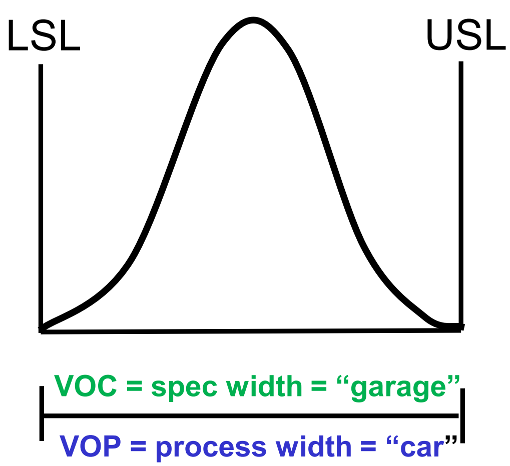
$$C_p = \frac{(USL - LSL)}{6 \times \sigma} = \frac{\text{voice of the customer}}{\text{voice of the process}} = \frac{\text{spec width}}{\text{process width}}$$

- A great way to visualize this ratio is to think of a **car** and **garage**





Cp = 1 (in this example)

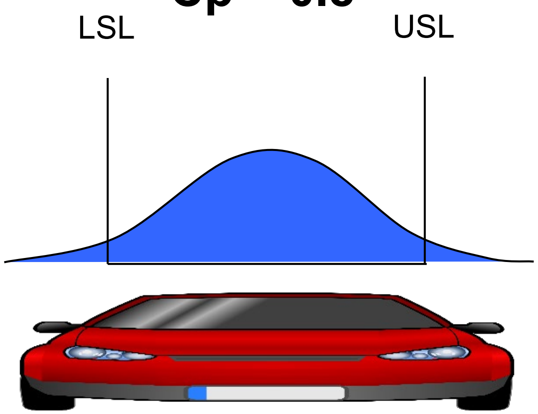


How many **C**ars can **P**ark in the garage? (potentially)

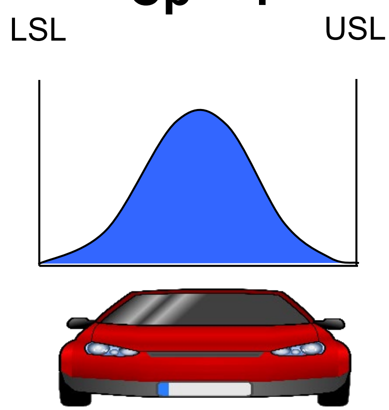
note: Cp assumes that data is approximately normally distributed (be sure to check a histogram of your data)

Cp Examples

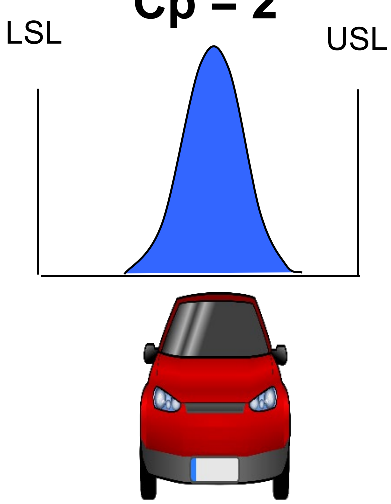
Cp = 0.8



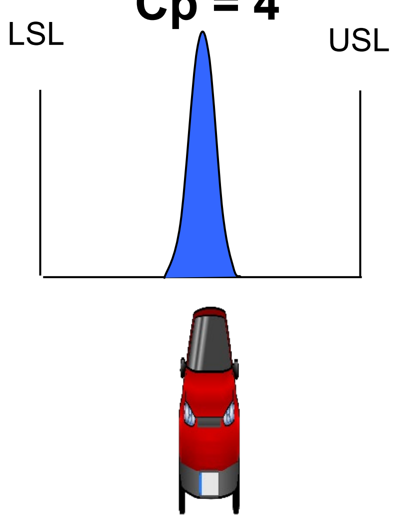
Cp = 1



Cp = 2

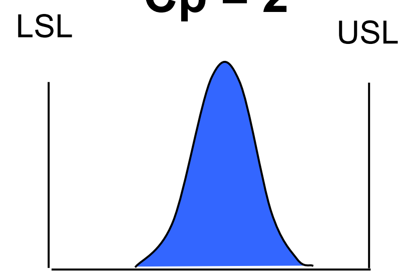


Cp = 4

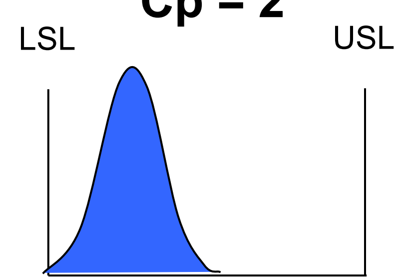


. . . but, Cp alone doesn't tell the whole story!

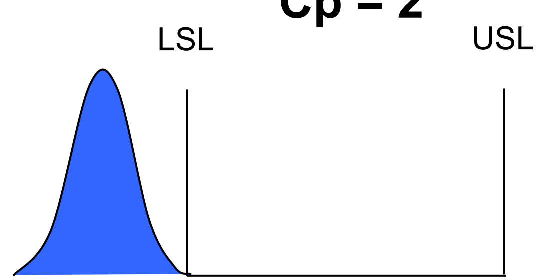
Cp = 2



Cp = 2



Cp = 2

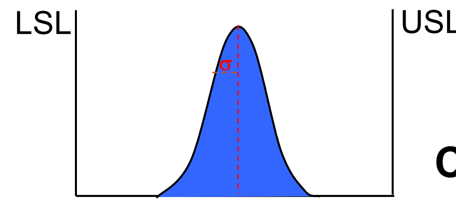


Process Capability (Actual) (Cpk)

- Cpk takes the process average into consideration

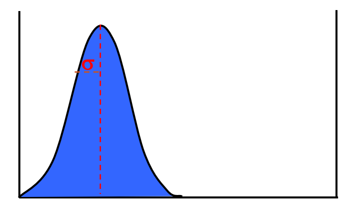
$$Cpk = \min\left[\frac{(USL - \bar{y})}{3 \text{ x } \sigma} \text{ or } \frac{(\bar{y} - LSL)}{3 \text{ x } \sigma}\right] = \frac{\sigma_{level}}{3}$$

- Cpk = Cp when the process is perfectly centered



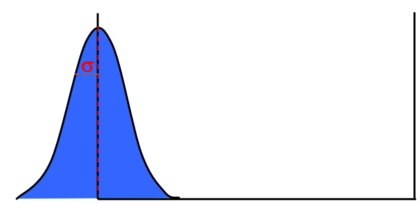
Cp = 2
Cpk = 2

- Cpk < Cp when the process is not centered



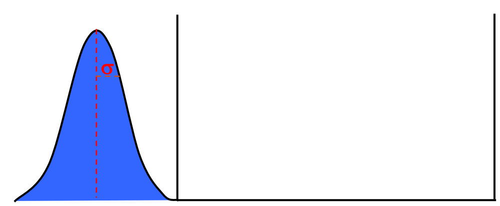
Cp = 2
Cpk = 1

- Cpk = 0 when the process mean is equal to one of the specification limits



Cp = 2
Cpk = 0

- Cpk becomes a negative value when the process mean lies outside of the specification limit(s)



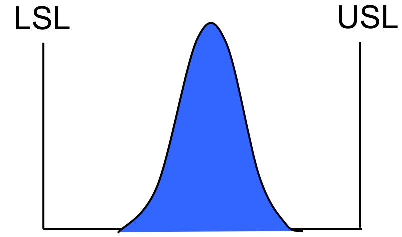
Cp = 2
Cpk = -1

Cp and Cpk (Practice)

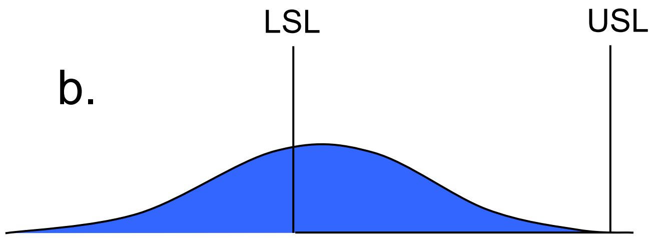
Match the description at the left, with the appropriate picture on the right

1. Cp = 4, Cpk = 1
2. Cp = 0.8, Cpk = 0.8
3. Cp = 2, Cpk = 2
4. Cp = 0.8, Cpk = 0.1

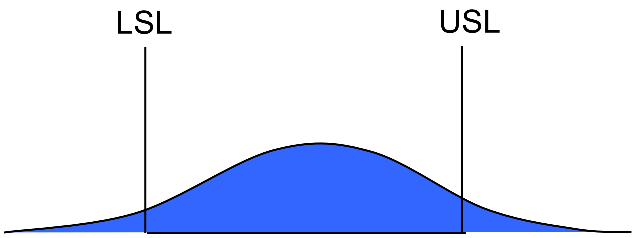
a.



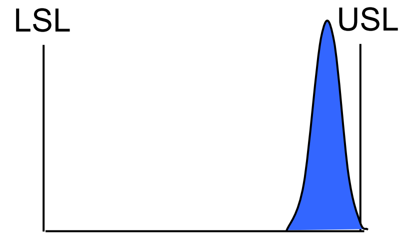
b.



c.



d.



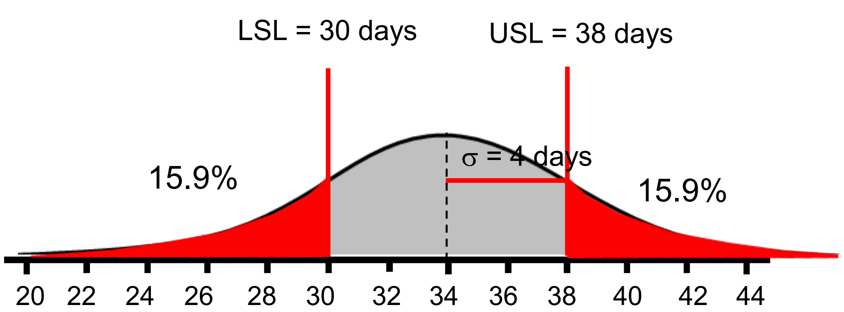
DPM and Sigma Capability

- For variables data, defect per million (DPM) is the area under the curve outside of the specification limits.

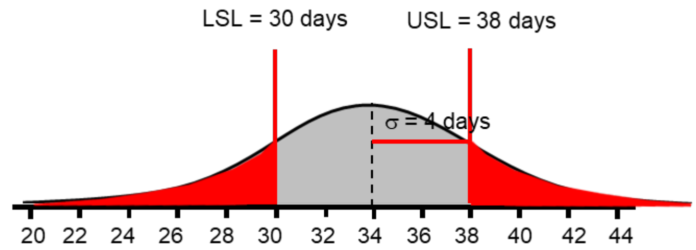
- Software such as SPC XL will compute this. Recall, however, that Cp and Cpk assume the process data is approximately normally distributed. A histogram should be plotted to ensure this is a reasonable assumption. If not, data transformations might be used, or fitting of the exact statistical distribution in order to accurately estimate the dpm (beyond the scope of this session)

- In the example below, 15.9% of the distribution falls below the LSL and 15.9% of the distribution falls above the USL. Adding these two areas together gives us 31.8% of the area falling outside of the customer specifications. Expressed on a “per million” scale, this is equivalent to saying the dpm is 318,000. In other words, if we repeated the process 1,000,000 times we would expect to NOT meet the customer requirements 318,000 times.

- Sigma capability is calculated by converting the dpm using the same table as previously discussed in the attribute capability section.



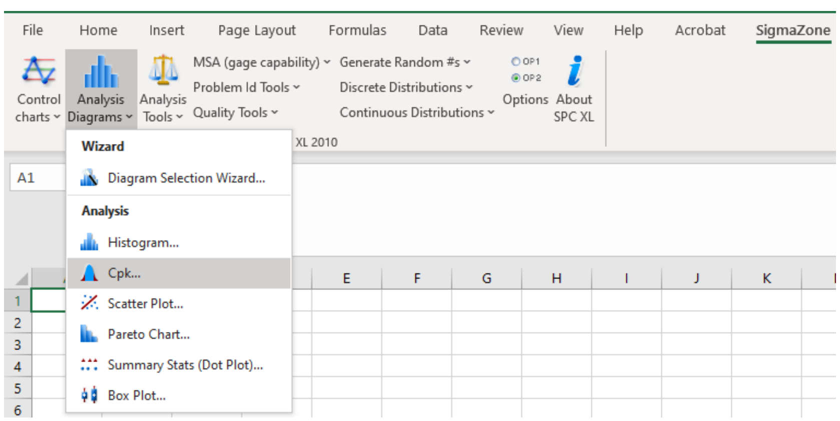
Capability Analysis using SPC XL

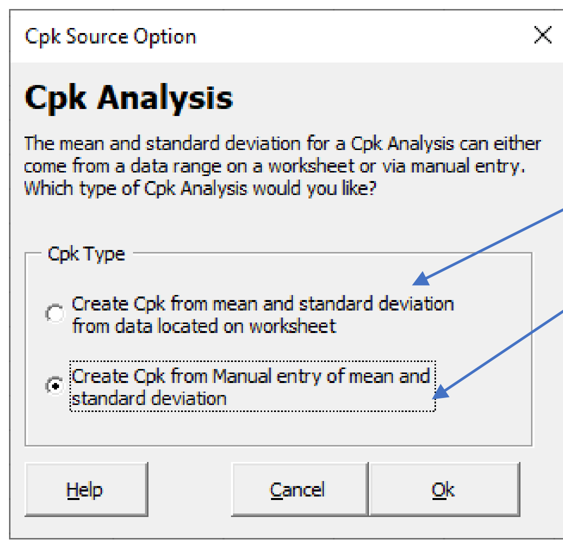


- Let's use the example from the previous page

- Suppose that the cycle time for an accounts payable process follows a normal distribution. The average time to process a payment is 34 days and the standard deviation is 4 days. The LSL is 30 days (no incentive to pay early) and the USL is 38 days (longer than that will incur penalties)

- To find Cp, Cpk, sigma level, dpm, and sigma capability, from the SigmaZone (SPC XL) Ribbon select: **Analysis Diagrams / Cpk**





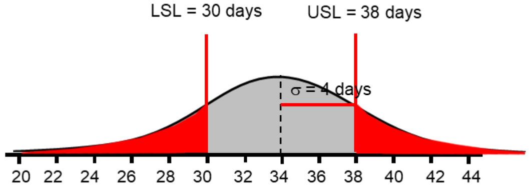
Source data can be stored in a **spreadsheet,**

or you can manually enter the mean and standard deviation.

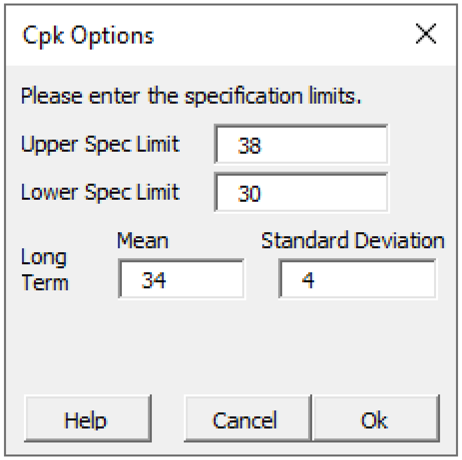
Note

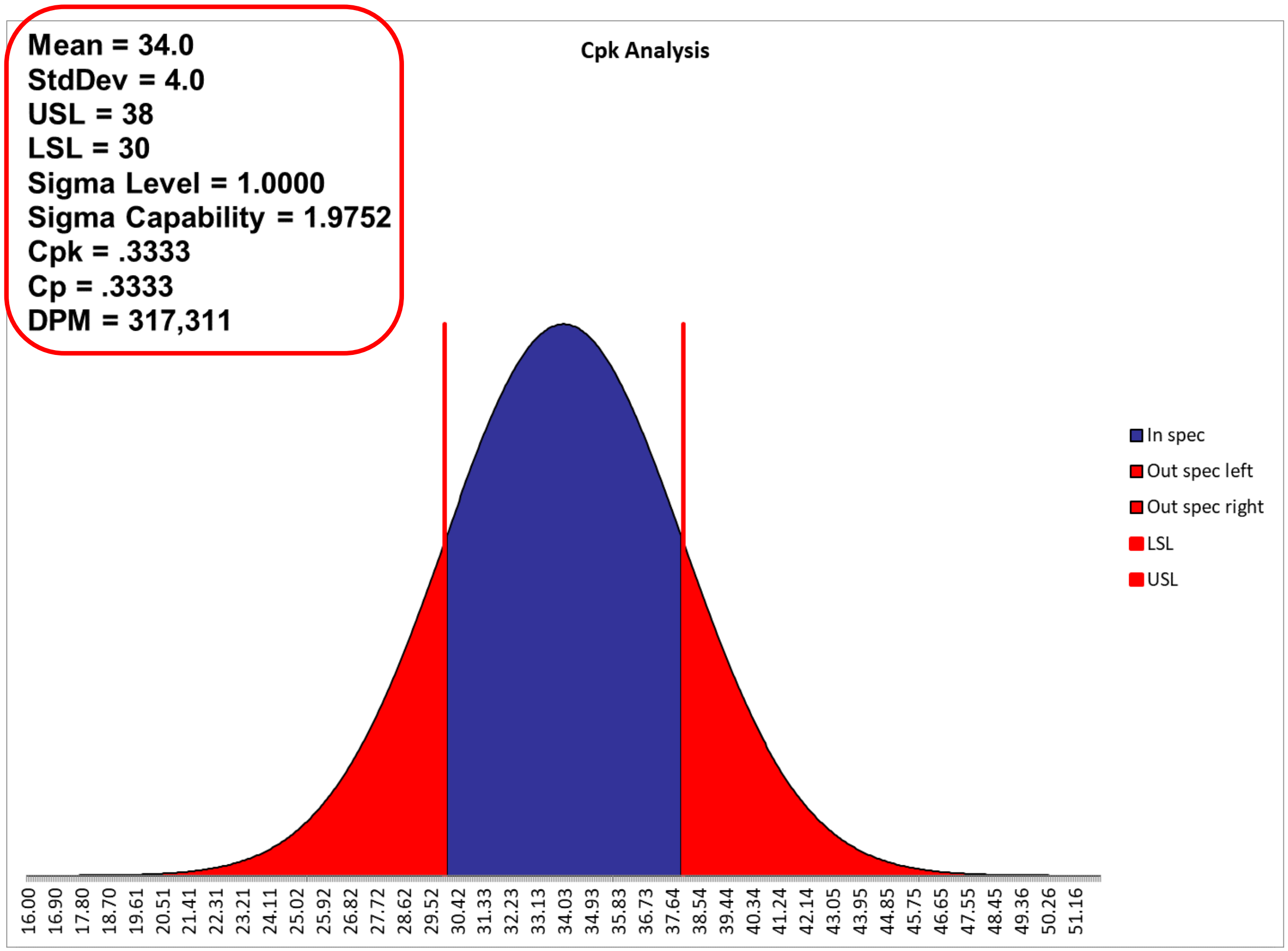
For video instruction on generating Cpk analysis, go to:
https://airacad.com/our-insights/training-videos/spc-xl/

Capability Analysis using SPC XL



- Let's use the example from the previous page





Cp = 0.333, Cpk = 0.333

DPM = 317,311 >>> we can expect to NOT meet the customer requirements about 31.7% of the time

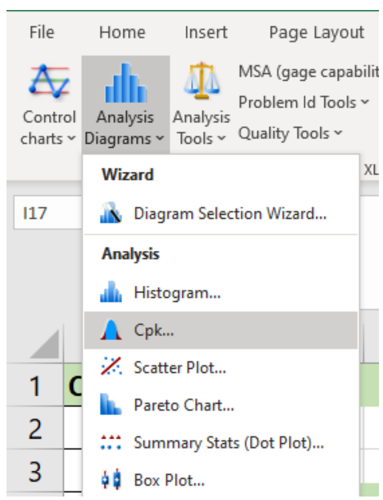
Capability Analysis using SPC XL (baseline data)

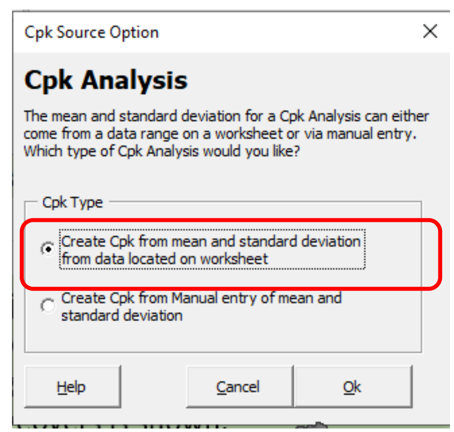
- A team was focused on reducing the cycle time for completing a changeover on a piece of equipment. Baseline data for the past 20 changeovers was gathered.

	A	B
1	Cycle Time (minutes)	
2	53	
3	30	
4	41	
5	38	
6	51	
7	46	
8	59	
9	44	
10	49	
11	35	
12	64	
13	54	
14	48	
15	57	
16	61	
17	41	
18	51	
19	67	
20	55	
21	45	

- The goal is to complete a changeover within 50 minutes (i.e., the USL = 50 minutes)

- What is the current process capability, in terms of meeting that requirement? What is the Cpk and dpm?

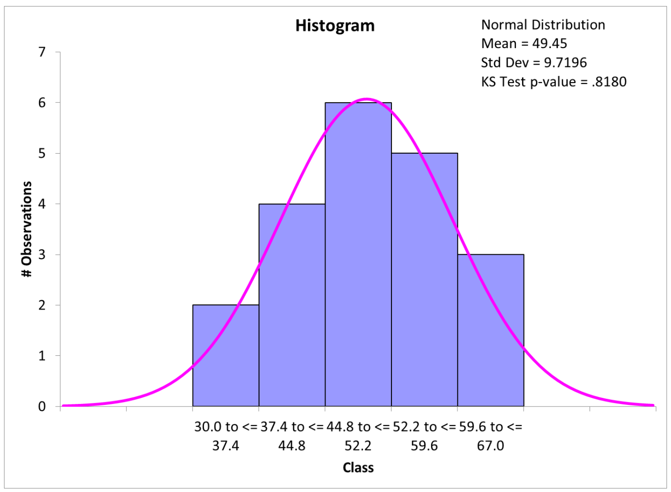




Data file: capability data.xlsx

Capability Analysis using SPC XL (baseline data) (cont.)

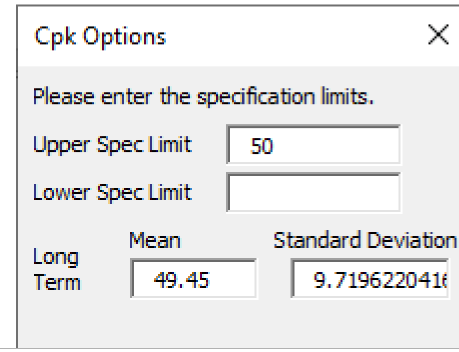
- Histogram of the data shows changeover times are approximately normally distributed (**SigmaZone / Analysis Diagrams / Histogram**)

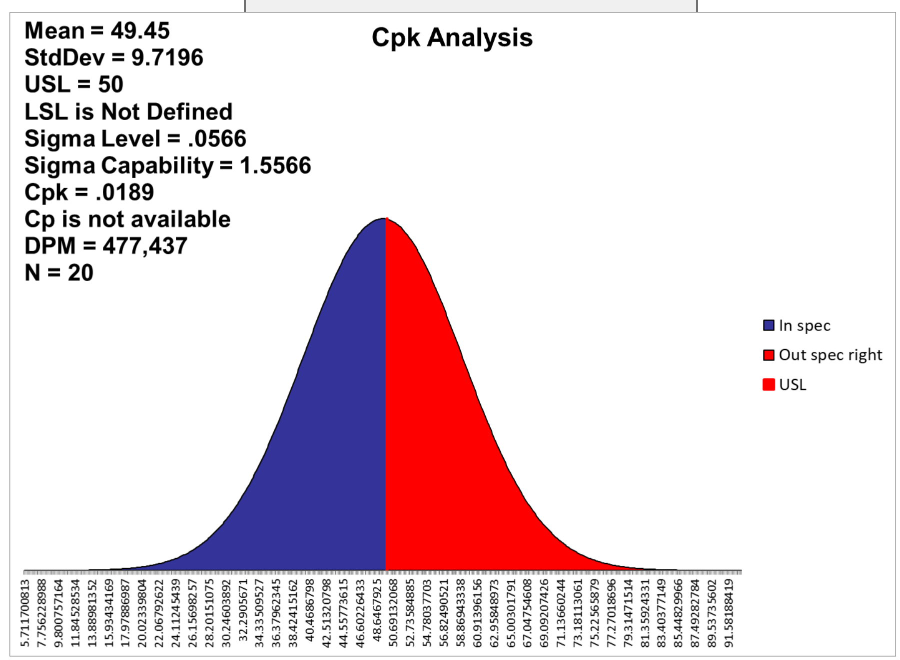


- The average changeover time is 49.4 minutes and the standard deviation is 9.7 minutes.

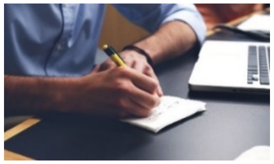
Data file: capability data.xlsx

- Cpk analysis shows Cpk = 0.189 and DPM = 477,437, meaning we are not meeting the requirement about 47.7% of the time (**SigmaZone / Analysis Diagrams / Cpk**)





Key Takeaways



- As a review, you may want to pause the video at this point and summarize the key learnings from this session, at least from a high-level view. When you are finished, resume the video.

Key Takeaways

- When assessing process capability, define the customer requirements so that you can answer the question:
  - "How is the process or product performing, in terms of meeting the customer requirements?"

- Choose one (or more) measures that make sense for your application and track these over time and strive for improvement
  - Attribute data:
    - First Pass Yield (FPY), Rolled Throughput Yield (RTY), and Defects per Unit (DPU) are the most commonly used measures
    - DPMO and sigma capability may also be used
  - Variables data:
    - Cp, Cpk, sigma level and defects per million (dpm) are the most commonly used measures
    - Sigma capability may also be used

- Variables data is preferred over attribute data, when possible, because it contains more information

- Go NorthEast! – simplify and perfect!

Supplemental Material

- Suggested Reading:
  - ***Lean Six Sigma: A Tools Guide*** by Adams, Kiemele, Pollock and Quan (pp. 45 - 53)
  - ***Basic Statistics – Tools for Continuous Improvement*** by Kiemele, Schmidt and Berdine, 4th edition (pp. 9-8 – 9-15)
  - ***Design for Six Sigma: The Tool Guide for Practitioners*** by Reagan and Kiemele (pp. 39 - 56)
  - Air Academy's app: ***Six Sigma Quick Tools***

GET IT ON Google Play
Download on the App Store

- SPC XL™ software training tutorials:
  - https://airacad.com/our-insights/training-videos/spc-xl/

- The data files for this session can be downloaded from the site where you are accessing this course

Additional Practice / Review Questions

1) What question are we trying to answer with a process capability analysis?

2) What are some of the commonly used capability/quality measures with attribute data?

3) What are some of the commonly used capability/quality measures with variables data?

4) If a process has two main steps, one with a FPY = 90% and the other with a FPY = 70%, what is overall rolled throughput yield (RTY) for the entire process?

5) A random sample of 500 parts ("units") were inspected, and a total of 650 defects were found. Some parts had no defects, while others had 1 or more defects. There are 5 critical to customer performance characteristics on the part (i.e., opportunity count per part is 5). What is DPU for the process, the dpmo, and the sigma capability?

Additional Practice / Review Questions (cont.)

6) The diameter of a part follows a normal distribution. The average diameter is 1.2 inches and the standard deviation is 0.3 inches. The customer requirements (specs) are 1.4 +/- 0.3, meaning that the LSL = 1.1 and USL = 1.7. What is the Cp and Cpk for the process? What is the estimated percentage of time the process does not meet the customer requirements? What type of improvement, if any, is needed?

7) The weight of a part is normally distributed. If the capability analysis for part weight shows a Cp = 3 and Cpk = 1, is the part weight centered in spec? Is there excessive variation in the part weight compared to the specs?

8) For a process performance measure that is normally distributed, if the Cp = 1 and the Cpk = 0.1, what do these measures tell you about the process?

We can help…
Connect With Us

Remote Project Coaching

There are times when help outside your organization is needed. When that time comes, benefit from a partner that is experienced, tested, and trusted.

Expert coaching is one of the Top Five Best Practices for generating step change in project execution, as well as enhanced return on investment. We can work remotely with your organization to provide coaching support.

Air Academy Associates
Phone: (719) 531-0777
Email: aaa@airacad.com
https://airacad.com/
https://sixsigmaproductsgroup.com/

Download on the App Store

There's an app for that!
Six Sigma Quick Tools