Notes:

Calculating Sigma Level and Process Yield

Key Learning Points

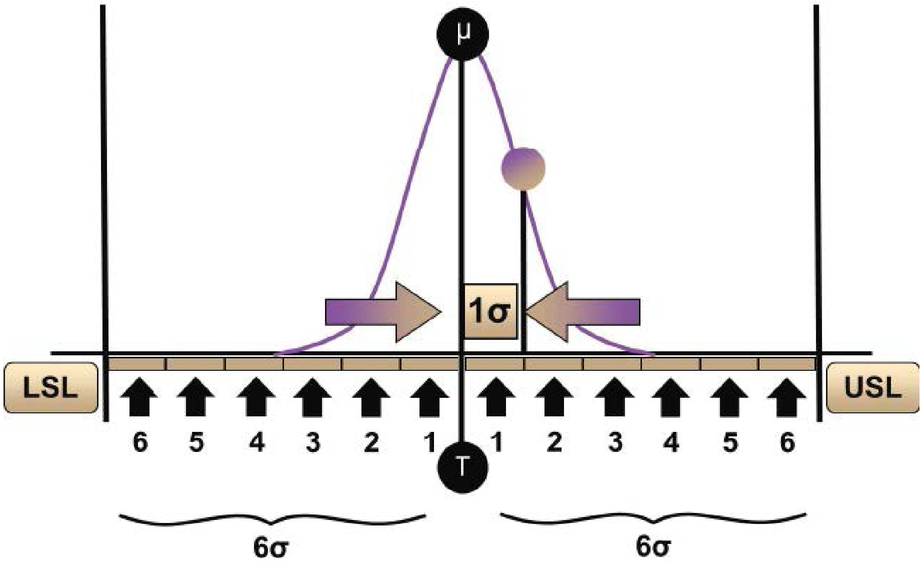
1. Describe the importance of calculating Sigma Level and Process Yield.
2. Explain how to calculate Sigma Level and Process Yield.
3. Utilize calculating Sigma Level and Process Yield in improvement projects.

Why Calculate Sigma Level?

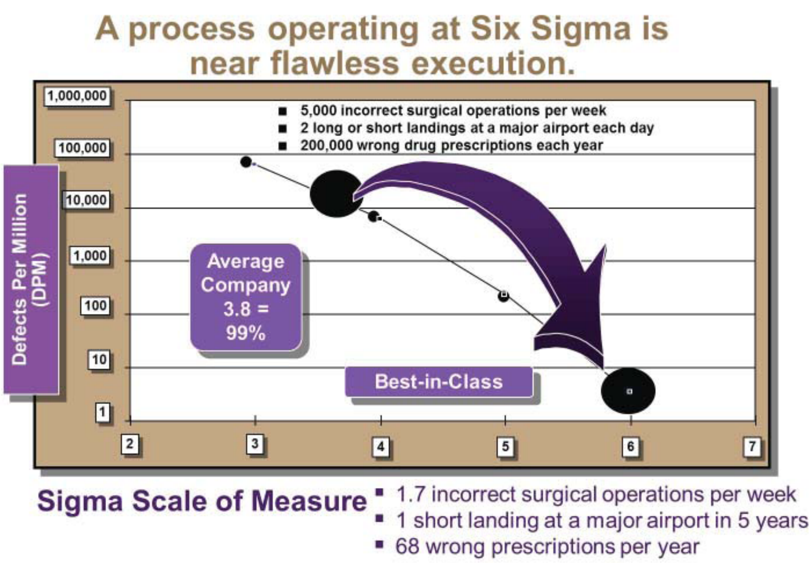
Sigma level describes the distance of the mean of a theoretical curve (normal) to a specification limit. The distance is measured in units of the standard deviation(s).

Calculating the Sigma Level for a process is essentially calculating the processes defect rate.

Six Sigma Level of Performance



Sigma is a Metric



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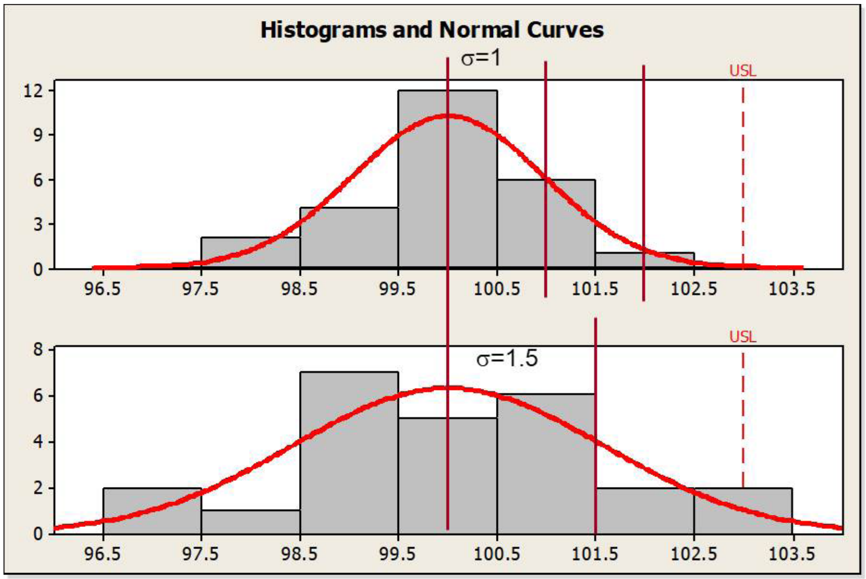
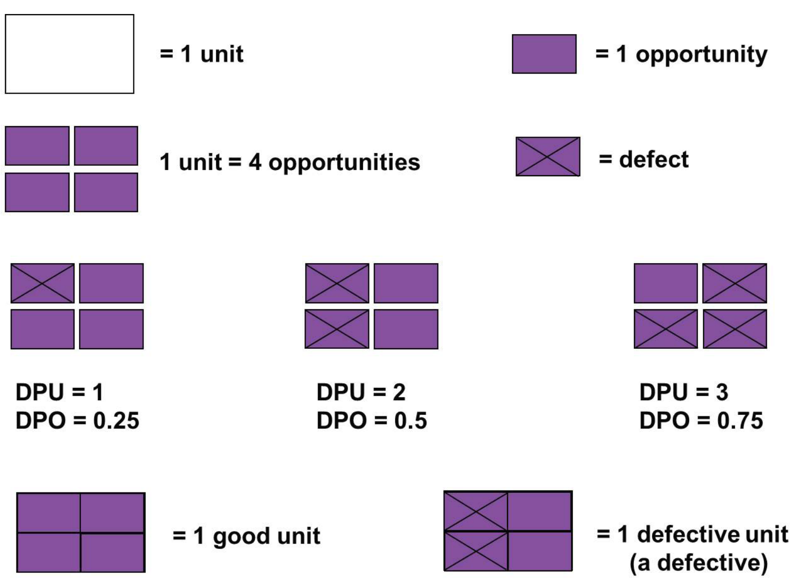
Sigma Level and Standard Deviation



- Both distributions have a mean of 100, and Upper Specification Limit of 103.
- The standard deviation for the upper data is 1, and for the lower data is 1.5.
- The sigma level for the upper graph is 3, and for the lower graph is 2.

Key Terms



- Unit: Anything that is produced or processed—a good, service, or information
- Defect Opportunity: Anything that provides a chance of not meeting a performance standard or CTQ
- Defect: Any occurrence of an opportunity in a process or product that does

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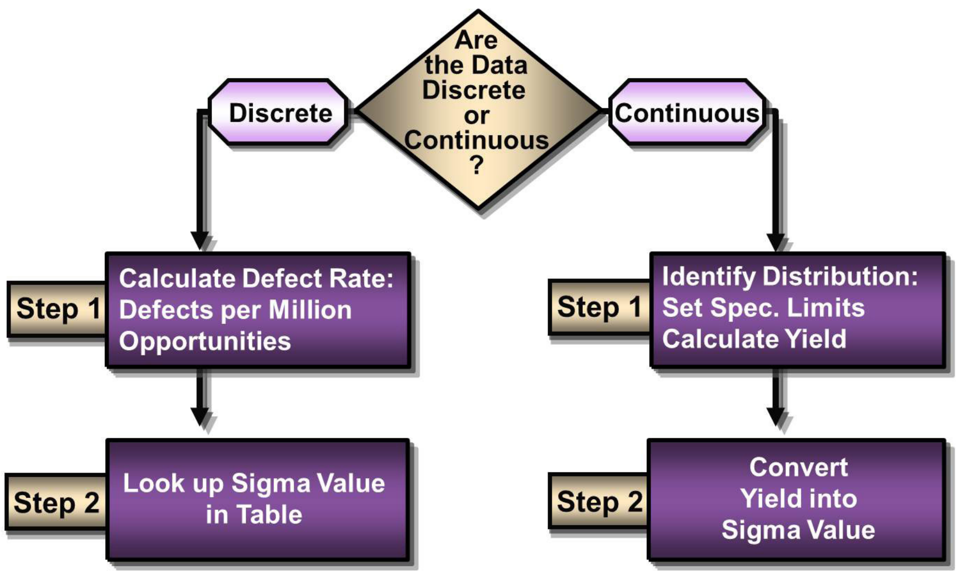
not meet the performance standard or CTQ

- DPU: Defects Per Unit—(count-of-defects/count-of-units-measured)
- DPO: Defects Per Opportunity—(count-of-defects/count-of-total-opportunities) typically expressed as DPMO, or Defects per Million Opportunities (DPO*1,000,000)
- Defective Unit (or a Defective): A unit with one or more defects
- Process Sigma: Summarizes the performance of a process in terms of the DPMO that it produces—A Six Sigma process produces 3.4 DPMO

Steps to Calculate Sigma Level

The method that you use to calculate sigma level depends on if you have discrete (categorical) or continuous data.



Calculating Sigma Level Using Discrete Data.

1. Determine the number of Units processed (n).
2. Determine the number of Defect Opportunities per Unit (o).
3. Determine the total number of Defects made (c).
4. Solve for Defects Per Opportunity (DPO).
5. Convert DPO to Defects per Million Opportunities (DPMO).
6. Look up Process Sigma (Sigma(ST))in an abridged process sigma conversion table.

$$DPO = c/(n*o)$$

$$DPMO = DPO*1,000,000$$

Notes:

Abridged Process Sigma Conversion Table

Long-Term Yield	Process Sigma (ST)	Defects Per 1,000,000	Defects Per 100,000	Defects Per 10,000	Defects Per 1,000	Defects Per 100
99.99966%	6.0	3.4	0.34	0.034	0.0034	0.00034
99.9995%	5.9	5	0.5	0.05	0.005	0.0005
99.9992%	5.8	8	0.8	0.08	0.008	0.0008
99.9990%	5.7	10	1	0.1	0.01	0.001
99.9980%	5.6	20	2	0.2	0.02	0.002
99.9970%	5.5	30	3	0.3	0.03	0.003
99.9960%	5.4	40	4	0.4	0.04	0.004
99.9930%	5.3	70	7	0.7	0.07	0.007
99.9900%	5.2	100	10	1.0	0.1	0.01
99.9850%	5.1	150	15	1.5	0.15	0.015
99.9770%	5.0	230	23	2.3	0.23	0.023
99.9670%	4.9	330	33	3.3	0.33	0.033
99.9520%	4.8	480	48	4.8	0.48	0.048
99.9320%	4.7	680	68	6.8	0.68	0.068
99.9040%	4.6	960	96	9.6	0.96	0.096
99.8650%	4.5	1,350	135	13.5	1.35	0.135
99.8140%	4.4	1,860	186	18.6	1.86	0.186
99.7450%	4.3	2,550	255	25.5	2.55	0.255
99.6540%	4.2	3,460	346	34.6	3.46	0.346
99.5340%	4.1	4,660	466	46.6	4.66	0.466
99.3790%	4.0	6,210	621	62.1	6.21	0.621
99.1810%	3.9	8,190	819	81.9	8.19	0.819
98.930%	3.8	10,700	1,070	107	10.7	1.07
98.610%	3.7	13,900	1,390	139	13.9	1.39
98.220%	3.6	17,800	1,780	178	17.8	1.78
97.730%	3.5	22,700	2,270	227	22.7	2.27
97.130%	3.4	28,700	2,870	287	28.7	2.87
96.410%	3.3	35,900	3,590	359	35.9	3.59
95.540%	3.2	44,600	4,460	446	44.6	4.46
94.520%	3.1	54,800	5,480	548	54.8	5.48
93.320%	3.0	66,800	6,680	668	66.8	6.68
91.920%	2.9	80,800	8,080	808	80.8	8.08
90.320%	2.8	96,800	9,680	968	96.8	9.68
88.50%	2.7	115,000	11,500	1,150	115	11.5
86.50%	2.6	135,000	13,500	1,350	135	13.5
84.20%	2.5	158,000	15,800	1,580	158	15.8
81.60%	2.4	184,000	18,400	1,840	184	18.4
78.80%	2.3	212,000	21,200	2,120	212	21.2
75.80%	2.2	242,000	24,200	2,420	242	24.2
72.60%	2.1	274,000	27,400	2,740	274	27.4
69.20%	2.0	308,000	30,800	3,080	308	30.8
65.60%	1.9	344,000	34,400	3,440	344	34.4
61.80%	1.8	382,000	38,200	3,820	382	38.2
58.00%	1.7	420,000	42,000	4,200	420	42
54.00%	1.6	460,000	46,000	4,600	460	46
50%	1.5	500,000	50,000	5,000	500	50
46%	1.4	540,000	54,000	5,400	540	54
43%	1.3	570,000	57,000	5,700	570	57
39%	1.2	610,000	61,000	6,100	610	61
35%	1.1	650,000	65,000	6,500	650	65
31%	1.0	690,000	69,000	6,900	690	69
28%	0.9	720,000	72,000	7,200	720	72
25%	0.8	750,000	75,000	7,500	750	75
22%	0.7	780,000	78,000	7,800	780	78
19%	0.6	810,000	81,000	8,100	810	81
16%	0.5	840,000	84,000	8,400	840	84
14%	0.4	860,000	86,000	8,600	860	86
12%	0.3	880,000	88,000	8,800	880	88
10%	0.2	900,000	90,000	9,000	900	90
8%	0.1	920,000	92,000	9,200	920	92

Notes:

Calculating Sigma Level Using Continuous Data.

Notes:

1. Select a response variable.
2. Establish a rational subgroup (time, distance, etc.)
3. This is a binomial process, something is either error free, or it contains errors. Run a binomial capability analysis from your data.

Note: You are not expected to do this calculation by hand. A statistical program such as Minitab or Juran's Sigma Calculation tool is necessary to calculate Sigma using Continuous data.

Example Using Discrete Data

A loan processing firm sends out an application form that needs to be completed by new or returning customers, which need to be completed so payments can be processed in a timely manner.

567 new or returning customers filled out forms. There were 63 opportunities for errors and each of these forms was examined. During this examination 336 defects were found.

Number of Units Processed	n = 567
Number of possible defect opportunities per unit	o = 63
Total number of defects detected	c = 336
DPO = c/(n*o) = 336/(567*63)	DPO = 0.009406
DPMO = DPO*1,000,000 = 0.009406*1,000,000	DPMO = 9,406
Find Process Sigma in Abridged Process Sigma Conversion Table.	Sigma(ST) = 3.85

Why Calculate Yield?

Yield is the percentage of opportunities in a process that are created or completed perfectly. Note that the term "yield" is also used in many "process" industries such as chemicals, petroleum, pharmaceuticals, and agriculture to indicate the amount of output as a percent of standardized amounts of inputs. That is not the usage here.

Defect Rates

Defect rates monitor the frequency with which things go wrong-Measured in Defects per Opportunity(DPO), or Defects per Million Opportunities(DPMO).

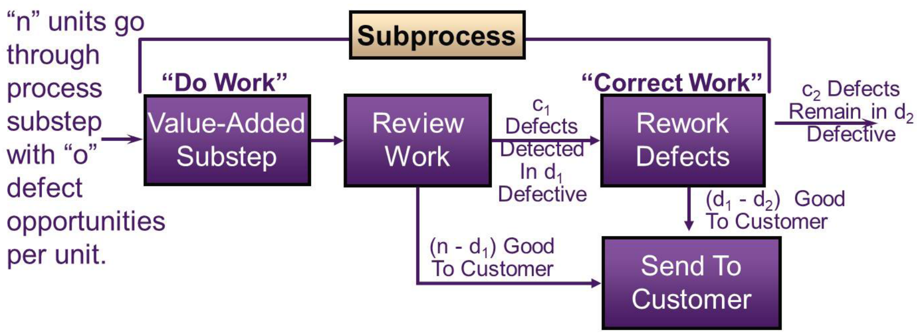
Yield

Yield is the complement of the defect rate. It is the percent of the opportunities that are good.

First-Pass Yield vs. Final Yield

Both Yield and Defect Counts can be calculated either before or after defects have been caught and corrected. The formulas are the same, but the results vary. First-Pass Yield is used to calculate process sigma for the following reasons:

- Defects, once produced, add waste and cost (some costs are easy to quantify and some are not)
- Even the best inspection processes cannot catch all defects
- The payback is generally greater when defects are kept from occurring



First Pass Yield

First-Pass DPO = c1/(n*o)

First-Pass DPMO = 1,000,000[c1/(n*o)]

First-Pass Yield = 1-[c1/(n*o)]

Final Yield

Final DPO = c2/(n*o)

Final DPMO = 1,000,000[c2/(n*o)]

Final= 1-[c2/(n*o)]

Notes:

Rolled Throughput Yield

Step 1: Receive parts from supplier. At this point you have 100% of product.

Step 2: Following receiving, inspection and line fall-out, 95.5% of product (yield) remains. 4.5% of the product has been wasted in the process.

Step 3: Following machining operations, 97% of product (yield) remains. 3.0% of the product has been wasted in the process.

Step 4: Following testing, 94.4% of product (yield) remains. 5.6% of the product has been wasted in the process.

Step 5: Rolled Throughput Yield is calculated by multiplying the yield percentages measured after each process step.

Yield Decreases When Complexity Increases

Yields thru Multiple Steps/Parts/Processes

# of parts, steps, or processes	Zst (distribution shifted 1.5σ) 3	4	5	6
1	93.32%	99.38%	99.9767%	99.99966%
5	70.77%	96.93%	99.88%	99.9983%
10	50.09%	93.96%	99.77%	99.997%
20	25.09%	88.29%	99.54%	99.993%
50	3.15%	73.24%	98.84%	99.983%
100		53.64%	97.70%	99.966%
200		28.77%	95.45%	99.932%
500		4.44%	89.02%	99.830%
1000		0.20%	79.24%	99.660%
2000			62.79%	99.322%
10000			9.76%	96.656%

Yields thru Multiple Steps/Parts/Processes

# of parts, steps, or processes	Zst (distribution shifted 1.5σ) 3	4	5	6
1	93.32%	99.38%	99.9767%	99.99966%
5	70.77%	96.93%	99.88%	99.9983%
10	50.09%	93.96%	99.77%	99.997%
20	25.09%	88.29%	99.54%	99.993%
50	3.15%	73.24%	98.84%	99.983%
100		53.64%	97.70%	99.966%
200		28.77%	95.45%	99.932%
500		4.44%	89.02%	99.830%
1000		0.20%	79.24%	99.660%
2000			62.79%	99.322%
10000			9.76%	96.656%

Remedy 1:
Reduce Parts/Steps

Remedy 2:
Improve Sigma per Part/Step

Notes:

Yield Calculation Example

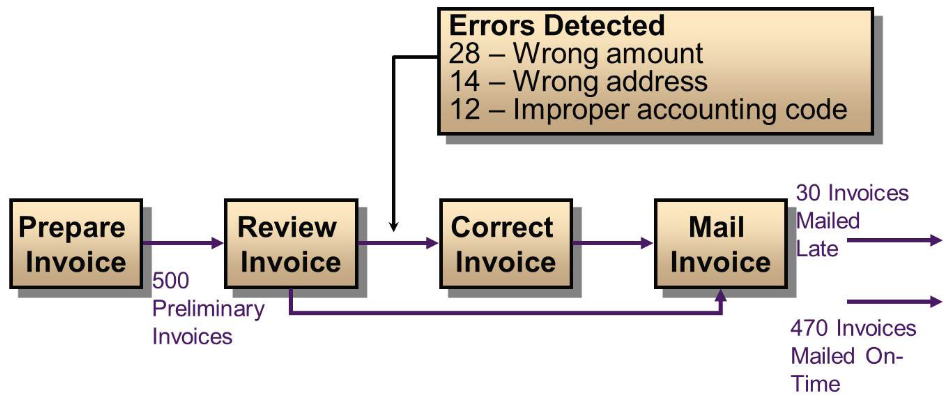
An organization has an invoicing process which has been receiving complaints from customers. A project team collected data, and came up with the following CTQs.

Customer CTQs:

- Invoice needs to be mailed on certain date
- Invoice needs to be error free (with the correct address and correct amount)

Internal CTQs:

- The invoices need to have correct accounting codes.



Customer CTQs:

- Invoice mailed on date specified
- Invoice is error free
- Correct address
- Correct amount

Internal CTQs:

- Invoice has proper accounting codes

Number of Units Processed:	n = 500
Opportunities for Error:	o = 4
Defects Detected:	c1 = 28 (wrong amount)
	c1 = 14 (wrong address)
	c1 = 12 (improper accounting code)
Defects that Remain:	c2 = 20 (invoices mailed late)

Notes:

Calculation of First Pass Yield

Notes:

Number of Units Processed:	n = 500
Opportunities for Error:	o = 4
Defects Detected:	c1 = 28 (wrong amount)
	c1 = 14 (wrong address)
	c1 = 12 (improper accounting code)
Defects that Remain:	c2 = 30 (invoices mailed late)

Calculation for First Pass Yield:
First Pass Yield = 1- [(all defects)/n*o)]
=1-[(c1+c2)/(n*o)]
=1-[(wrong amount+wrong address+improper accounting code+invoices mailed late)/(n*o)
=1-[(28+14+12+30)]/(500*4)
=1-(84/2000)
=1-0.042

First Pass Yield = 0.958

Calculation of Final Yield

Number of Units Processed:	n = 500
Opportunities for Error:	o = 4
Defects Detected:	c1 = 28 (wrong amount)
	c1 = 14 (wrong address)
	c1 = 12 (improper accounting code)
Defects that Remain:	c2 = 30 (invoices mailed late)

Calculation for Final Yield:
Final Yield = 1- [(defects that remain)/n*o)]
=1-[c2/(n*o)]
=1-[30/(500*4)]
=1-(30/2000)
=1-0.015

Final Yield = 0.985

Calculation of Rolled Throughput Yield

Number of Units Processed:	n = 500
Opportunities for Error:	o = 4
Defects Detected:	c1 = 28 (wrong amount)
	c1 = 14 (wrong address)
	c1 = 12 (improper accounting code)
Defects that Remain:	c2 = 30 (invoices mailed late)

Calculation for Rolled Throughput Yield:
Rolled Throughput Yield = (Yield of “Preparing Process, c1) * (Yield of Mailing

Process, c2)
=[1-(wrong amount+wrong address+improper accounting code)/(n*3)]*

[1-(invoices mailed late/n)]
=[1-(28+14+12)/(500*3)]*[1-(30/500)]
=[1-(54/1,500)]*[1-(30/500)]
=(1- 0.036)*(1-0.06)
=0.964*0.94
=0.90616

Rolled Throughput Yield = 0.90616

When Should Sigma Level and Yield Be Calculated?

- When defining Y.
- In Define, Measure, Analyze, and Control Steps of DMAIC.

Pitfalls to Avoid

Falling into trap that you need sigma or yield calculation for all projects.

Notes: