What is Six Sigma?

The concepts surrounding the drive to Six Sigma quality are essentially those of statistics and probability. In simple language, these concepts boil down to, “How confident can I be that what I planned to happen actually will happen?” Basically, the concept of Six Sigma deals with measuring and improving how close we come to delivering on what we planned to do.

Anything we do varies, even if only slightly, from the plan. Since no result can *exactly* match our intention, we usually think in terms of *ranges* of acceptability for whatever we plan to do. Those ranges of acceptability (or tolerance limits) respond to the intended use of the product of our labors–the needs and expectations of the customer.

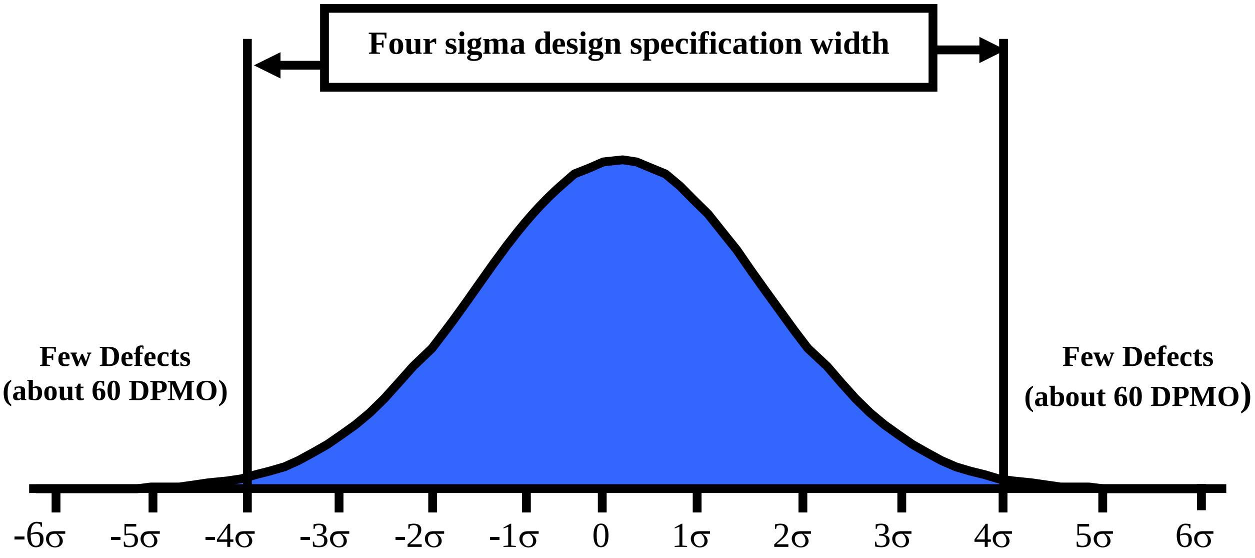
Here’s an example. Consider how your tolerance limits might be structured to respond to customer expectations in these two instructions:

“Cut two medium potatoes into quarter-inch cubes.” and “Drill and tap two quarter-inch holes in carbon steel brackets.”

What would be your range of acceptability–or tolerances–for the value *quarter-inch*? *(Hint: a 5/16” potato cube probably would be acceptable; a 5/16”threaded hole probably would not.)*Another consideration in your manufacture of potato cubes and holes would be the *inherent capability* of the way you produce the quarter inch dimension–the capability of the process. Are you hand-slicing potatoes with a knife or are you using a special slicer with preset blades? Are you drilling holes with a portable drill or are you using a drill press? If we measured enough completed potato cubes and holes, the capabilities of the various processes would speak to us. Their language would be distribution curves.

Distribution curves tell us not only how well our processes have done; they also tell us the probability of what our process will do next. Statisticians group those probabilities in segments of the distribution curve called *standard deviations* from the mean. The symbol they use for standard deviation is the lower-case Greek letter *sigma*.

For any process with a standard distribution (something that looks like a bell-shaped curve), the probability is 68.26% that the next value will be within one standard deviation from the mean. The probability is 95.44% that the same next value will fall within *two* standard deviations. The probability is 99.73% that it will be within *three* sigma; and 99.994% that it will be within *four* sigma.

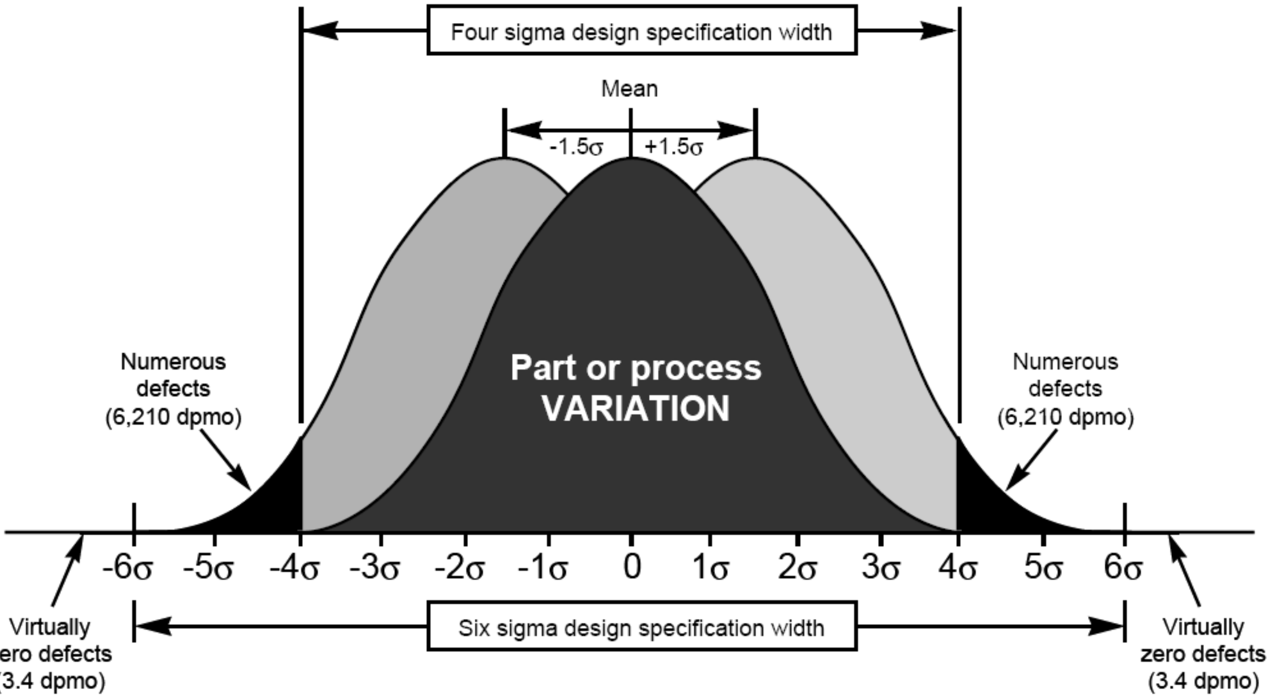


Standard distribution curve with mean, sigma values and four sigma tolerances.

DPMO = Defect Per Million Opportunities

If the range of acceptability, or tolerance limit, for your product is at or outside the four sigma point on the distribution curve for your process, you are virtually assured of producing acceptable material every time–provided, of course, that your process is centered and stays centered on your target value.

Unfortunately, even if you can center your process once, it will tend to drift. Experimental data show that most processes that are in control still drift about 1.5 sigma on either side of their center point over time.



For a product to be virtually defect free, it must be designed with both normal process variation and process drift in mind. With these things considered, a Six Sigma design specification width would produce a yield of 99.99966%–3.4 defects per million opportunities or virtually zero defects.

This means that the real probability of a process with tolerance limits at four sigma, producing acceptable material is actually more like 98.76%, not 99.994%.

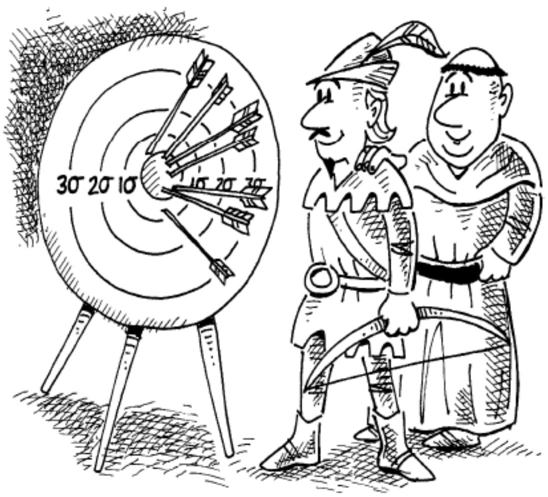
To reach near-perfect process output, the process capability curve must fit inside the tolerances such that the tolerances are at or beyond *six* standard deviations, or Six Sigma, on the distribution curve. That is why we call our goal *Six Sigma quality*.

Quality makes us strong

In the past, conventional wisdom said that high levels of quality cost more in the long run than poorer quality, raising the price you had to ask for your product and making you less competitive. Balancing quality with cost was thought to be the key to economic survival. The surprising discovery of companies which initially developed Six Sigma, or world-class, quality is that the best quality does not cost more. It actually costs less. The reason for this is something called *cost-of-quality*. Cost-of-quality is actually the cost of deviating from quality–paying for things like rework, scrap and warranty claims. Making things right the first time–even if it takes more effort to get to that level of performance–actually costs much less than creating then finding and fixing defects.

Shooting for Six Sigma: An illustrative fable

The underlying logic of Six Sigma quality involves some understanding of the role of statistical variation. Here's a story about that. Robin Hood is out in the meadow practicing for the archery contest to be held next week at the castle. After Robin's first 100 shots, Friar Tuck, Robin's Master Black Belt in archery, adds up the number of hits in the bull's eye of each target. He finds that Robin hit within the bull's eye 68% of the time.



Friar Tuck plots the results of Robin's target practice on a chart called a histogram. The results look something like this. "Note that the bars in the chart form a curve that looks something like a bell," says the friar. "This is a standard distribution curve. Every process that varies uniformly around a center point will form a plot that looks like a smooth bell curve, if you make a large enough number of trials or, in this case, shoot enough arrows."

Robin scratches his head. Friar Tuck explains that Robin's process involves selecting straight arrows (raw material); holding the bow steady and smoothly releasing the bowstring (the human factor); the wood of the bow and the strength of the string (machinery); and the technique of aiming to center the process on the bull's eye (calibration and statistical process control).

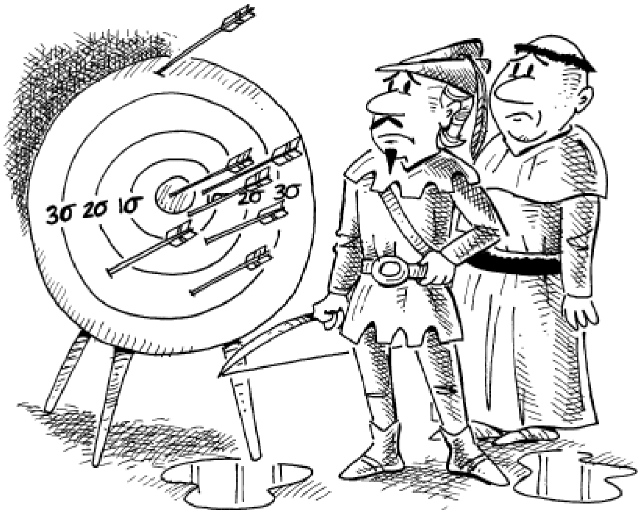
The product of Robin's process is an arrow in a target. More specifically, products that satisfy the customer are arrows that score. Arrows outside the third circle on these targets don't count, so they are defects. Robin's process appears to be 100% within specification. In other words, every product produced is acceptable in the eyes of the customer.

"You appear to be a three- to four-sigma archer," the friar continues. "We'd have to measure a lot more holes to know for sure, but let's assume that 99.99% of your shots score, that you're a four sigma shooter." Robin strides off to tell his merry men.

The next day, the wind is constantly changing directions; there is a light mist. Robin thinks he feels a cold coming on. Whatever the reason, his process doesn't stay centered on the mean the way it did before. In fact, it drifts unpredictably as much as 1.5 sigma either side of the mean. Now, instead of producing no defects, after a hundred shots, Robin has produced a defect, a hole outside the third circle. In fact, instead of 99.99% of his shot scoring only 99.38% do.

While this may not seem as if much has changed, imagine that, instead of shooting at targets, Robin was laser-drilling holes in turbine blades. Let's say there were 100 holes in each blade. The probability of producing even one defect-free blade would not be good. (Because the creation of defects would be random, his process would produce some good blades as well as some blades with multiple defects.)

Without inspecting everything many times over (not to mention spending an enormous amount for rework and rejected material), Robin, the laser driller, would find it virtually impossible to ever deliver even one set of turbine blades with properly drilled holes.



Overall Yield vs. Six Sigma Quality Level
(Distribution Shifted +/- 1.5σ)

Number of parts or steps	+/- 4σ	+/- 6σ
1	99.379%	99.99966%
7	95.733%	99.9976%
10	93.96%	99.9966%
20	88.29%	99.9932%
40	77.94%	99.9864%
60	68.81%	99.9796%
80	60.75%	99.9728%
100	53.64%	99.966%
150	39.38%	99.949%
200	28.77%	99.932%
300	15.43%	99.898%
400	8.28%	99.864%
500	4.44%	99.830%
600	2.38%	99.796%
700	1.28%	99.762%
800	0.69%	99.729%
900	0.37%	99.695%
1,000	0.20%	99.661%
1,200	0.06%	99.593%
5,000	-	98.314%
20,000	-	96.656%
70,000	-	78.820%

Since defects are cumulative, as more parts or more operations are added, the chance of producing a defective product goes up. With process drift as a factor, if the number of parts or process steps exceeds 1200, four-sigma processes are virtually incapable of making one good product. On the other hand, a Six Sigma process with 1200 parts or steps would still be producing a yield of 99.593% good products.

Not only would the four-sigma producer have to spend much time and money finding and fixing defects before products could be shipped, but since inspection cannot find all the defects, she would also have to fix problems after they got to the customer. The Six Sigma producer, on the other hand, would be able to concentrate on only a handful of defects to further improve the process.

How can the tools of Six Sigma quality help? If Robin the archer were to use those tools to become a Six Sigma sharpshooter instead of a four-sigma marksman, when he went out into the wind and rain, he would still make every shot score. Some arrows might now be in the second circle, but they would all still be acceptable to the customer, guaranteeing first prize at the contest. Robin the laser driller would also succeed; he would be making virtually defect free turbine blades.

The steps on the path to Six Sigma quality:

1. Measurement

Six Sigma quality means attaining a business wide standard of making fewer than 3.4 mistakes per million opportunities to make a mistake.

This quality standard includes design, manufacturing, marketing, administration, service, support–all facets of the business. Everyone has the same quality goal and essentially the same method to reach it. While the application to engine design and manufacturing is obvious, the goal of Six Sigma performance–and most of the same tools–also apply to the softer, more administrative processes as well.

After the improvement project has been clearly defined and bounded, the first element in the process of quality improvement is the measurement of performance. Effective measurement demands taking a statistical view of all the processes and all the problems. This reliance on data and logic is crucial to the pursuit of Six Sigma quality.

The next step is, knowing what to measure. The determination of sigma level is essentially based on counting defects, so we must measure the frequency of defects. Mistakes or defects in a manufacturing process tend to be relatively easy to define–simply a failure to meet a specification. To broaden the application to other processes and to further improve manufacturing, a new definition is helpful: *a defect is any failure to meet a customer satisfaction requirement*, and the customer is always the next person in the process.

In this beginning phase, you would select the critical-to-quality characteristics you plan to improve. These would be based on an analysis of your customer's requirements–(usually using a tool like Quality Function Deployment.) After you clearly define your performance standards and validate your measurement system (with gage reliability and repeatability studies), you would then be able to determine short-term and long-term process capability and actual process performance (Cp and Cpk).

2. Analysis

The second step is to define performance objectives and identify the sources of process variation. As a business, we have set Six Sigma performance of all processes within five years as our objective. This must be translated into specific objectives in each operation and process. To identify sources of variation, after counting the defects we must determine when, where and how they occur. Many tools can be used to identify the causes of the variation that creates defects.

These include tools that many people have seen before (process mapping, Pareto charts, fishbone diagrams, histograms, scatter diagrams, run charts) and some that may be new (affinity diagrams, box-and-whisker diagrams, multivariate analysis, hypothesis testing).

3. Improvement

This phase involves screening for potential causes of variation and discovering interrelationships between them. (The tool commonly used in this phase is Design of Experiment or DOE.) Understanding these complex interrelationships, then allows the setting of individual process tolerances that interact to produce the desired result.

4. Control

In the Control Phase, the process of validating the measurement system and evaluating capability is repeated to insure that improvement occurred. Steps are then taken to control the improved processes. (Some examples of tools used in this phase are statistical process control, mistake proofing and internal quality audits.)

Words of Wisdom about Quality

If you believe it is natural to have defects, and that *quality* consists of finding defects and fixing them before they get to the customer, you are just waiting to go out of business. To improve speed and quality, you must first measure it–and you must use a common measure.

The common business-wide measures that drive our quality improvement are *defects per unit of work* and *cycle time per unit of work*. These measures apply equally to design, production, marketing, service, support and administration.

Everyone is responsible for producing quality; therefore, *everyone* must be measured and accountable for quality. Measuring quality within an organization and pursuing an aggressive rate of improvement is the responsibility of operational management.

Customers want on-time delivery, a product that works immediately, no early life failures and a product that is reliable over its lifetime. If the process makes defects, the customer cannot easily be saved from them by inspection and testing.
A robust design (one that is well within the capabilities of existing processes to produce it) is the key to increasing customer satisfaction and reducing cost. The way to a robust design is through concurrent engineering and integrated design processes.

Because higher quality ultimately reduces costs, the highest quality producer is most able to be the lowest cost producer and, therefore, the most effective competitor in the marketplace.

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