Reducing the Cost of Poor Quality

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ABSTRACT
A simple definition of the cost of poor quality (COPQ) is all the costs that would disappear if your manufacturing process was perfect. This includes all appraisal, prevention, and failure costs. Anyone running a company knows these costs exist, but what they may not realize is how much of their expenses are tied directly to COPQ. The industry average is around 20% of sales with a range of 1% of sales in a six sigma organization up to 40% of sales at a three sigma organization [1], meaning for the average company there is large potential for improvement. By using the basic six sigma tools of Statistical Process Control (SPC) and Capability Processes, the average factory can reduce the cost of poor quality and increase their bottom line profits.

Key Words: COPQ, Capability, Six Sigma, Cpk, Quality, Quality Assurance, rework, scrap.

INTRODUCTION
A widely used rule of thumb says if a defect costs $100 to fix in the field it would only cost $10 to fix in your facility and only $1 to prevent, so in this case an ounce of prevention is definitely greater than the pound of cure. This means in the manufacturing process we want to stop defects before they are created. The six sigma capability and SPC tools can stop the defects before they are created and reduce the COPQ by allowing maintenance to move toward a predictive model instead of a reactive one. The ability to schedule downtime and get to issues’ root causes allow for less production interruptions and better quality.

As a company moves toward becoming a six sigma corporation the COPQ as a percent of sales will drop drastically (Figure 1). The better your control over the process, the less defects you will have, reducing the cost of poor quality. That is an intuitive principle with which no one would disagree; many companies even have corporate slogans to this end. Yet there are only a few organizations embracing this at the factory level. Even fewer companies maintain these initiatives past the initial quality blitz. Why is this true? There are two possible reasons. The first is people overestimate their current process control, which leads to an underestimation of the cost of poor quality – they don’t even know there is an issue. The second reason could be that they have not seen a true correlation between their past quality initiatives and making more profit. In either case their facility has been settling for lower profit. They need to take a look at their process through a true six sigma approach and determine what needs to be done to improve.

Six Sigma Goal
The goal of a six sigma organization is to increase the company’s profit by reducing variations and thus improving their process. One of the key phases of the DMAIC (Define/Measure/Analyze/Improve/Control) process is the control phase. Without properly implanting that control phase a factory won’t be able to maintain meaningful, long-term results. Two commonly used tools in the control phase have been part of process improvement programs since the 1960s. These simple tools are control charts and capability studies. The trick for today’s factories is actually implementing them correctly and in a cost-effective manner. Spending money alone doesn’t always equate to correct implementation. Doubling the number of your QA inspectors, putting an inspection machine in every line, and having redundant visual inspection will raise your cost, but will they increase your quality? A better way to improve your quality is to understand the process to make informed decisions. Good data is required in order to do that and in many cases this data is collected in the SPC process. An
understanding of process capability allows the user to take the data and make informed decisions about what needs to be done.

**Control Charts as Predictive Tools**

Control charts determine if your process is repeatable and predictable. This is done by consistently taking data over time and plotting it against the control limits. Control limits are always set at plus or minus three standard deviation (+/-3σ) level. These limits are not user selectable; they are determined by the process. These charts improve manufacturing by allowing an engineer to better understand their processes and detect early changes to those processes. If the control limits move, a SPC test fails and the engineer is informed that something needs to be done. SPC tests can be selected by the engineer depending on how aggressive they want to be in alerting of potential problems. The more tests applied, the greater the chance of catching a problem before a defect is created, but this will also increase the chance of false calls. Too many false calls and the system becomes unreliable and people give up using it. The real challenge is how to intelligently setup the system to balance false calls with detecting changes in a process before defects are created. Typically maintenance gets called when defects are discovered. They try to figure out a quick solution to the problem to get production running again. They never have the time to get to root causes of the problem, which allows the problem to reoccur. When the system is working properly, maintenance can now schedule the most appropriate time to research the issue noted by the control chart. They can plan for a large enough block of time to get to the root of an issue and really fix it, not just band-aid the process. This allows the facility to reduce their downtime and their cost of poor quality.

**Case Study – Inadequate Control Charting Costs Money**

If a company is not careful they can lose track of their facility’s cost of poor quality. The company in this study had a quality initiative about 6 years ago that was very successful in reducing the COPQ in their facility. They were confident that the processes that put in place would maintain their high quality levels. But this facility started having problems with misplaced parts; maintenance was called to the line 12 times over 2 months for the same issue. Maintenance would try to get the line up and running as quickly as possible to reduce their COPQ, but the problem kept returning since they were never able to get to the root. This line’s DPMO during these 2 months was above 40. When the root cause was found and fixed the DPMO was reduced to below 15 and at times as low as 7. One broken part had cost the company thousands in downtime and defects. As part of their quality initiative, they put a procedure in place to weekly check the accuracy of the placement machines. They felt confident that this procedure would alert them to any problems and allow them to fix the machines before defects were created. The inspection didn’t identify the problem due to 4 issues with the inspection procedure. First, the fixture had loosened up over time and now the inspection failed GR&R, so the data wasn’t reliable. When they started inspecting their placement machines the smallest component placed by the process was a 2125 (Figure 3). Now their smallest component was a 1005 and moving towards 0603. Their specification limits had not changed over this time and now were too large for the smaller parts they were running. This meant they could be creating defects even when passing their Cpk checks. Third, they were using the same component for the last 6 years and it was no longer representative of their product. Finally, they didn’t test the machine completely – only 1 rotation was measured. So if the machine had problems placing parts at different rotations, these defects would not be found. This company’s DPMO and cost of poor quality kept rising and they could not determine the reason. If their control procedures were reviewed and updated over time, the problem could have been discovered before defects were created. They could have scheduled time during their weekly maintenance to address the issue and get to the root much quicker. The control charts and procedures would have even alerted the maintenance technician to the area of the machine that had the mechanical failure. If the company had the proper control procedures in place they could have saved over $30K per month in scrap (Figure 4). This example is just looking at 1 line, but this could be happening in their entire facility.
Capability Defined

Having a process that is controlled is not enough. The process also needs to be capable. The definition of capability is the ability to perform the required actions. For a manufacturing process, capability is defined as having a process that can make the final product without defects. This is determined by using a statistical number called the Process Capability Index (Cpk/PpK). This index is a ratio between the control limits and the specification limits. So a Cpk of 2.0 means that 2 times the process’ control limits fit inside the product’s specification limits. When looking at Figure 5 it is easy to see the difference between a 1.47 Ppk process and a 2.19 process. In a true six sigma process if a point moves outside the control limits and is flagged by the SPC chart, it does not create a defect. However, if the process is a four sigma process a defective part could possibly create a defect. If the process is a three sigma process, by definition, a point outside the control limits is also a point outside the specification limits.

How to make Capability Meaningful

In most cases changing control limits is difficult since it requires a fundamental change to the process. This fundamental change usually means buying new equipment. Changing specification limits is difficult as well, since these limits should be tied directly to the products being built by the process. What happens all too often in the industry is that the specification limits are not tied to the product but to some predetermined guideline or the machine vendor’s specification. When this occurs the Ppk/Cpk numbers are no longer useful in their intended purpose, which is to predict yield. If the process specifications are tied to a company standard instead of the product’s needs, new products with tighter specifications can cause defect levels to rise and no one in the company may understand why this is occurring. Parts are continually getting smaller in electronics manufacturing - going from 1608s-1005s-0603s, for example. Along with this change, the specification limits for the process should be reduced as well. If a reduction in the specification limits does not occur, the Cpk will remain high and DPMO will increase since the process needs to be tighter to remain free of defects (Figure 6). Management will question why there are so many defects when their process is still passing Cpk. This mistake can leave many managers feeling like Cpk is a useless number that cannot predict anything in their facility.

The companies who tie their specification limits to machine vendor’s specifications also have a similar problem. As newer machines are brought into their facilities, the specifications are changed to the tighter one of the new machines. Now the same products may be running on lines with a different specification. This doesn’t make much sense since the board requires one specification. The board doesn’t care if it is built on a new machine or an old one. If the Cpk of the new line is 1.6 with the 0.05mm specification, and they get the same 1.6 Cpk on the old line with a 0.100 specification, it doesn’t mean they will get the same amount of defects on each line. It all depends on the boards being run on each line. In this case the manufacturer is still not getting real value from their capability tests.

To get correlation between capability and COPQ, manufacturers should do two things: the first is to qualify their lines to different capability levels and the second is to determine the capability/specification of each product. This will tell which product should run on which lines. This can also aid in determining when equipment should be retired. As product requirements increase and the old lines have fewer products available to be run, it will be obvious when the equipment is no longer useful in the facility. In most facilities though, these lines continue to run, building products they are no longer capable to build and pushing the cost of the poor quality up over time.
Case Study – Correlation between Calibration and First Pass Yield

A large EMS company was expanding very rapidly for a number of years. Their focus was on growth while quality initiatives were at the bottom of the list due to the high demands of constant expansion. After 4-6 years of the growth focus they noticed some alarming statistics about quality in their facility. The first pass yield was very low on some of their lines. One of the lines in question had a first pass yield of 75%. Since no control charts or capability studies had been done on these machines in over 2 years, they didn’t know why the first pass yield was so low. The first order of business was to determine a baseline for process capability. The measured Ppk numbers were very low, all below 1.0. Very little information was kept for maintenance records so it was hard to determine why the machines were in their current state. After some research it was determined that some mechanical parts had been replaced over the two-year period and, due to the lack of jigs, not all the factory calibrations were done. So the machines were calibrated and the Ppk values were checked using an external optical inspection machine. The values were now on a range of 1.5-2.5. The first pass yield for the next week were 89% - a 14% overall improvement. The calibration only took 45 minutes and would save $35,000-$60,000 a month if applied to all 10 lines. This doesn’t even take into account the soft saving of reduced maintenance time and production down time. Originally specification limits for the capability test were 0.05 mm since this was the facility standard. This specification had no tie to the product running on the lines so it could not be used directly to predict their DPMO. To get some idea about their DPMO, an estimate was obtained using Figure 7, the IPC9621 estimated yield chart and knowing they have about 7,000 opportunities a board. A first pass yield of 75% and 7000 opportunities gives that line an estimated 50 DPMO value. The final first pass yield of 89% estimates a 22 DPMO value. This DPMO change directly reduced the COPQ $35,000-$60,000 per month.

Case Study – Quality Initiatives and ROI

The six sigma process’ main goal is to increase a company’s profit. Putting quality initiatives in place consume resources and cost money. There needs to be a good ROI, balancing the cost of the defects and the cost of the procedures put in place to eliminate them. How often a machine needs to be checked for capability will depend on the machine, the process, the accuracy required, as well as how long the machines have been in use. For example, a three-year-old car doesn’t necessarily have the same reliability as another three-year-old car. The number of miles driven, how often the oil was changed, the type of car, and how it was driven will determine how consistent and reliable it will perform over time. The same is true for a manufacturing process with how tight the tolerances have been, the type and age of the machines, how many shifts are run, and how well the preventative maintenance schedule was followed. In processes with good controls a 1.5σ mean shift is expected over time. If the process mean is deviating more than 1.5σ, action should be taken to bring the machine back into specification. How often a machine needs to be checked is determined on a machine-by-machine basis. The following study was performed to get an idea of the average minimum time between tests.
The customer selected had a large quantity of equipment, good maintenance procedures, 1005 chips very commonly placed, and ran 3 shifts/24 hours/seven days a week. Over an 8 month period 15 machines were measured during installation to determine baseline Ppk values. After about a year the machines were measured again. At this point the machines had operated 24/7 anywhere between 11-21 months between the inspection tests. The machines were calibrated by updating offsets; no mechanical adjustments were made. Figure 8 shows the data collected. Ppk averages dropped from the 3.0+ Ppk to a 1.36-1.65 Ppk level. After 1 to 2 years of production most of the machines were still performing at acceptable levels, but, depending on the product, that may not have been good enough. After calibration the machines were back above their 3 Ppk averages. The conclusion that can be drawn from this data is that new machines hold up well over time but will degrade from the installed date at some rate. Since calibration only took about 30 minutes per machine, it is a good idea to check the machines more frequently than once every 1-2 years. Increasing that number to quarterly control charts are still of little value since many of the control chart tests are setup to run on a much more frequent basis. One example is a test that states if 6 points in a row are ascending/descending, the machine is moving out of control. For this test 6 measurements need to be taken before it is even valid. Inspecting machines like this on a quarterly basis would take at least 18 months to see if the test has been failed. Data from the study showed that within 18 months intervention was needed to maintain the machines to the highest levels; a control chart run quarterly would not provide the best results. However, if the customer sets up a procedure to quarterly calibrate their machines and is not concerned about tracking the machine longevity, this could be a cost-effective approach. There would be two risks involved though; the first is possibly wasting time if calibration is only needed every 6 months and the second would be the possibility of an operator breaking something two days after the calibration – the DPMO would remain high for the remaining 3 months. Both of these risks can be minimized.

An ideal system would eliminate these risks by using control charts and checking more frequently. It could be expected that nothing would need to be done most of the time if the machines were checked every week. But this added resolution will help maintenance find issues before defects are created. Trends can be analyzed and special cause variation can be identified well before parts are placed outside specification limits. Weekly tests may be too frequent, in some facilities bi-monthly or monthly tests are more appropriate. This should only be done if there is enough data to backup the conclusion that the process is stable. Since it is better for a facility to check their machines at more regular intervals, the emphasis of engineering should be on reducing downtime associated with running these tests. If the systems are setup properly, capability tests can be run with minimal affects on production. In some facilities these checks take less than 10 minutes and can be performed during shift changes. When running capability tests doesn’t affect production more tests can be run and maximizing the ability of maintenance to make informed decisions about the process. This will in turn decrease the cost of poor quality in their facilities and increase profit.

Conclusion

While a few companies dedicated to the variation reduction can be spending as little as 1% of their sales on the COPQ, the majority are spending 20% or more. Reducing the COPQ can be a gold mine for most companies. As simple as it may seem, a good company can become great by using control charts and capability studies appropriately. These are not new ideas in manufacturing or quality; they just need to be implemented properly. By doing this companies can bring down the cost of poor quality and increase their profit. In the competitive manufacturing market, can you really afford to throw these dollars away?