Test for Success – Fundamentals of Statistical Process Control

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Introduction

A manufacturing process can, at any given point in time, be in any of an infinite number of given states. Total and complete characterisation of such a complex system is virtually impossible. While identification of all of the variables (chemical, thermodynamic, environmental etc.) is an idealised objective, there are many things which can be done to control and improve such a system. How would we go about undertaking such a seemingly impossible task? Well, the first thing to do is to realise a couple of key points. Firstly, even though there are a huge number of variables in the system, they are not all equal, i.e. a small number of variables provide the major influence and thus define the system characteristic, while the vast majority of these variables have little, if not negligable effect on the system. Secondly **-** and this is probably one of the fundamental concepts of manufacturing process control **-** these variables combine to have an overall net effect on the process. Even though this is a highly non-linear and 'many to one' relationship, there are ways that such systems can be characterised, at least to such an extent that the key variables can be identified and controlled. Once the system is under control, there exists significant scope for further improvement.

Though the obvious goals of process improvement, simply stated, are to make better products, meet manufacturing, customer and industry specifications and to reduce defects etc. A shrewd implementation of modern Statistical Process Control (SPC) methods can have far reaching implications on a company's fortune, which extend far beyond the production floor and Quality Control departments.

Not many of us would disagree that the optical media industry is facing some of the most challenging times in its history. As if competition from online content delivery, emerging competitive storage formats, overcapacity and global economic influences are not enough to deal with, we have experienced, over the last couple of years, a high degree of volatility in the price of raw materials in the market. These factors have had a significant impact on the industry in general, leading to heavily compromised profit margins for manufacturers.

While these external influences are outside of our control, it is important for the disc manufacturer to realise that a well-implemented QC system, particularly in the current industry climate, can help to reduce exposure to some market influences, particularly to the impact of raw materials costs but also in the case of reducing the risk of lost business due to product failures.

A naïve approach to product testing.

To many people, product testing is simply seen as a means of ensuring that products meet basic specifications. While of course this is a key requirement, there is a lot more that you can do to ensure that effective utilisation of your test equipment *can* provide a means to an improved return on investment far beyond just providing the capability of saying that your products pass or fail.

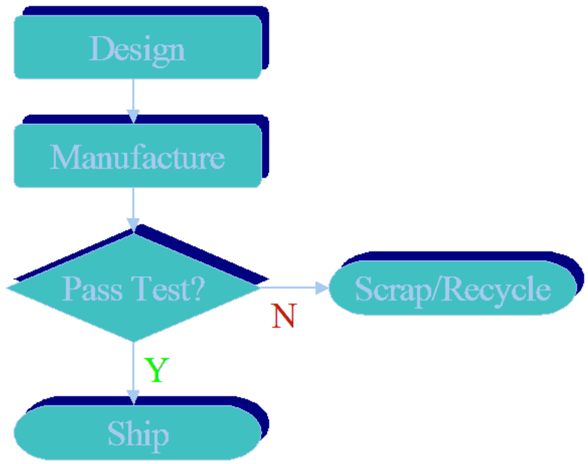


Figure 1.

Figure 1 Shows a test system implementation in its most basic form. While this addresses the fundamentally held concept of testing in its most basic form and is significantly better than no testing at all. It can be shown that a better-implemented testing strategy can address a lot more than just ensuring that products meet specification

Some key definitions from SPC

While a thorough discussion of statistical theory, is beyond the scope of this article. I will attempt to introduce some high level concepts from SPC which can at least serve as an introduction tp the subject and perhaps encourage the reader to undertake further study of the subject area. Well-implemented SPC methodology is not the sole reponsibility of the Quality Control department. Indeed, for SPC to truly succeed within an organization, the concept must be understood and supported from all facets and at all levels including top management. Anything less is just a token implementation and will never reach it's true potential.

Sources of variation.

Fundamental to the concept of SPC is the idea of process variation. Put another way, variation, is a fundamental measure of product and process performance. While variation can come from many sources which can, with proper testing and procedures, be identifed and minimised, a basic rule of thumb is that reducing variation is a step in the right direction so, in a nutshell, the smaller, the better.

Process 'Signal to Noise Ratio'.

The concept of Signal to Noise Ratio or SNR comes from the field of Information theory and Communications Engineering which are, at a deeper technical level intimately entwined with optical disc technology but in a different sense to what we are describing here. In these fields, the concept of SNR which is defined as the signal amplitude, divided by the noise power, is used as a basic figure of merit which describes a communications channel's ability to carry information without loss of fidelity. In the area of process control it has a slightly different interpretation, however it's ability to describe an overall figure of merit of a production process is essentially no different. In this context, we define the signal 'amplitude' as the distance between the process mean or average value and the nearest process control limit and the 'noise' as the process standard deviation. Now if we take a moment to reflect on this definition, it may strike us that there are two things that we can do to make this ratio bigger: 1) we can make the amplitude bigger and 2) we can make the noise smaller. Well, the short answer is yes and the longer answer is yes but with limitations. Perhaps some illustrations can provide a better insight into the concept.
Figure 2. Shows a graph of a normally distributed variable, which could for argument's sake represent a key process variable, that we are trying to control.

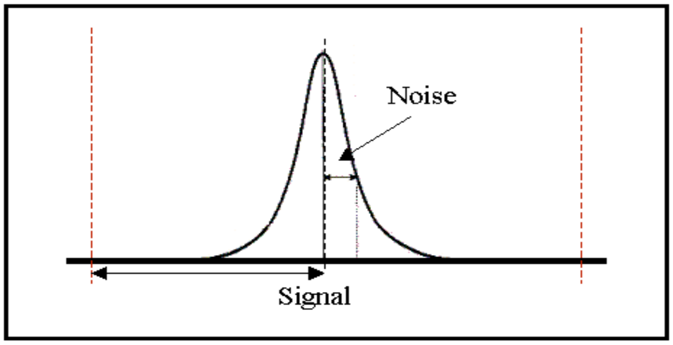


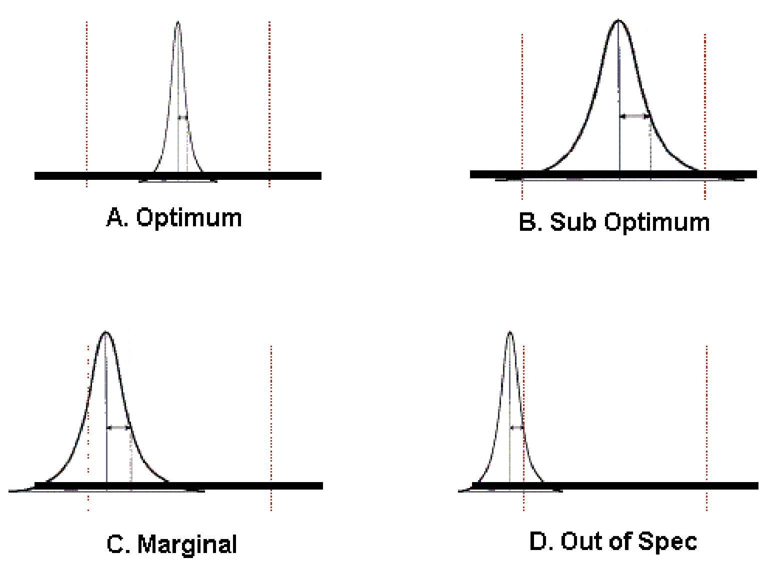
Figure 2.

Figure 2. Shows the concept of a process'Signal to Noise Ratio. The signal amplitude being defined as the distance to the nearest process limit, and the noise, equivalent to the standard deviation. The figure may make it more apparent, that we can tweak the process to increase the amplitude, however, in many cases the process variable has an upper and lower limit and thus we can only approach an optimum by centering the process mean exactly between the limits.

Now, with this information in hand, let us explore some basic ideas about our process, how it could perceptually behave and the kind of information that testing can give us about the situation. Figure 3. Shows four possible process conditions (among many) which could represent the condition of a real world process. Now the question here is; what will our testing and Quality Control strategy tell us about these scenarios? Well, in the first instance (Figure 3.A) the process is pretty much optimum so Go/NoGo testing and SPC will tell us that everything is OK in this situation. A truly ideal condition would be a straight vertical line, perfectly centred between the two limits but for the purposes of practicality, we will confine ourselves to the real world! Figure 3.B shows a scenario where the mean is centred but the standard deviation or 'process noise' is higher. This is a sub optimum situation, in that while it may seem OK we know by now that we can do better. SPC will tell us this because it also looks at the standard deviation.

Now by the time we get to the situation in Figure 3.C the picture gets a bit fuzzy. SPC will tell us that we are sailing too close to the wind because our magic SNR number is getting very low. Conventional Go/NoGo testing in this situation, is a bit of a coin toss, because chances are that our discs will pass. Obviously if we tested enough discs we would see occasional failures (the astute reader with a set of Z scores at hand could probably tell us the odds). Figure 3.D is probably more cut and dried, in that SPC will tell us that we're in big trouble as most likely will Go/NoGo testing but you can still see that Go/NoGo also has a non zero (in fact fairly significant) probability of passing discs.

Figure 3. Four possible process conditions



The concept of a 'Cost Function'.

Before we get lost in the world of advanced probability and statistics let us stop and take stock of what we have learned and how this abstract concept of Signal to Noise has an impact on our business, not just in an abstract technical way, but in a way that relates to our bottom line. To do so we will define the concept of a Cost Function C(x). Although this may appear to be a mathematical abstraction, it will give us an idea of how our manufacturing costs can vary as a function of our process SNR. Because our Cost Function can be counted in Dollars and Cents you may appreciate the underlying tangibility and appreciate it as more than a simple theoretical construct. However, let us proceed and define our cost function C(x) as the relative cost, as a function of our process mean from its optimum location. In this case, the function is quadratic and can be described by the the function $C(x) = ?x^2 + b$, where ?x is defined as the difference between the process mean and the process optiumum (in the canonical form of the equation) . Figure 4 shows the general idea.

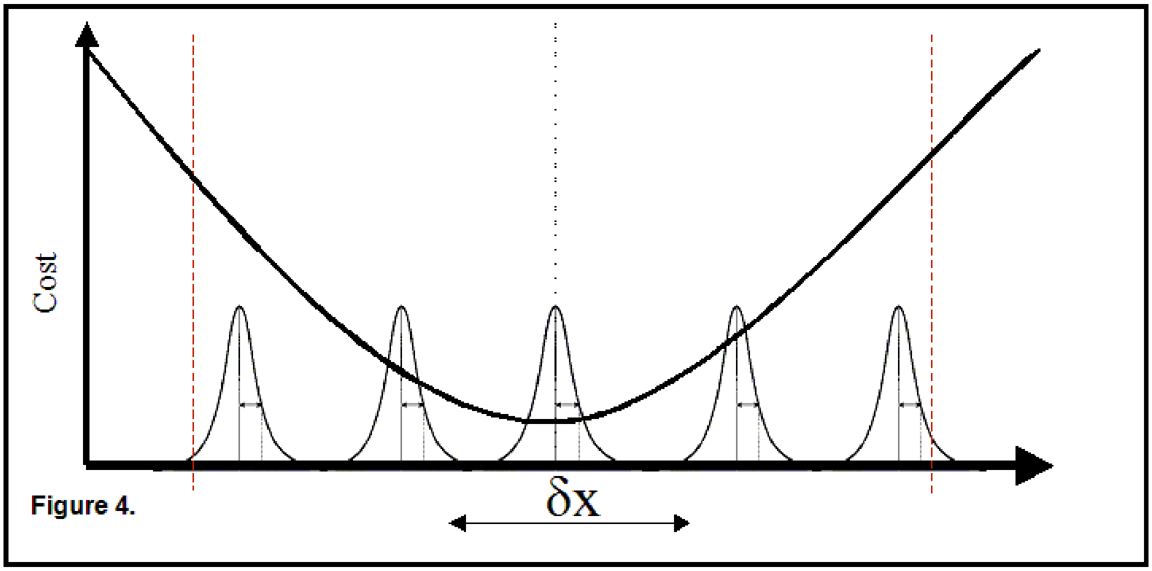


Figure 4.

Now, the striking feature of this curve, is that as our process mean moves away from the optimum by a factor of ?x, our cost increases by a factor of $?x^2$! This is certainly no joke where money is involved. The process noise has a different effect, in that the curve is still parabolic, however the 'noise' affects the b factor in the equation, thus translating the whole curve upwards, the minumum is still at the centre but the minimum achievable cast is higher.

Test Equipment, the cost of ownership.

The decision to purchase test equipment, like any other capital investment, is a decision, which is not taken lightly. Many factors are routinely considered. In making a capital purchasing decision, industry executives usually consider the obvious costs of ownership such as the purchase price, value for money, operating costs and manpower costs such as operator training, hands-on time for calibration, routine maintanance and so forth. Less often considered are the hidden costs of test equipment ownership. For instance, low sensitivity, on the part of a test player, can fail to characterise the true nature of a process. Another critical factor, tester accuracy, can indicate a false postion in relation to the optimum process centre. This is a particularly insidious effect since the concept of a cost function, as demonstrated above, tells us that any movement away from the optimum increases our cost by a function of $?x^2$, this basicall means that tester error costs money. Low tester repeatibility increases our perceived process noise, this can cause a scenario where unnecessary corrective action is taken to improve a process which is already optimum, again costing money.

Another key factor for consideration is test time. Signal theory tells us that we can completely characterise a signal by sampling it at twice the highest frequency component of the signal, this is known as Nyquist's Theorem, another mathematical abstraction yes, but one nonetheless that made CD and hence this industry possible. So essentially, if our test times are too slow we may fail to completely characterise short-term process variations our own 'signal' of interest.

Closing the Process Loop.

There are a number of key lessons, which hopefully we have learned by now. We have seen that SPC, as opposed to Go/NoGo testing, addresses the continuous nature of the variables that affect our manufacturing process. It takes history into account and can tell us where we are, where we have come from and to a certain extent, where we are going with our process. This continuous aspect of SPC gives us a means to learn what factors affect our process both postively and negatively in a way that attributes (Go/NoGo) based methods cannot. By doing more of the things which make our magic numbers like SNR, which I should also point out is widely known as Cpk in quality control parlance, and less of the things which make the numbers go down we have effectively closed the process loop. This overall concept is summarised in figure 5.

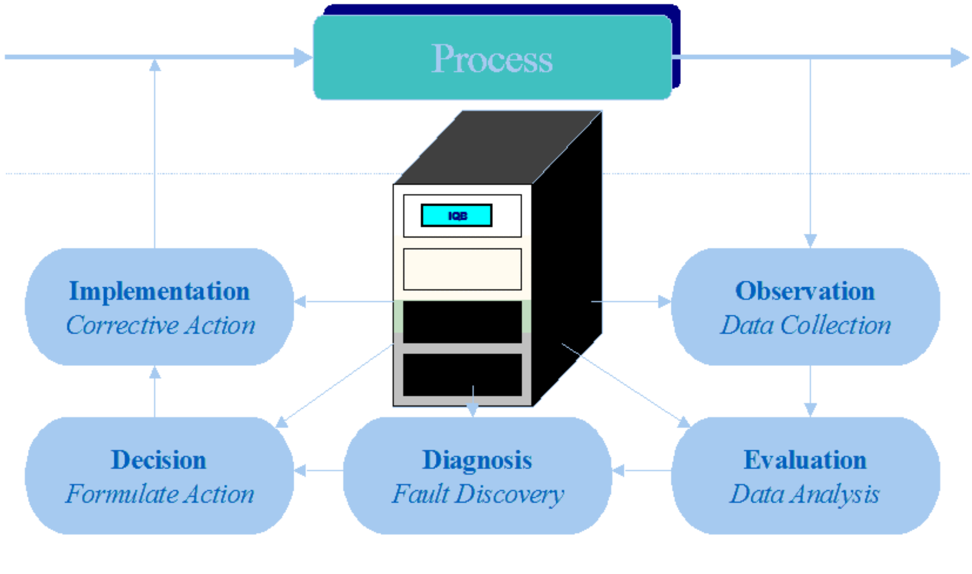


Figure 5

Shameless self-promotion.

Quantized Systems is a manufacturer of test equipment, which addresses all of the issues outlined above, and many more. By working closely with manufactureres we have identified not just the key test parameters involved manufacturing but also rapid test times, high accuracy, repeatibility and reproducibility all key to the effective utilisation of test equipment as discussed above. In addition we have developed a unique solution for the presentation of this information together with a state of the art SQL based database which can calculate the key SPC parameters at the touch of a button. We have taken care of the complexities of data analysis and number crunching so that you can use this information to close your process loop.

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