STATISTICAL PROCESS CONTROL: REQUIREMENTS FOR SUCCESS
"M.4 DESIGN QUALITY: PRODUCIBILITY AND PROCESS OPTIMIZATION"

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ABSTRACT

Statistical process control (SPC), one of the major quality techniques that is being emphasized as part of the resurgence of quality focus in this country, has gained wide appeal with quality experts and novices alike. Basic concepts of SPC are relatively simple statistical operations, but the implementation of a successful, long-term program is not necessarily as straightforward. The paper will concentrate on this sometimes elusive implementation process from a manager's perspective. It will begin by laying the groundwork for SPC both in terms of design and manufacturing, set the stage for startup, and discuss what critical elements must be present for success. SPC's essential role in design and its relationship with manufacturing will be thoroughly detailed. Traditional problem areas of SPC will be covered including what process or product parameters need to be controlled, what charting techniques should be used, and how requirements should be levied on suppliers. The paper will also attempt to dispel some of the common myths of SPC such as the need for long production runs. After establishing the ideal implementation environment, a few case studies will be presented on the successes and failures of several companies' efforts to start an SPC program.

Finally, the real and long-term benefits of SPC including increased communications among all departments, better insight into cost reduction opportunities, variability reduction, continuous quality improvement, and more effective design and manufacturing interface will be addressed to show why this methodology has such great potential to succeed in today's extremely competitive global environment.

INTRODUCTION/BACKGROUND

It wasn't until the United States industrial base hit hard times that the quality theories of past started to resurface. Quality and productivity fell behind countries who just a short time ago were flocking to the U.S. for advice. Japan's success with many of these homegrown methods remains well publicized.

(They are called "homegrown" because international companies like AT&T, IBM, Kodak, and Xerox pioneered these quality initiatives in the 1950's and 60's). One of the quick fixes being promoted in the early 1970's was quality circles (QC). Many industries rushed to adopt this management philosophy without giving second thought to its long-term implications. Implications of not merely identifying areas of improvement but setting up a feedback loop for correction, providing an atmosphere of management-worker cooperation, and looking to the line worker as a legitimate source for quality improvement. As the results failed to reach expectations, some tossed the QC idea off as only being able to succeed in the Japanese culture. What was forgotten was QC, or for that matter any other quality technology, must be a part of a larger company-wide effort to improve product quality. Of course, as many industries can attest, there were and are no quick fixes for the U.S. competitiveness problems and what resulted was a frustrating and painstakingly slow learning process.

My point here is simple. Manufacturing organizations looking to SPC as the sole savior of their quality problems without overhauling other areas of the company are doomed to fail, just as the quality circles of the 70's failed. But SPC used in conjunction with a larger quality improvement program can pay huge dividends.

The purpose of this paper is a discussion on establishing the atmosphere for success in implementing a statistical process control (SPC) program. As I have eluded to in the QC example above, other areas of quality influence must be present for SPC to be fully effective. Throughout most of the paper I will assume the problems associated with the actual number crunching and charting, like what size sample to use?, how often should samples be taken?, what type of chart should be used?, etc. do not exist. I am not being naive, but those problems become almost trivial if the framework for SPC is properly set up. However, in a later section I will provide a perspective on the aspects of charting.

AN OUTLINE

I will begin the paper with a slightly different perspective on SPC. Then I will discuss the vital link between management's commitment and the program's success. Next a review of the needed training before beginning the effort. Following training will be a discussion on design's role in developing a strategy of what to control. The relationship with supplier's and the prime will be detailed. After that, manufacturing's side of the SPC equation will be covered and illustrated with an example. I will spend some time differentiating between attribute and variable charting and highlight the strengths and weaknesses of each. Finally, I will attempt to put to rest a few of the persistent misconceptions of SPC and end with a summary of the powerful, long term benefits found in successful SPC programs.

The keys for success of an SPC program identified below are in priority order and build upon each other. In other words, it is organized in a cookbook fashion. I believe as each key area is covered in order, it will reduce the prospect of taking a step backwards and will avoid the common pitfalls of implementation. I'll begin by offering a new light in which to view SPC.

SPC IN PERSPECTIVE

One of the best definitions I've heard for a successful SPC environment is it is a **tool** of a philosophy to do it right the first time. I have emphasized the word tool because SPC should be viewed in that light. A hammer is useless without nails and wood, so the same is with SPC. And it is not the only tool available, but it is likely the cheapest and most effective because of its use of simple statistics, its ability to prevent defects and reduce variability around a target value. SPC's true selling point is defect prevention. IBM once estimated that if it could eliminate all forms of inspection, that is those procedures that do not **prevent** actual product defects, its work would fall by **33%**. (More on variability reduction will follow towards the end of the paper.) Like anything else, planning the SPC program is critical, perhaps more important than the actual number crunching and charting. To plan for an SPC program, realignment of management's view on quality, in the form of defect prevention rather than detection and quality's role in day-to-day operations, is essential.

MANAGEMENT COMMITMENT

That brings me to my first point. Statistical Process Control starts with management's commitment to its success. As over used and generalized as that statement sounds, it doesn't lessen its importance in implementing SPC. If you don't have management's word, forget the whole effort and don't waste your

time. When Ford Motor Company started their quality program back in the late 70's, they demonstrated their commitment to quality by a very controversial decision. As their market share continued to erode, plant closing became inevitable. Prospective plants were targeted and narrowed until only a couple remained. One was a relatively new plant equipped with a substantial amount of state-of-the-art capital investment and the other was one of their older facilities. But what separated the two was their quality record. The newer plant apparently had been plagued with startup problems and its production quality was notoriously known throughout the company. Ford chose to shutdown the newer plant. Think of the effect that had on those who doubted Ford's commitment to quality.

TRAINING

This is where management's commitment will be first tested, because money talks the loudest. And my first suggestion will not be inexpensive. For large and small companies alike, I would recommend an outside consultant for a couple of reasons. First, the consultant will bring a consistent philosophy to the training. Secondly, an experienced consultant will be familiar with the problems associated with changing the from detection to prevention. This is a point that shouldn't be overlooked. Changing 30 years of habit isn't easy.

Thirdly, the consultant will bring an outsider's perspective. This is important for a company that is used to doing the "old quality approach" of sampling and inspecting their way to quality. It is also important because it will be his only tasking. Someone chosen from within the company as a training source will likely split time with other responsibilities. That simply will not work. Outside resources devoted to SPC training will one of the best investments a company can make.

The next step is to determine which portion of the organization to train first since it is likely not all can be schooled at the same time. I recommend selecting senior representatives from both design and manufacturing. If training both is not possible start with design. I will elaborate on design's role in the following section.

What to cover...

The next step is to determine what to cover. Having been exposed to many different training sources over the last few years, I have developed a somewhat comprehensive list of topics. Ideally, the training should be divided into three broad sections.

A Prelude...

Remaining consistent with the theme that what to control is a more pressing problem than

the charting, so follows my first section. Start with the techniques that can help zero in on those segments of the process that are big players in controlling the characteristics, identified by design, which correlate to product quality. Simple, but powerful techniques like Pareto Analysis and some forms of design of experiments provide a great prelude to the charting exercises (...some forms' because methods like Taguchi's are beyond the scope of most statisticians). This will establish a framework upon which to build the entire philosophy behind SPC. The depth of this section will vary with the type of people being trained. Design and the manufacturing engineers should be thoroughly versed in this area. Plant floor personnel responsible for the charting probably will need only a tertiary knowledge.

In addition, exercises in group problem solving will provide the necessary skills to make the transition from classroom to production proceed more smoothly. These can be as easy as brainstorming and diagrams as long as the problems discussed relate to the company facilities.

The Basics...

This section should deal with the basic statistical assumptions behind the various types of charts. The statistical background is extremely important to making the correct interpretations from the data gathered. Without proper interpretation, process refinement will be a stab in the dark. It should also include procedures for selecting the appropriate sample sizes, hands-on calculations of ranges, averages, control limits, etc. I have emphasized hands-on because the training should simulate, as closely as possible, the production environment. Above all, stress the role the charts play in process refinement and variability reduction around an optimal target value. The goal of SPC efforts is not necessarily controlling the process as much as refining it towards variability reduction.

Implementation...

For lack of a better term, I've titled this training section implementation. It is all the other information that should be covered but would not logically fit under the umbrellas of problem solving or charting. Many of the SPC courses I have attended have addressed the first two areas well, but did not include discussion on how to implement a program. Mainly this section separates the consultants from the statisticians. Successful consultants know the problems of implementation through a combination of trial and error, experience and knowledge of internal corporate procedures.

Specifically, the training should have several exercises devised to simulate a production part to be controlled by SPC. Small

groups could determine what characteristics of the part to be tracked, where in the process the charts be placed, appropriate sampling, and the techniques for continuous improvement. How successful the trainer is in this section will play a large role in the ultimate success of the program.

DESIGN'S KEY ROLE

Design has the key role of determining what to control both in-house and at the suppliers plant. They should explicitly state to the suppliers the characteristics to be controlled and let the supplier's determine how to control them. With in-house manufacturing, they have the exact same responsibility. It is a matter of describing exactly what you want but not how to get it. These key characteristics will be the basis for reporting and verifying quality. The relationship with the supplier is discussed in the next section.

HANDLING THE SUPPLIERS

I should forewarn you and say that this section of an SPC program may be the most difficult of any I will address. Mistakenly, many companies will strive for stringent and unyielding data requirements and in the process shift the objective of the SPC data from verifying incoming material to meeting company policy on the data format. What should govern all actions with the suppliers is two basic data requirements; justification for choosing specific processes and evidence of their control.

In the short term, convincing the suppliers of the need for SPC with its added data requirements will loom large. They will view it as another data requirement tacked onto an already unsurmountable pile of paperwork. To quiet those fears, two objectives of SPC must be promoted: 1) to improve processes by reducing variation through increased knowledge, and 2) with that reduced variation establish process predictability. The two long term goals of SPC should be increased quality and reduced inspection. Suppliers successful at controlling and reducing variation will earn a commensurate status; virtually no receiving inspection and significantly reduced periodic on-site reviews. In effect, by increasing quality documenting it, the suppliers get the prime off their back. The suppliers should be willing to aim for that goal.

Companies undertaking SPC should provide their suppliers with the needed training before such a supplier program begins. This accomplishes several goals simultaneously. To start, it develops all suppliers in approximately the same time frame and provides a consistent training philosophy. Secondly, it sets the tone for what is expected of their programs and gives an opportunity to establish some general ground rules on how the suppliers will be evaluated. And lastly, it simply creates a

communication forum from which to air misunderstandings, differences of opinion and overall concerns with the SPC program.

From the very beginning, companies should insist on a strategy on how the supplier program will be started. I am not talking in terms of a sweeping document describing with great detail the supplier's planned road to quality improvement, but rather just a prioritized list of processes to attack, why they decided on those processes and a simple time table for implementation. Also, there should be identified a focal point with whom the responsibility of SPC resides.

Above all, keep it simple for the beginning. There will be enough problems with the start-up. Encourage and develop the suppliers and slowly. Work with them to set reasonable goals for the effort. In the end you will benefit from the increased communication and from a relationship judged not only with regard to schedule and cost but a documented quality record.

MANUFACTURING

Let me start this section by making a bold statement - Manufacturing is the last place to start an SPC program! You will notice manufacturing resides far down on my recipe for SPC. I don't want to offend the many manufacturing engineers out there (I am one of them), as manufacturing's part in SPC should not be slighted, but don't expect drastic changes in quality if the responsibility for SPC is laid here. The reason is very simple. As stated in the section on design, knowing what characteristics to control is of higher priority than the actual charting done on the plant floor. That is a point many consultants and SPC advocates seem to ignore. There are two sides to the equation: figuring what to control and then controlling it. Design is better suited to determine what aspects of the product must be charted. Personnel on the plant floor should be consulted as to what and where in the process charts be placed.

To make it clearer, I'll give an example. Suppose we are in the business of building car engines and for the moment we'll concentrate on one piece of the engine, the pistons. Design's role would be to establish what characteristics of that piston are critical to its performance. A good bet would be the rings since their size compared to the cylinder wall directly affects how well the engine runs. Then manufacturing must develop a strategy to control that size. They have to ask themselves which processes, of the many that go into making that ring, are responsible for its accurate, consistent size. Is it the surface finishing?, the initial cut?, the plating process?, or is it the metal supplied that has a varied content?

Manufacturing also has the role of determining what tolerances are reasonable. All to

often, tolerances are arbitrarily established or taken from past practices or design rules. Remember capability of a machine or a process is generally determined by comparing the design allowable spread to the natural variation found in the machine. Unreasonable tolerances can make a machine look worse than it actually is. Of course this goes both ways. Finding machines that will never hold design requirements can be justification for new capital investment.

CHARTING

There are two types of charts: attribute and variable. Attribute data charts can be divided into two sections, defectives and defects. See Figure 1.

ATTRIBUTE DATA *

<i>PROPORTION</i>	<i>NUMBER</i>
P CHART	D NP CHART
<i>FRACT NONCONFORMING</i>	<i>E NO NONCONFORMING</i>
EXAMPLE:	<i>F</i>
FRACTION OF BAD	<i>E</i> EXAMPLE:
WELDS IN A DAYS	<i>C</i> NUMBER OF REJECTED
PRODUCTION	<i>T</i> LOTS PER MONTH
	<i>S</i>
U CHART	C CHART
<i>NONCONFORMITIES/UNIT</i>	<i>D</i> <i>NO OF</i>
EXAMPLE:	<i>E</i> <i>NONCONFORMITIES</i>
NUMBER OF PEOPLE	<i>F</i>
ABSENT IN A DAY	<i>E</i> EXAMPLE:
	<i>C</i> NUMBER OF
	<i>T</i> SCRATCHES IN AN "O"
	<i>I</i> RING GROOVE
	<i>V</i>
	<i>E</i>
	<i>S</i>

* SOURCE: GE SPC CALCULATOR

FIGURE 1

Attribute Data...

Very simply, attribute data tracks attributes of a product. Typically these charts are referred to as pass/fail or go/no-go charts. If metal fabrication is your business and the parts, for example, only require a certain minimum tensile strength, then those that

exceed that minimum value are passed and those falling below the value fail. Some applications of these charts aren't nearly as straightforward. While these charts are binary in nature, deciding which is good and which is bad can be very subjective.

An example of this is found charting imperfections in a car paint job. Determining imperfections will vary from inspector to inspector. When this inspector variability is introduced, the information from the charting may be just which inspectors are picky and which are complacent. In other words, the inherent characteristics of the process may be masked by the human variances that are a part of the data gathering. Inferences made on attribute charts about the process may have nothing to do with the process itself but, rather, the inspector. Therefore, the basic reason for SPC, process improvement through increased process knowledge, can be easily defeated by subjective data gathering.

There is another aspect of attribute charting that makes them less than optimal. Generally, attribute charts are placed near the end or at the end of the process, so the opportunity for preventing defects is less. The earlier in the process the chart is placed the greater the quality impact.

Variable Data...

To get more bang-for-the-buck, X-bar and R charts are the best. The difference between X-bar and the P, NP, C, and U charts is that X-bar tracks variable data. By tracking the process rather than the attributes of a process or a combination of processes, X-bar charts can reveal more about the quality of parts being produced. And the power behind SPC comes from the analyzing the charts and making refinements. Attributes charts fall short in providing enough information to refine the process. To be fair, there are techniques which convert attribute values to variables data by utilizing a rating scale of "goodness". However, a degree of accuracy is lost in that conversion.

Variable charting is also essential for continuous improvement of characteristics where it is economically justified. Attribute charting tracks number of defects or percent defective but doesn't relate the degree to which those parts are defective or good. It is that extra degree that enables much more information to be read from variables charting, i.e. how close to the optimal value.

Some would argue that in the paint example about the only way to chart the process is to use the attribute charts. I would offer another solution. Undoubtedly, more than one step makes up the final paint process. And that paint process has an optimal combination of inputs that results in a high quality finish. Attributes charts would track good and poor finishes but not necessarily the root cause.

To use variable charting on the paint process I would start keeping tabs on the chemical composition of the paint (or have the supplier do so), the metal preparations before painting (primer, surface finishing, etc.), the room conditions during painting (humidity, temperature, pollution content, etc.). Here is where it becomes tough to get around attribute charting. The question is how to chart the actual painting result. I would recommend using the attribute charts to track the final paint job but use it in conjunction with the other variable charts and establish a correlation of varied inputs to output. This is in effect a design of experiments exercise, although not as statistically robust or elegant. See Figure 2.

FIGURE 2

Of course, there is a precursor to the X-bar use. What is being tracked must be relevant to the quality output. That is why design is so critical to SPC's success. Charting the wrong characteristic won't do a bit of good for your quality.

COMMON MISCONCEPTIONS/PITFALLS

As mature and well known as SPC is, there remains a few persistent misconceptions. One of the most common is the thought that narrowing the tolerances will accomplish the same goal of reducing variability around an optimal

target value. That is not true for the simple fact that the process has not been changed, only the tolerance. Illustrated in Figure 3, moving the tolerances inward only produces more scrap and with it more inspection.

FIGURE 3

This theory, I suspect, must have been an outgrowth of our production-oriented manufacturing base of World War II. Schedules rather than quality dominated the plant floor at the time and quality was inserted in the line where convenient. During that period and until recently, building to tolerance equated to building quality. If it is within tolerance (or sometimes close enough), ship it! That is based upon the false assumption that all parts within tolerance are of the same quality. In fact, before Ford Motor Company vigorously adopted the techniques of SPC, their corporate goal of quality was to have each and every part to within spec the first time. Consider it a major step towards quality improvement when this idea is accepted, because without understanding the need to reduce variation the theme of continuous improvement will fall on deaf ears.

Another equally misunderstood concept is that SPC does not require long production runs. Before the ranting and raving begins, let me clarify that statement. I am not talking in terms of statistically controlling 1 or 2 parts, but realistically it does not require production quantities of 100,000 either. Remember it is statistical process not product control. If the only change in the process is the part being produced then process control can remain in effect through different part runs. Generally, there are only a few basic processes that form the backbone of a manufacturing facility. Batch runs of different parts on the same set of processes can, as a whole, be controlled as one long run. However, close tabs must be kept regarding sample size, measurement scale, the timing of samples taken, and other factors to properly link these varying parts into one continuous process.

The Pitfalls...

One area that is vital to any successful SPC program and is often overlooked is the

measurement system. This is, in effect, the eyes through which SPC sees and interprets the process. The measurement system's criticality is analogous to the principle of "garbage in, garbage out." Its portion of overall process variability is estimated to run as high as 30%. Obviously, correcting measuring deficiencies can go a long way in curing "inherent or normal" variability. Because of the many sources of measurement error, it is an area that needs constant attention and training. When specifying the characteristics to be controlled, make sure instructions on the proper technique to gather the data are thoroughly detailed.

Another aspect of SPC that seems to be a common stumbling block to long term success is the feedback loop by which process refinement occurs. Many companies enthusiastically chart but fail to utilize the information to improve the process. Some mistake SPC's goal as charting and not process improvement. SPC maybe is better thought of as SPI - statistical process improvement and not necessarily control. What the charts should provide is a common ground between design and manufacturing to encourage communication. That communication is possibly one of the best spin-offs of undertaking an SPC program. This is also a great example of why I so heavily emphasized senior management's role up front. Without their consent or help, getting these two organizations to mesh synergistically will not happen.

BENEFITS - REAL AND LONG TERM

After undertaking an SPC effort, some very real benefits will begin to emerge. Probably the biggest of these is the increased communication between design and manufacturing. In fact, one of the best measures of the result of their communication is Cpk. Loosely defined Cpk is the process mean minus the nearest specification limit (absolute value) divided by 3 sigma of the process variation. By calculating this ratio is shows both how well manufacturing is controlling the process (the denominator) and how well design has chosen its tolerance with respect to the machine capability. In my mind it is one of the best measures of their relationship.

Another benefit of SPC is justification for capital investment. Tracking a machine that consistently produces scrap or rework provides evidence of the cost of non-quality. Financial considerations taking into account that cost compared to the price of a new, more capable machine can reveal areas in need of capital infusion. (Actually, you will probably find the old machines are very much capable. State-of-the-art machines don't necessarily mean state-of-the-art quality.)

Companies will also benefit from judging suppliers not only on cost and schedule but also on a documented quality record. Receiving inspection will no longer have to rely on the supplier's word or ineffective and wasteful

sampling techniques to judge quality. In addition, the ability to differentiate between those just meeting the tolerance and those consistently producing very close to the optimal nominal value will play big in any type of assembly operation.

SPC also allows continuous improvement, where it makes sense, instead of merely aiming for all parts within a tolerance band. More consistent parts, especially around a narrow, optimal width greatly influences any assemble operation. With that consistency comes increased reliability and predictability in product performance.

Finally the increased knowledge of processes will greatly enhance manufacturing's ability to get a handle on quality problems on the floor instead of snuffing out fires in a reactive mode. This knowledge translates into decreased processing time, decreased development time and in the end increased quality of production.

SUMMARY

I have often been assured by companies beginning SPC programs that within a year they will have fully implemented a successful program. In all likelihood, that is not realistic since SPC requires a change of attitude from defect detection to defect prevention. Changing attitudes and changing "the old way of doing business" means being in it for the long run. Sure the X-bar and R charts will posted in a short time, but the more meaningful changes of how a company views quality will take significantly longer, so be patient.

Secondly, I hope I haven't led anyone to believe the going will proceed smoothly. Anything worthwhile necessitates some problem solving and tough decisions. However, after changing the philosophy of your company you will be amazed of the results.

And lastly, be committed. If anything can destroy a SPC program quickly it is promoting quality and then shipping shoddy products when the schedule dictates. Put your money where your mouth is.

The Big Picture...

Here's one way to envision your SPC efforts. Think of design as the head coach of a football team. Design formulates the areas to attack during the game, i.e. a game plan. Then the speciality coaches, the defensive coordinator, the special teams coach, etc. are manufacturing. They are the people in the trenches during the game (production). They evaluate what plays (processes) will accomplish the game plan objectives (what to control). The scouts (the suppliers) are a precursor to everything because without talented players (quality incoming material), no team can be expected to win on Sunday (production). It all

revolves around the head coach (design). Also, without constant communication between coaches (departments), don't expect to have a winning season (quality products). The teams that follow this philosophy are the teams that reach the Super Bowl (world class quality).