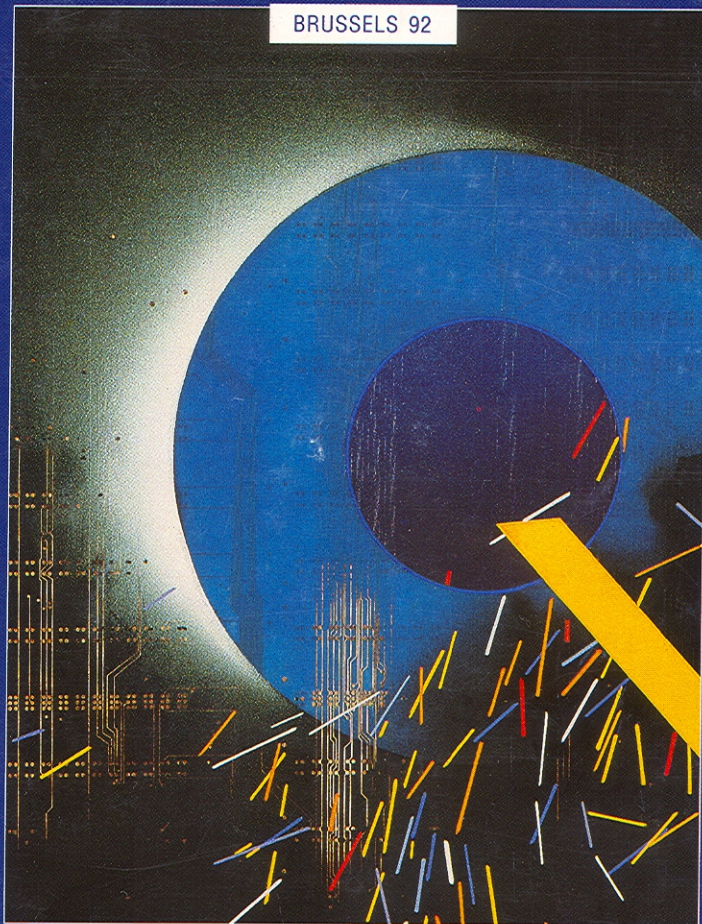


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M/PCPS AND SIX SIGMA MANAGEMENT - ROADMAPS FOR PERPETUAL IMPROVEMENT

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Abstract

This paper presents a successful methodology whose ingredients became necessary to facilitate the implementation of quality program for achieving manufacturing excellence. These ingredients have been integrated into a system comprised of seven blocks: Classification of Processes and Equipment, 5-Year Plan, Training, M/PCpS Methodology, Request for Engineering Experimentation, Control Charting System, Monthly Reviews of System and the Award and Recognition. See Exhibit 1. This system, which will be referred to as the Six Sigma Management System, SSMS, is structured to provide a philosophy, discipline and direction to the organization. The M/PCpS Methodology block of the SSMS system is explained fully, showing its benefits and how it interfaces with the other blocks. Finally, it presents the benefits of using this methodology, and how it would increase the overall quality level of an organization.

(Exhibit 1)

Introduction

The challenge most companies are facing in today's global market is producing products of best quality in an efficient manner and at the lowest cost. To achieve these objectives these companies must set very aggressive goals and totally commit to achieve exceptional levels of productivity and quality. The philosophy that carries this goal setting is Six Sigma, and the methodology that allows to achieve it is called M/PCpS, the Machine/Process Capability Study.

The level of quality in manufacturing is best represented by the degree of uniformity of the product from a specific target. If all the units produced are identical to each other and to a selected target then the products are perfectly uniformed with no variation. They are also said to be very predictable given that the product is not expected to differ from each other. But, on the other hand, if the units produced differ from each other and from their selected target then the production is non-uniformed, is unpredictable, has variation and is obviously of lesser quality.

What is Sigma?

The index that measures this non-uniformity or variability is in simple terms called 'sigma'. The Greek letter sigma, σ , is a mathematical symbol used in statistics to represent the average or 'standard' deviation of individual data points from an average formed with all data points. The sigma or standard deviation (which is calculated from a sample as a predictor of the sigma), can be thought of as a measure of

uniformity, a measure of deviation from target or as a measure of quality.

The lower the value of sigma the more uniformed the product would be and the better the quality. As the value of sigma get higher, the variation in the product increases along with its unpredictability and poor quality.

The Normal Distribution

Since most physical phenomena and engineering characteristics (manufacturing processes) can be approximated with the normal distribution; once goodness of fit is established, we can make use of the characteristics of the normal distribution to make predictions and inferences about the behavior and variation of our physical processes.

Given that a normal distribution has within its plus or minus one sigma (+1s) limits about 68.26% of its area, we can therefore state that 68.26% of the output product from a normally distributed manufacturing process would fall within plus or minus one sigma of the mean.

It can also be said that 95.45% of the output product would fall within plus or minus two sigma, 99.73% within plus or minus three sigma, 99.99966% within plus or minus four and a half sigma and 99.999998% within plus or minus six sigma.

Furthermore, if we compare the various sigma levels of these normally distributed manufacturing process against process specification limits we can predict the number of defective turned out by these processes.

(Exhibit 2)

What is Six Sigma?

A process specification generally consists of a lower specification limit (LSL) and an upper specification limit (USL) and a target value (T) somewhere in between these limits. A normally distributed manufacturing process in a state of statistical control would be characterized by a mean (μ) and a standard deviation (σ).

In ideal conditions when the process mean is center with the target of the specification we can compare the variation in the process (sigma) against the lower and upper specification limits to determine the defective and in turn its quality level.

A process with plus or minus one sigma within specification limits would produce about 32 percent defects. A plus or minus three sigma process would produce about 2.7 percent defects; a process with plus or minus four and a half sigma process would produce about 0.00034 percent defects or 3.4 defects per million, DPM. A plus or minus six sigma process would produce 0.000002 percent defects or less than .002 defects per million and a 99.999998 percent defect-free product.

Six sigma is a long-term goal of having plus or minus six standard deviations or sigmas within the upper and lower specification limits. This goal when achieved would guarantee such a degree of uniformity in the product that even if at worst conditions a 1.5 sigma shift occurs, the quality would not be jeopardized and the expected quality level would be of no more than 3.4 defects per million produced or a product yield equal to 99.99966 percent.

(Exhibit 3)

Capability Indices

Another way to quantify the number of sigmas between the specification limits is by using two indices of capability, the process potential, Cp and the process capability, Cpk. The Cp and Cpk are unitless functions of the process parameters, mean (m) and standard deviation (s), and the process specification, USL, LSL and the target (T), designed to provide a common indicator for quantifying the performance of a process.

Process Potential, Cp

The Cp measures the potential of capability of a process by calculating the ratio of the allowable variation over the actual variation. The allowable variation being the tolerance of the specification, calculated by subtracting the lower specification limit from the upper specification limit. The actual variation is the variability of the process and is calculated by six standard deviations.

$$Cp = \frac{USL - LSL}{6s} \quad (1)$$

For a given sigma process such as a three sigma process (+ 3s), there is a specific Cp value, thus relating these two indices. A three sigma process has six sigmas between the USL and the LSL and would have a Cp equal to one.

$$Cp = \frac{\pm 3s}{6s} = \frac{6s}{6s} = 1$$

(Exhibit 4)

A six sigma process (+ 6s) having twelve sigmas between the USL and the LSL would have a corresponding Cp equal to two. But, the reverse relationship does not hold true. Given a Cp of two, it does not imply that the process has twelve sigmas inside the lower and upper specification limits, yielding product within specification. But, what can be implied is that the process has such a small variation that twelve sigmas could be fitted between the distance of the specification (USL minus the LSL). In other words, the Cp index does not measure the degree of centering of the process average with the midpoint of the specification, or the overlapping of the actual process variation with the allowable variation. So, the Cp could be used only to measure the potential of a process to be a specified level of sigma or the potential of a process to produce product within specification.

Process Capability, Cpk

The process capability index or Cpk measures the ability of a process to produce product within specification. The Cpk is the ratio of the distance between the actual process average and the closest specification limit over three times the standard deviation or sigma of the actual process.

$$Cpk = \text{[Smallest of: } \frac{\bar{X} - LSL}{3s} \text{ ; } \frac{USL - \bar{X}}{3s}] \quad (2)$$

The Cpk is defined to be zero when the right side of equation (2) has a negative value. The Cpk measures the number of sigmas between the process average to the closest specification limit and divides this by three sigma (3s). If the number of sigmas between the process average to the closest specification limit is three, then the Cpk equals one, and it can be said that the process has plus or minus three sigmas inside the specification limits. If the Cpk equals two, then the process has plus or minus six sigmas (12s) inside the specification limits.

What the Cpk does not quantify is if the process average or distribution is centered with the midpoint of the specification. The highest value the Cpk can achieve is the value of the Cp. When the Cpk is identical in value with the Cp then the process average is centered with the midpoint (in most instances the target) of the specification and the Cpk has achieved its potential.

So, in theory, a six sigma process (+ 6s) has a Cpk equal to two and a Cp equal to two. If a process has a Cpk equal to two and a Cp much greater than two this process would still be six sigma process, but a higher Cp would imply the process is not centered. The Cp and the Cpk are indices which can be used in conjunction to measure the progress of the process under improvement toward six sigma.

Achieving Six Sigma

Achieving three sigma is not a difficult task and it can be achieved by a continuous improvement process utilizing the standard problem solving tools (Flow Charts, Run Charts, Pareto Diagrams, Check Sheets, Ishikawa Diagrams) and techniques of Statistical Process Control, SPC.

On the other hand, achieving six sigma quality levels is not an easy matter and requires significant company time, efforts and funding. But most importantly, it requires a more sophisticated set of statistical tools and a sound, logical and systematic methodology for improvement. Such a methodology is an integration of different techniques; Structured Problem Solving, Measurement System Analysis, Process Capability Analysis, Design of Experiments, and Statistical Process Control and it is called M/PCpS™ which stands for "Machine/Process Capability Study - A Five Stage Methodology for Optimizing Processes".

Machine/Process Capability Study, M/PCpS™, Methodology

A Machine/Process Capability Study is a stepwise analytical investigation using a standardized methodology for determining the current capability of a process and for identifying and reducing or eliminating its major sources of variability. A study does not end until the goal capability ($Cpk=2.0$) is achieved or further investigation is no longer economically feasible. The methodology is divided into five progressive stages:

- Stage 1: Process Characterization
- Stage 2: Metrology Characterization
- Stage 3: Capability Determination
- Stage 4: Optimization
- Stage 5: Control

(Exhibit 5)

The Machine/Process Capability Study defines a standard methodology for the purpose of characterizing and optimizing equipment and manufacturing processes. The five stages presents a logical progression and a sequence of events designed in such a particular order to preserve and guarantee mathematical and statistical assumptions throughout the analysis.

The standard forms and worksheets of the M/PCpS leads the practitioner through all important steps necessary to achieve capable manufacturing processes. They also become part of the documentation of the studies which could then be stored in a computer database system for sharing with other manufacturing sites. See Exhibit 6.

(Exhibit 6)

1st Stage: Process Characterization

The purpose of this stage is to thoroughly describe the machine and process under study. This is done by dissecting the machine and process into its functional characteristics and then continuing by identifying all the independent variables by each functional characteristic. Once this is done, all the response variables or dependent variables are listed and ranked according to their interrelationship with the independent variables into the C&E Cross-reference Table. The C&E Cross-reference Table is very critical and is used throughout the study, and is the key for successful statistical experimentation.

2nd Stage: Metrology Characterization

The second stage defines the metrology needed to evaluate the response variables under investigation and quantifies the amount of variation that it brings into the overall study. This stage brings the necessary techniques to apply to quantify this variability.

3rd Stage: Capability Determination

The objective of this stage is to determine the current capability of the machine and/or process by running product through the process at known optimum levels. It is in this stage that data is collected for the purpose of making predictions and inferences about the behavior of the machine and process through time. Descriptive statistics are computed to understand the central tendency and variability of the process. Goodness of fit tests are done to validate the shape of the distributions. Then the data is analyzed for stability and statistical control, and studies of repeatability, potential and capability are conducted. By going through these levels of detail, the individuals gain such exceptional knowledge of the process that lead themselves into conducting very productive statistical experimentation and optimization.

4th Stage: Optimization

Optimization is the most important stage because it focuses in reducing the amount of variation encountered in the Capability Determination stage. Reduction of variance (or standard deviation) is the solution to many manufacturing problems, especially when processes are found not to be capable, $Cpk<1.0$, or when they have a capability less than the goal of a $Cpk=2.0$.

Statistically designed experimentation is the primary tool used in the optimization stage. First, theories are formulated and then converted into statistical problems (hypothesis), and then proven or disproven with statistical tests. These tests are of various types: parametric tests, non-parametric tests, single factor, and multi-factor experiments. During optimization, statistical designed experiments are conducted with the following objectives in mind: a) to center the distribution of the response variables against the specification limits, b) to reduce the amount of variation (standard deviation) in the response variables, c) to determine the main and interactive effects of the "vital few" independent variables, and d) to identify the optimum levels of those independent variables. See Exhibit 7.

The different designs of experiment that could be used in this stage are: Full Factorial design experiments, Fractional Factorial design experiments, Orthogonal Arrays (Taguchi designs), Plakett-Burman screening designs, Central Composite designs. Some techniques for optimization are: Response Surface Methodology, RSM, and Evolutionary Operations, EVOP.

(Exhibit 7)

5th Stage - Control

The fifth and final stage in the Machine/Process Capability Study methodology is the Control stage. After the machine or sub-process is capable, either by the Capability Determination stage or by Optimization through statistical experimentation, necessary preventive and reactive controls are put in place. Process controls are the last things that should be done when analyzing manufacturing processes

and/or conducting capability studies. Unfortunately, because of the misconception that Control Charts and Pre-control are simple in nature, they are usually the first things to get implemented, leading to frustration on the part of operators and engineers when confronted with out-of-control conditions for which the corresponding influential independent variables are not known. For this reason, process controls, such as Control Charts, Pre-Control methods, and PosiTrol Plans, are setup after a complete understanding of the machine and sub-process (main and interactive effects of the "vital few" independent variables) is obtained. It is at this stage, where all the knowledge that has been obtained from the previous four stages, is transferred to production and to the operators. The critical response variables are monitored and controlled with Pre-Control. The important independent variables are monitored with a PosiTrol Plan and

PosiTrol log. These will assure that the independent variables will remain at their optimum levels as they were defined in the optimization stage. The "vital few" independent variables that influence variability whose optimum levels are difficult to control and unstable (even after optimization) are monitored with the PosiTrol Plan and with Control Charts. At this point, the whole sub-process and machine are locked at the optimum levels and the response variables should exhibit minimal variation.

Benefits and Conclusions

The use of the Machine/Process Capability Study methodology has provided a standard approach for engineers to increase the predictability of their process and the capability of their equipment. It also has stimulated individuals to conduct statistical experimentation for optimizing their manufacturing processes.

The standardization of the methodology has created a common language communication when relating issues about characterizing equipment and processes.

Management has obtained clear definitions of the progressive steps necessary for conducting process capability studies and this has simplified managing quality improvement efforts.

Companies which have adopted the M/PCpS methodology for characterizing and optimizing their processes and have standardized it throughout their organization have witness significant yield improvements, have achieved better product predictability and have experienced reduction in process variation and productivity improvements in the hundred of thousands of dollars.

The M/PCpS methodology is a clear successful path to six sigma quality and six sigma management

References

1. Thermotron Industries, Six Sigma Quality, Holland, Michigan, 1990.
2. M. Perez-Wilson, Machine/Process Capability Study, Advanced Systems Consultants, Scottsdale, Arizona, 1988, pp. 3, 21, 51, 87, 163, 189.
3. Sam Thomas, Six Sigma: Motorola's Quest for Zero Defects, APICS, Atlanta, Georgia, 1991