Fred Spiring

Determining and Assessing Process Capability for Engineers and Manufacturing

Quality Control Engineering and Manufacturing Series

NOVA

QUALITY CONTROL ENGINEERING AND MANUFACTURING

DETERMINING AND ASSESSING PROCESS CAPABILITY FOR ENGINEERS AND MANUFACTURING

FRED SPIRING

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Chapter 1

INTRODUCTION

HISTORICAL OVERVIEW

Process capability continues to receive a great deal of attention from practitioners and researchers alike. Since Sullivan (1984, 1985) introduced the concept to North America the focus on process capability is due in part to the changing philosophy in Quality Assurance. Slogans such as "doing things right the first time" and "building a quality product" are terrific motivators, however if a process is not capable of meeting requirements, resources will be wasted. For example, if a mechanical process is not capable, the operators, regardless of their dedication and effort, will be unable to produce a quality product. Similarly if the operators are not capable of meeting the demands of the machinery a quality product will not result. Processes that are not capable, regardless of their incapacity, waste resources.

Waste results from:

i. resources used to produce a non-conforming product
ii. the cost of identifying non-conforming product (either through inspection or customer dissatisfaction) and
iii. repair/replacement of any non-conforming product. Some of these costs are tangible (such as repair/replacement) others (such as loss of business due to customer dissatisfaction) may be more difficult to quantify, but certainly exist.

Although it seems like common sense to use a process that is capable of meeting engineering requirements, it is not always the practice. The Ford

Motor Company once reported that only 50% of those processes surveyed from suppliers with some form of Quality Assurance program were capable. Regardless of how one defines process capability there is clearly a problem.

In the past many companies have tried to inspect quality into the product. Inspection teams were created whose role was to inspect the output for non-conforming product. This is both costly and in most cases ineffective. By designing a process that is capable and robust to input fluctuations, inspection becomes unnecessary. Once a process has been deemed capable, sampling is used only to monitor the procedure or to assess modifications made to the process. The ideal process would produce "identical" units under conditions which may include heterogeneous raw materials, different operators and a variety of operating conditions.

Initially process capability was synonymous with process variability or process spread, with early process capability indices relating process variability to the process specification limits (e.g., upper specification limit (USL) and lower specification limit (LSL)). However as fostered by Dr. Genichi Taguchi, proximity to the target has forced researchers and practitioners to include proximity to the target value when considering process capability. Taguchi's loss function highlights the need to have small variability around the target. The best process, in terms of Taguchi's definition of quality, would be one that produced its entire product at the target. When this is not the case the loss function suggests that both process variation and proximity to the target should be considered when assessing product quality. A process with its entire product just inside the upper (or lower) specification may not be as desirable as a process with larger variation but centered on the target.

Clearly the best process will be one that produces its entire product at the target, with the next best being the process with the smallest variability around the target. Figure 1.1 relates three populations with different levels of variation to the loss function. Changes in the definition of a quality product have forced changes in the procedures used to assess process capability. The ability of a process must now be measured in terms of process variability and proximity to the target. Good variability, but not on target, is just as undesirable as on target but with large variation. Research efforts in the area of process capability have largely been devoted to finding a better process capability index (PCI) and to a lesser extent on the stochastic behavior of the estimated PCIs. Much of this development has gone unused for many reasons including:

a) plethora of indices,
b) interpretation,

c) software support,
d) standards and
e) dissemination.

The addition of the indices appears to have had little impact on the practitioners. *Cp* and *Cpk* (including *Cpl* and *Cpu*) continue to be the most heavily used indices with *Cpm* and *Cpmk* occurring occasionally. The addition of stochastic assessments for estimated PCIs is a positive development; however statistical developments have frequently lacked background knowledge and implementation ease, hindering use by practitioners.

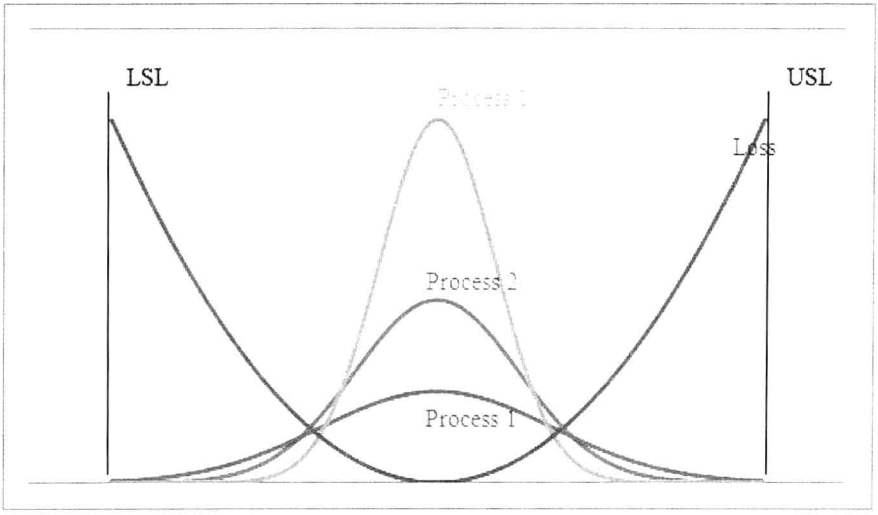

Figure 1.1. Loss Function with Three Processes following Normal Populations.

The goal of the book is to illustrate use of the most common process capability indices with the sincere hope that it will foster the safe use and development of PCIs among practitioners and researchers.

ASSESSING PROCESS CAPABILITY

Process capability has been defined in many ways and as a result many measures of process capability exist. The most common definition describes process capability as the range over which the output of a process varies. This

quantity is also referred to as the actual process spread. Measures in this group depend upon the measuring units (i.e., meters, kilograms, ...) and hence do not encourage comparisons among processes with different quality characteristics. The most common process capability indices relate the allowable process spread, usually a customer or engineering requirement, to the actual process spread in the form of a ratio

$$\frac{\text{Allowable process spread}}{\text{Actual process spread}}.$$

The measure is unit less, thereby inviting comparisons among processes with different quality variables and promoting similar inferences regardless of the product or quality characteristic measured (i.e., widgets, televisions, ...). For example, an index value of one indicates that the allowable process spread is equivalent to the actual process spread. While a process capability index of two indicates that the allowable process spread is twice that of the actual process spread, suggesting that the process is capable of producing within specifications (Figure 1.2).

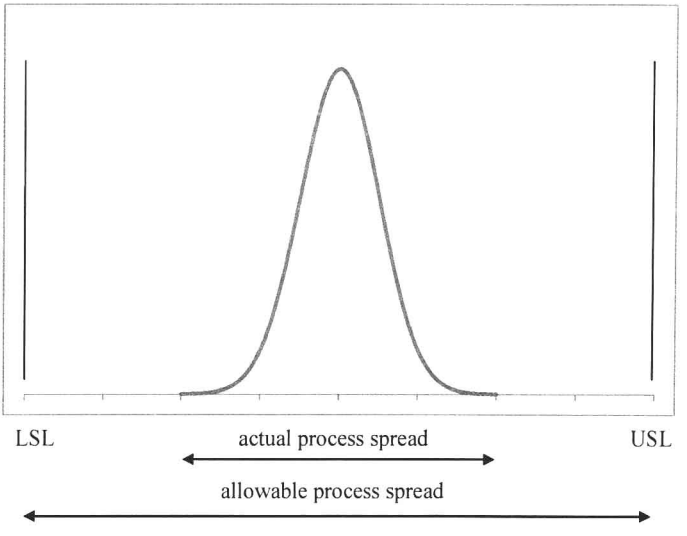

Figure 1.2. An Example of a Process with a Capability Index of 2.

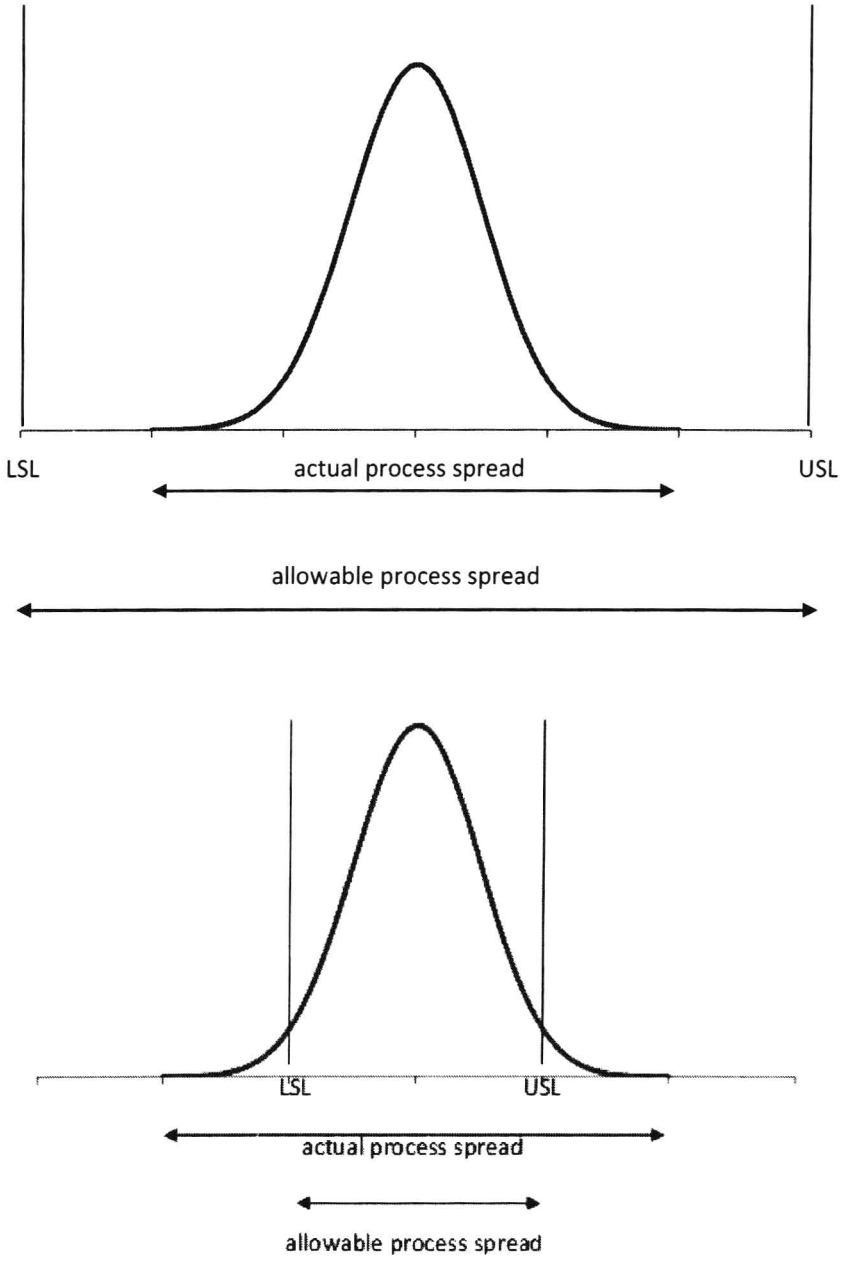

Figure 1.3. Processes with Actual Process Spread less Than Allowable Spread and Actual Process Spread Greater Than Allowable Spread.

Index values of less than one indicate that the actual process spread is larger than the allowable process spread, suggesting that non-conforming product results (Figure 1.3). Initially, actual process spread was taken to be 6σ which represents, in normal theory, the width of the interval that contains 99.73% of the population. The difference in the upper (USL) and lower (LSL) specification limits (i.e., USL - LSL) was used to indicate allowable process spread, resulting in the ratio

$$\frac{\text{USL} - \text{LSL}}{6\sigma}$$

which is referred to as the process capability index, *Cp*. The allowable process spread is generally considered fixed while the actual process spread in general must be estimated; hence the resultant measure of process capability will be stochastic.

Unfortunately it has become the practice to ignore the stochastic nature of the estimated process capability index and to simply judge a process capable if the estimated process capability index is greater than one, and incapable if less than one. This can be a dangerous practice and will be discussed in Chapters 2 and 3.

The process capability index *Cp* is also used as a measure of non-conforming product. An index value of 1 represents 2700 parts per million (ppm) non-conforming, while 1.33 represents 63 ppm; 1.66 corresponds to .6 ppm; and 2 indicates less than .1 ppm. These values are correct if and only if the process measurements arise from a normal distribution centered at the midpoint of the specification limits. If this is not true, the process capability index will underestimate the percent non-conforming. Processes 1 and 2 of Figure 1.4 have equivalent index values, but process 2 has roughly 20% non-conforming, where process 1 has near zero percent non-conforming.

Cp's failure to consider proximity to the target value makes it incompatible with Taguchi's loss function concept of assessing quality. However there are measures that are similar to *Cp* but with the ability to assess proximity to the target in addition to process variation. These modified process capability indices reflect the current feeling in Quality Assurance.

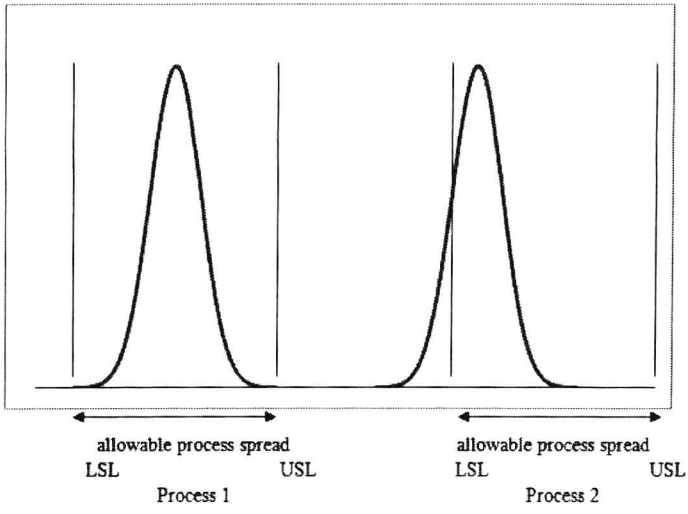

Figure 1.4. Processes with Equivalent Capability Index but Different Non-conforming.

REFERENCES AND ADDITIONAL READING

Sullivan, L.P. (1984), "Targeting Variability - A New Approach to Quality", *Quality Progress*, pp 15-21.

Sullivan, L.P. (1985), "Letters", *Quality Progress*, pp 7-8.

Chapter 2

CONDUCTING A CAPABILITY STUDY

ESTABLISHING CAPABILITY GOALS

The general goal of a capability study is to determine the ability of a process to meet a set of specifications. The specifications need not simply be the upper and lower boundaries but may include the target value and any other concept deemed important. As a result the manner in which we conduct and analyze capability studies may change as new ideas and concepts are integrated into the definition of process capability. Regardless of the manner in which we analyze a capability study, care should be taken in first determining the questions that are to be answered by the study and secondly in the way the observations are obtained.

FREE OF VARIATION DUE TO ASSIGNABLE CAUSE

Process capability studies are conducted and their associated measures determined under the assumption the process variation is due only to random causes, and are in fact valid only once the process under investigation is free from any special or assignable cause (i.e., in a state of statistical control). For those processes affected by special or assignable causes, process capability should be assessed only during periods where the special causes are not present. The frequency and affect of special causes can vary from infrequent minor changes in the process (that are often undetectable) to large sustained systematic influences.

Regardless of the frequency or magnitude of the assignable cause, traditional process capability measures should not be used in the presence of

variation due to assignable cause. In processes where variation due to an assignable cause exists, the overall variation consists of i) variation due to assignable cause and ii) variation due to random causes. As a result traditional measures of process capability are invalid as they confound the true process capability with some measure of assignable cause. In Chapter 7 we will examine methods of removing variation from systematic assignable cause from process capability calculations and use the resulting values to assess process capability.

SAMPLING CONSIDERATIONS

All measures of process capability will involve knowledge of the process mean (i.e., average) μ and standard deviation σ under investigation. In most situations this information is not available, with the usual practice being to take a sample from the process and to calculate the sample mean, $\hat{\mu} = \bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$ and standard deviation, $\hat{\sigma} = s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$. Practitioners then use the sample measures to determine process capability. The resulting measures are based on sample results and should be accompanied by some expression of confidence. Traditionally practitioners have used large sample sizes (i.e., $n > 50$) to avoid several problems that arise in determining confidence levels for the resulting estimates of process capability. However more recently authors have dealt with the small sample properties and confidence levels for the more common capability measures.

Many practitioners now promote the use of confidence levels in conjunction with the estimates of capability. As a result the standard practice of taking samples of size 50 or more need not be blindly followed. The questions of "How many? How often?" will depend on the process under investigation; however certain basic rules can be followed. Techniques for determining confidence levels for estimates will depend on several concepts including the type of measure used, these techniques are discussed in subsequent chapters.

USING CONTROL CHART DATA

Once the process has been brought in to a state of control it is possible to determine process capability from the information provided by the control charts. The procedures involve use of the information contained in control charts to arrive at estimates for the process mean and standard deviation, which in turn are used to determine estimates for a process's capability. Assuming that the number of subgroups (k) used is reasonably large (i.e., k>10) σ can be estimated using $\hat{\sigma} = \frac{\overline{R}}{d_2}$ where $\overline{R}$ is the average of the ranges of the k subgroups and d_2 is a constant which depends on the number of measurements made in each subgroup. Values of d_2 for various subgroup sizes (i.e., n) include

n	2	3	4	5	6	7	8	9	10
d_2	1.128	1.693	2.059	2.326	2.534	2.704	2.847	2.970	3.078

Several measures of process capability involve knowledge of the process mean μ, which may also be estimated using results from the control chart data. The general form of the estimator will be $\hat{\mu} = \overline{\overline{x}} = \sum_{i=1}^{k} \frac{\bar{x}_i n_i}{n_1 + n_2 + \ldots + n_k}$ where $\bar{x}_i$ and n_i represent the subgroup mean and subgroup sample size respectively.

WHEN CONTROL CHART DATA ARE NOT USED

Estimates for μ and σ can be obtained from data not acquired from control charts as well. However it must be stressed that the process must be in a state of statistical control before any assessment of capability is made. The usual estimators of μ and σ based on a single sample of size n are

$$\hat{\mu} = \overline{x} = \sum_{i=1}^{n} \frac{x_i}{n} \text{ and } \hat{\sigma} = s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}} .$$

respectively. The estimates can then be used in determining estimates of process capability, properties of which will be discussed in Chapter 4.