Global Journal of Management and Business Research: G Interdisciplinary
Volume 16 Issue 3 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4588 & Print ISSN: 0975-5853

Process Capability-A Managers Tool for 6 Sigma Quality Advantage

By Dr. Vinod N Sambrani

Karnatak University

Abstract- "You can't manage what you don't measure"; organisations are quantifying the capability of their manufacturing process to measure and manage 'quality'. Six Sigma offer several tools, which helps measure the performance of a process. The process capability analysis is one such tool, which helps measure whether the process is proficient of producing consistent products that meet the standards. According to Dr Genichi Taguchi variability of the process has to be controlled even though the process is meeting all the specifications. Process capability analysis helps to reduce variability in the production processes. Process capability indices (PCIs) measure the capability of the process numerically. Process capability indices are used to explain a manufacturing process ability to produce items as per the voice of the customer (i.e. within the specified limits) and compare the intrinsic variability in a process with the customer's design. Capability index is important, since it simplifies complex information about the process to a single unit less number.

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GJMBR-G Classification: JEL Code: J50

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Process Capability–A Managers Tool for 6 Sigma Quality Advantage

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Abstract- "You can't manage what you don't measure"; organisations are quantifying the capability of their manufacturing process to measure and manage 'quality'. Six Sigma offer several tools, which helps measure the performance of a process. The process capability analysis is one such tool, which helps measure whether the process is proficient of producing consistent products that meet the standards. According to Dr Genichi Taguchi variability of the process has to be controlled even though the process is meeting all the specifications. Process capability analysis helps to reduce variability in the production processes. Process capability indices (PCIs) measure the capability of the process numerically. Process capability indices are used to explain a manufacturing process ability to produce items as per the voice of the customer (i.e. within the specified limits) and compare the intrinsic variability in a process with the customer's design. Capability index is important, since it simplifies complex information about the process to a single unit less number. In this paper different process capability indices viz. potential process capability index (C_p), real process capability index (C_{pk}), and process centering index (K) will be analysed to understand the process capability and their implications in managerial decision making in quality improvement activities and quality program implementation.

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I. Introduction

Why 99 percent quality level is not tolerable to companies around the globe? Because from a cumulative perspective it means for example in medical surgical procedure, 99 percent quality is 500 incorrect surgeries per week or two unsafe plane landings per day at a major airport, which is simply not acceptable, so what next? Such questions were troubling big corporations. In 1986 Motorola developed a statistically-based method for performance measurements to reduce variation, and found that quality level corresponded to failure rate of two parts per billion, Motorola named this program as "Six Sigma". Six sigma methodologies result in the process outcomes which are 99.9997 percent defect free; Six sigma focuses on reducing defects to 3.4 DPMO [Defects per Million Opportunities]. Six Sigma is the answer for the above question. Hence, opportunities denotes the potential chances for a defect to occur in a unit. Two characteristics needs to be controlled in DPMO viz., 'opportunities'- in terms of reduction in total steps of the process and 'defects'- in terms of reduction in defects at every step of the process through improvement of process continuously, thus aiding the quality improvement. Today Six sigma is used in all kinds of sectors like government, hospitals, banks and many more areas. In recent times it is combined with lean manufacturing and is called "Lean Six Sigma".

One of the important six sigma methodologies is the Process Capability Analysis [PCA]; the determination of process meeting the specification limits is done using this prominent technique. It is the measure of the absolute quality of any process, after all the corrective measures, which must be considered to guarantee the level of Six Sigma being achieved. Process capability is the standard measure of conformance to specifications. Bothe (1997) has defined "process capability as the ability of a process to meet customer expectations". The variation in the process with respect to specifications is measure quantitatively using PCA.

Process capability is the ratio of actual process spread to the permissible process spread, measured by six process standard deviation units. The quantitative measure of process capability is given by Process Capability Indices [PCIs]. Process variability and specifications are statistical indicators of process capability used by PCIs. The most widely used basic indices are C_p by Juran (1974), C_{pk} by Kane (1986), and C_{pm} independently by Hsiang & Taguchi in 1985 and by Chan, Sheng & Spiring in 1988. In this article, the objective is to look into the various process capability indices and understand the inferential aspects of these capabilities.

II. Literature Review

Mahesh S. Raisinghani[1] has mentioned that to insure a level of Six Sigma has been obtained, it is important to the measure the quality of any process. A standard measure which checks for conformity with the specifications is the Process capability (C_{pk}). The variations between the process and specifications are measured in quantitative terms using this. Process capability indices are developed to measure the process capability numerically by Özlem Şenvar and Hakan Tozan [2]. The earliest description of capability indices was published by Sullivan. Kane provided the first discussion of the indices' sampling characteristics.

Author: Associate Professor, Kousali Institute of Management Studies, Karnatak University, Dharwad-580003 Karnataka, India.
e-mail: vinodsambrani@gmail.com

Feigenbaum and Juran used 6σ as a measure of process capability. They presented the measure as a representation of the inherent variability of a process. But capability was still considered independent of the specifications.

Juran created a stronger link between process variability and customer specifications by comparing 6 σ to the tolerance size as a technique of defining the need for process development actions. However, capability was still deduced separately from the requirements. Juran and Gryna proposed a capability ratio, which provided the first metric that directly compared process variability to customer specifications:

$$Capability\ Ratio = \frac{6\sigma\ variation}{Tolerance\ Width} \qquad (1)$$

All process capability indices clearly link process variability to customer requirements, thus emphasizing the supplier's accountability to meet those requirements Kurt Palmera, H and Kwok-Leung Tsuib[3].

The wide use of PCIs in seeking/ provisioning quantitative measures over the ability of a process to meet the manufacturing requirements is upheld in many literatures. They (PCIs) acts as significant tool enhance the process activities and enable quality program initiatives. The first two process capability indices appeared in the literature are the process precision index C_p and the process performance index C_{pk}, which were defined by Kane (1986) Chien-Wei Wu[4].

Many articles appeared from the work of Kane (1986), presenting new indices and/ or exploring the further possibilities with the old ones. Kaminsky et al. (1998) have criticized upon the use of these indices and proposed a future measurement. Schneider et al (1995) and Latzko (1985) have discussed the use of PCIs in supplier certification and administration.

An extensive bibliography on PCIs was provided by Spiring et al. (2003). A common consent of the idea, to use PCIs is that, a process must be in "Statistical Control". The majority of the process capability indices discussed in the literature are associated only with processes that can be described through some continuous distributions of the characteristics and, in particular, normally distributed characteristics Mahendra Saha and Sudhansu S. Maiti[5]

Process with one-sided specification limits were presented using graphical method by Vannman and Albing which was useful for analysing process capability. At a given significance level, with the assumption of normality, projected process capability plots are used to judge the process capability. They recommended that graphical method is required to improve the capability, thus, determining the deviations from the specifications and variability or both.

Sagbas. A, suggested that "in order to satisfy the process capability measures, it is necessary to improve the quality level by shifting the process mean to the target value and reducing the variations in the process" Ajit Goswami & Harendra Narayan Dutta [6]

III. Process Capability Analysis

Process Capability Analysis is defined as the engineering study to calculate the process capability; it is about how well a process meets its specification limits. In other words process capability analysis helps to estimate, monitor, and reduce the variability in the processes. An estimate of DPMO (defects per million opportunities) is often produced from the sample data from a process for the PCA. It also provides, at least one capability indices. This assesses the sigma quality level of the process operations.[1]

Process Capability Analysis is based on two important assumptions; i) process data is normally distributed and ii) process is in control.

Process capability analysis graph is as below [See Figure 1]. The graph indicates the lower specification limit (LSL) and the upper specification limits (USL) and allows visualizing the average μ that represents the process central tendency, and the target value τ. The basic methods to study the Process Capability Analysis are: Probability plots, Histogram, Design of Experiments and Control Charts.

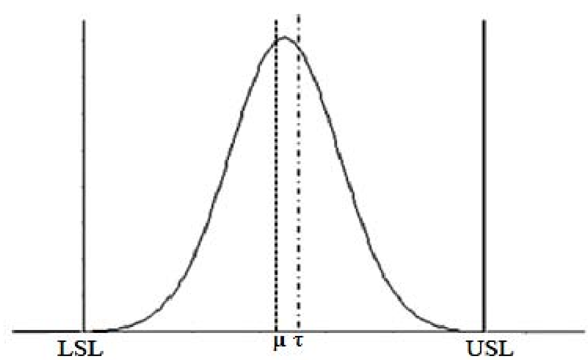

Figure 1: Process Capability Analysis

IV. Process Capability Indices

Process capability indices (PCIs) are developed to measure the process capability numerically. It is a quantitative measure that compares the behaviour of process (measured in sigma) to the specifications. Capability indices that succeed process potential and process performance are applied tools for positive quality improvement accomplishments and quality program execution.

The original five capability indices as described by Sullivan, as observed in use at Japanese manufacturing facilities, were C_p, C_{pk}, K, C_{pu}, and C_{pl}. However manufacturing industries use potential process

[1] Şenvar, Ö. and Tozan, H., 2010. Process capability and six sigma methodology including fuzzy and lean approaches.

Global Journal of Management and Business Research (G) Volume XVI Issue III Version I Year 2016

capability index (C_p), real process capability index (C_{pk}), process centering index (K) and Taguchi index (C_{pm}) to gain a statistical measure of process potential and performance.

a) What Is 'C_p'?

Potential process capability index [C_p], the first generation capability index presented by Joseph M. Juran in 1974 is based on the philosophy of statistical process control, which maintains that all measurements within required tolerance are intended to be good; measurements outside the tolerance are taken to be bad.

C_p is the ratio between what you want the process to do (management's hope or allowable spread) versus what the process is actually doing (reality).[2]

$$C_p = \frac{Hope\ (Tolerance\ Range)}{Reality\ (Process\ Range)}$$

Mathematically process capability index C_p is calculated as;

$$C_p = \frac{USL - LSL}{6\sigma} \qquad (2)$$

USL and LSL are the upper and lower specification limit respectively and σ symbolises the standard deviation (SD) of the studied characteristics. The multiplier "6" in the denominator is selected after announcement that three sigma-limits work fine in practice [Deleryd, 1995].

It is important to note that C_p is the reciprocal of Juran and Gryan's capability ratio see equation 1.C_p value does not take the location of the process into consideration. Table 1 gives the description of the different C_p values and their inferences.

Table 1: Cp values and their implications[3]

C_p Value	Rating	Managerial Decision
C_p 2.2	World class	It has 6 σ quality
C_p> 1.33	1	satisfactory for existing processes
1 <C_p<1.33	2	Partially adequate, requires a strict control.
C_p =1	3	At least 99.73% of the products are conforming to specifications (0.27% nonconforming)
0.67 <C_p< 1	4	Not adequate for the job. A process analysis is necessary. Requires serious modifications to reach a satisfactory quality
C_p< 0.67	5	Not adequate for the job. Requires very serious modifications

'C_{pk}' Index

Montgomery (2009) has defined "C_{pk} as the measurement of the actual capability in the process. C_{pk}

$$C_{pk} = Min\left[\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right] \qquad (3)$$

takes process centering into account. The magnitude of C_{pk} relative to C_p is the direct measure of how far from the center the process is operating."C_{pk} is calculated using equation 3, in which μ represents the process average, σ the standard deviation and USL and LSL lower and upper C_{pk} by Kane [1986] explains the impact of μ (process mean) on the process capability indices. If the process mean is away from the center with respect to the specifications, the specification limit closer to the process mean becomes the focal point for process capability calculation hence the word "minimum" in the formula.

The change in the denominator from six to three standard deviations is the result of the two one-sided quality concerns. Table2 depicts the quality condition associated with the different C_{pk} value.

Table 2: C_{pk} values and their Quality Condition[4]

C_{pk} Value	Associated Quality Condition
C_{pk}<1.00	Inadequate
1.00 ≤ C_{pk}<1.33	Capable
1.33 ≤ C_{pk}<1.50	Satisfactory
1.50 ≤ C_{pk}<2.00	Excellent
2.00 ≤ C_{pk}	Super

b) The 'K' Index

The index Krepresents a measure of the distance that the process lies off-center. The index of the process K is calculated using equation 4.

$$K = \frac{\mu - N}{(USL - LSL)/2} \qquad (4)$$

μ is the process mean, N is the specification midpoint .N= (USL + LSL)/ 2.

[2] Philimon, N., Daniel, M., Caston, S., Edward, C. and Munjeri, D., 2011. A holistic application of process capability indices. *African Journal of Business Management*, *5*(28), p.11413.

[3] Rábago-Remy, D.M., Padilla-Gasca, E. and Rangel-Peraza, J.G., 2014. Statistical quality control and process capability analysis for variability reduction of the tomato paste filling process. *Industrial Engineering & Management*, *2014*.

[4] Pearn, W.L. and Chen, K.S., 1999. Making decisions in assessing process capability index C-pk. *Quality and reliability engineering international*, *15*(4), pp.321-326.

The relationship between C_p, C_{pk}, and k is $C_{pk} = (1 - |k|) C_p$

V. Introduction to the Case Study

In order to test the different process capability indices and make managerial inference the case study is considered, the data collected is about the boring operation on the center frame component, which is used in the excavators.

The desired quality characteristic specification for bore C [see figure below] is 71mm diameter with a tolerance limit of +0.15mm and -0.07mm. The upper and lower specification limits are 71.15mm and 70.93mm respectively.

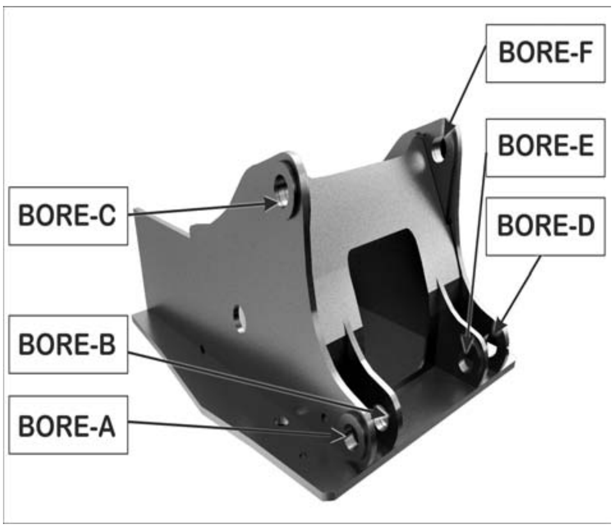

Figure 2: Center Frame

In order to perform the process capability analysis it is first required to test whether the data follows a normal distribution and the process is under statistical control. The following techniques are used to prove the above two conditions before going for computation of various capability indices;

Normality Test: The normal probability plot is used to check the normality of the data. The null and alternative hypotheses for checking normality of the data are defined as below;

H_0: The data follows a normal distribution.

H_1: The data do not follow a normal distribution.

The Anderson-Darling test is applied on to the collected data; Minitab 17 is used to plot the probability plot. Figure 3 displays the output of the normality test.

The p-value in comparison with the significance level is use to determine the whether the data follows normal distribution. Generally, a significance level [α] of 0.05 works well. 5% risk of concluding that the data do not follow a normal distribution is depicted by a significance level of 0.05 when they truly do follow a normal distribution.

The normal probability plot shows that P-value $>\alpha$ [0.062 > 0.05], hence the decision is to fail to reject H_0 because there is not enough evidence to conclude that your data do not follow a normal distributionand conclude that the data follows a normal distribution.

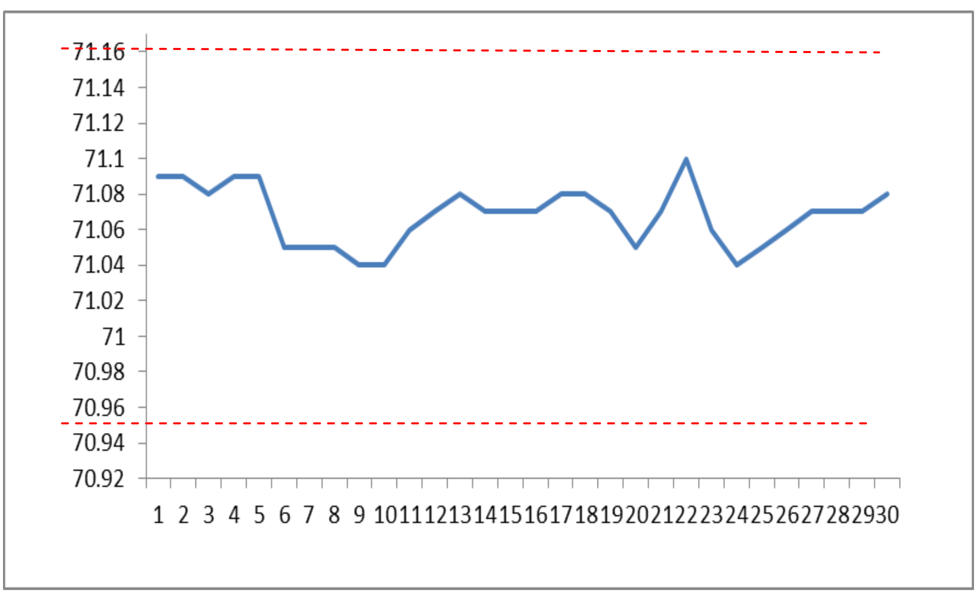

Figure 3

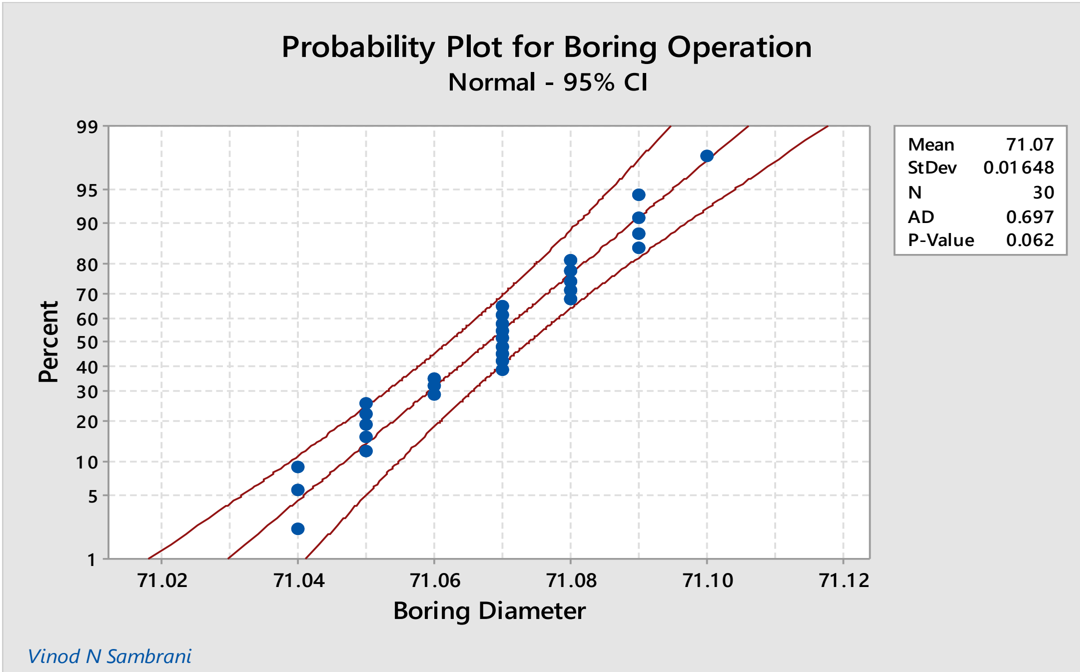

Figure 4: Normal Probability Plot for Case Study Data

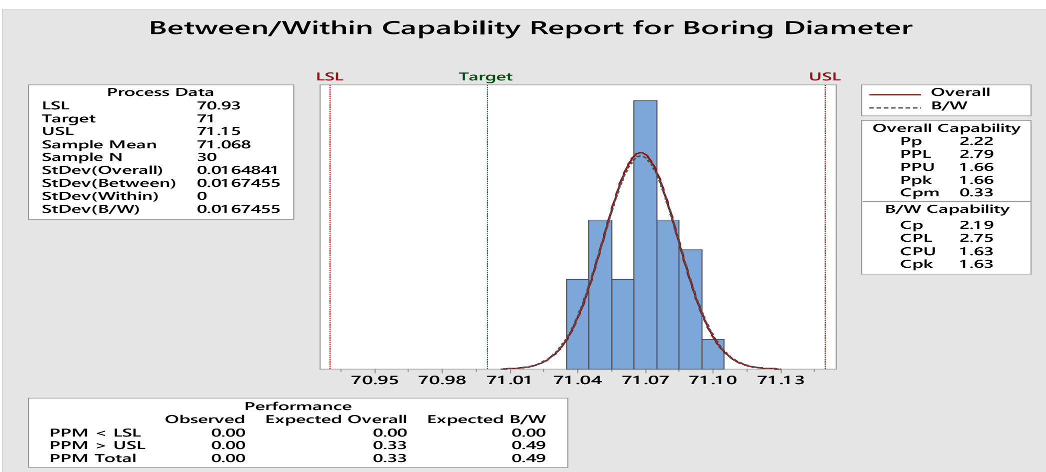

Figure 5: Process Capability Analysis Based on Normal Distribution Model

Interpretation of the Process Capability Report

1. The upper left box in the figure 4 reports the process data, which displays the upper and lower specification limits, the target values. The process mean 71.06 deviates insignificantly from the target value of 71 and is marginally greater than the target value, the boring operation leans towards the upper specification limit.
2. While inputting the data, the sub group is considered as 1, that is there is no grouping of the standard deviation overall and standard deviation within, hence the standard deviation does not make much difference as a result they are similar.
3. The data to the left bottom side indicates the observed performance, expected overall and expected between performance, the inference is as below;

a. All the measurements are located within the specification limits, hence PPM< LSL and PPM >USL are Zero.

b. The expected "overall" performance values quantitatively represent the actual process performance. The expected values are calculated using the overall sample variance. PPM < LSL = 0 and PPM > USL= 0.33.

It means that on the LSL side there will be zero expected measurements and 0.33 parts per million are expected to have measurements greater than the USL.

c. The expected "within" performance values quantitatively represent the potential process performance if the process did not have the shifts and drifts between subgroups. The expected values are calculated using the within-subgroup variation. PPM< LSL = 0 and PPM >USL= 0.49, implies that 0.49 parts per million are expected to have measurements greater than the USL on the lower side it is zero.

4. The values in the between capability box indicate the status of the process. The C_p index of 2.19 indicates that the process is performing at 6sigma standards. The value 2.19 implies that the specification spread is 2.19 times greater than 6σ spread. C_{pk} index of 1.63 which is less than C_p [$C_{pk}<C_p$] indicates that the process is off centred [The process mean has drifted toward the upper specification limit]; however the quality condition is excellent.

a) The 'K' Calculation

The k index is a unit less linear measure describing the distance that the process mean lies off-centre and is therefore an appropriate measure of process centering. C_{pk} demonstrates the reduction in process capability produced by the absence of centering. The minimum value of K is 0 and the maximum value of K is 1.

K value is calculated using equation 4.The process mean μ is 71.068, N is the specification midpoint, given by N = [USL + LSL] /2.

N= [71.15 + 70.93]/2= 71.04

Substituting the values in the equation $K = \frac{\mu - N}{(USL-LSL)/2}$

$$K = \frac{[71.068 - 71.04]x2}{[71.15 - 70.93]} = 0.25$$

Interpretation:

When K = 0 designates that the process is centered at the target which is the midpoint of the specification i.e. μ = N. K=1 designates that the mean is situated on one of the requirement limits. If 0< K <1, the process mean is positioned somewhere between the target and one of the requirement limits. K>1 indicates that the process mean is situated outside the requirement limits.

The K value of 0.25 [0< 0.25 <1] indicates that the process mean is between the target value and one of the specification limits, in this case the upper specification limit. In other words it means that the mean value has moved towards the right of the target of 71mm, by about 25% enabling a six sigma process capability meeting the required specifications, which is evident from figure 4.

An estimate of C_{pk} = C_p (1-K), substituting the values in the formula to estimate C_{pk}.

C_{pk} = 2.19(1-0.25) =1.64~ 1.63, the C_{pk} value from figure 4 signifying that the K value calculation is correct.

b) Managerial Implications

Process capability studies help mangers to decide whether a manufacturing process is fit and is capable of meeting the necessary quality standards.

Capability indices help manager set a static goal for performance, so as to avoid nonconforming outputs. This will help build customer – supplier relationship. The index value provides a measure for continuous improvement. Production manager will be able to monitor the index value for improvements both at the individual process and for a collection of processes. Production manager can use the index values as a common process performance language to communicate with mangers from other departments liked finance marketing, design department for improvement and cost calculations for up grading or purchase of new machines. Indexes help mangers to make process to process comparison and understand the need for improvement or investment and fix the priority for different processes. Index values guide the mangers in quality audit programs to identify deficiencies in sampling, measurement, process control, etc.

Process capability analysis helps mangers predict the extent to which the process will be able to meet customer specifications. Managers will be able to detect the need for redesigning and implementing a new process that will the source of variability in the existing process. Process capability analysis will enable the manager to decide from among competing processes and select the best one that meets customer requirements.

Mangers with little or no statistical training can use process capability indices to understand the status of the process and make informed statistical decision regarding quality performance requirements while designing of new process and purchase of new machinery. Following are some of the guidelines based on C_p and C_{pk} values.

1. If $C_p = C_{pk}$, the process is centred at the midpoint of the upper and lower control limits.
2. If $C_{pk}<C_p$, the process is off-centred.
3. If $C_{pk} = 0$, the process mean is exactly equal to one of the specification limits
4. If $C_{pk}< 0$, the process mean lies outside the specification limits
5. If $C_p< 0$, then the process mean is outside the specification limits.
6. If $C_p = 1$, it implies that the process is centered.
7. For a normally distributed product $C_p = 1$ implies that 2700 parts per million (ppm) are non-conforming i.e., fall out rate of 2700 ppm for two sided specifications.

8. If $C_p < 1$, it implies that the process is not fully capable.

If C_{pk} is less than 1, the manger should go for 100 percent inspection as some of the manufactured products may be out of specifications.

A C_p value of 1 means that the process will continue to produce atleast 99.73% of the products that will conform to specifications (0.27% nonconforming).

VI. Conclusion

The expected industry benchmark value for C_p and C_{pk} for assessing the capability of a process is 1.33, corresponding to a process which will produce nearly 99.9937% good product or 0.0063% bad product. Process capability measures have been used to provide number of abnormal products.

C_p measures the requirements spread relative to the 6 σ spread in the process, signifying the ability of the process to produce components conforming to requirements. C_p does not contemplate where the process mean is situated with respect to the specification limits. C_{pk} on the other hand takes the process centering into account. In the words of Douglas C Montgomery, C_p measures potential capability in the process whereas C_{pk} measures actual capability.

In order to direct process adjustments, however, capability indices must be considered collectively. Collective indices of C_p, C_{pk}, and k signal the need for planned process location adjustments and or process variability reductions. Therefore, both C_p and C_{pk} should be used to evaluate the process capability and K measures the distance, the process is off centred. In the case study considered, C_{pk} index of 1.63 which is less than C_p value of 2.19 [$C_{pk} < C_p$] indicates that the process is off centered. The C_p value of 2.19 is greater than the industry standard of 1.33, hence it is concluded that the process is operating at six sigma capability. The C_{pk} value of 1.63 is greater than the industry standard of 1.33, it is concluded that the quality condition is excellent and the process is capable of producing excellent quality output. The mean value has moved towards the right of the target of 71mm, by about 25% enabling a six sigma process capability meeting the required specifications. PCIs provide important information about how the process meets customer requirements. PCIs calculation helps managers avoid unreliable results, incorrect decision making, and wastage of time, resources and money. This tool not only helps managers in the above aspects, but also will give sharp advantage to overcome the market competition with quality products to their customers. Despite the numerous studies on the above field, there is a lack of knowledge awareness and interest in using PCIs in regular activities by managers for their own sustainability.

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