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MODEL BASED SIX SIGMA CONCEPT AND PROCESS CAPABILITY INDICES: THE RESEARCH STUDY OF OIL INDUSTRIAL CASE IN YEMEN

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ABSTRACT

Process capability indices are utilized extensively in the quality control inspection process, both at the level of production and for general business operations. They take into consideration both the location and the deviation from the specified limits and targets. Several literatures have contained contributions on this issue. Existing PCIs based on Six Sigma, on the other hand, merely displayed a range of quality levels rather than a single quality level value. Thus, previous studies have found the insufficient and ineffective deployment of Six Sigma to process control and yield process. Motivated by industrial Aden oil refinery process performance case study, we discuss the density characteristic of oil to estimate the process yield, and the capacity of the process.In addition, an effort to identify the level of quality in which the refinery operates. By investigating two different methods for estimating process yield, the sigma level, which areby extends the indicesto estimate capacity, level of sigma, and yield process. The analyses and findings indicated that the indicesoutperformed the existing indices. Ultimately, Six Sigma-based process yield index represents a potential approach that other industries and practitioners can utilize to assess process performance and quality control.

1. INTRODUCTION

In today's competitive enterprises are expected to provide high-quality and cost-effective products that continuously fulfill the engineering design specifications and consumer desires (Felipe et al, 2017; Krolczyk et al., 2015). So, companies must focus on quality and process capabilities to gain a competitive edge in a world of informed customers (Leiva, et.al, 2014; Lupo, 2015; Krolczyk et al., 2015). Manufacturers have always tried to identify variation sources to reduce it (Goodwin, 2015). Process capability means a process can consistently fulfill customer expectations and design criteria (Felipeet al, 2017). It is a scientific and methodical method that employs control charts and capacity indicators to identify and eliminate artificial causes of variation until statistical control is achieved. where the variation hinders process capability and output, according to Kotz et al, (1998); Shahriari et al, (2009) "Since process variation can never be entirely eliminated, the management of such variation is the key to product quality, "Process capability indices PCIs are sophisticated statistical tools used by industry to evaluate manufacturing process performance and analyze variability compared to specification limitations (Chakraborty & Chatterjee, 2016). They utilize the

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mean and variation of a product attribute to assess manufacturing tolerance. PCIs are easy and useful tools for engineers to communicate and provide numerical measurements of whether a manufacturing process can produce consistent products within set specification boundaries (Pan, et al 2016; Srinivasan, et al, 2016; Pearn, et al 2014; Pham, 2015).

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Several PCIs, including as together with other essential statistical tools for quality assurance, are utilized in order to evaluate the performance of the production process for cases containing a single quality characteristic feature (Chakraborty et. al 2016; Coetzer et al, 2016; Dianda,et al 2017; Felipe,et al 2017; Lupo, 2015; Pearn, et al 2011). PCIs are a type of statistical measurement that is used in industrial enterprises to assess the performance of processes for scenarios that include a particular product attribute (Goodwin, 2015).

Quantitative quality control relies heavily on the assessment of the process capability, and process capability indices (PCIs) are statistical measurements of the process capability (Chakraborty et. al 2016; Coetzer et al, 2016; Dianda, et al 2017; Felipe, et al 2017; Lupo, 2015; Pearn, et al 2011). In the most recent decades, a great number of PCIs have been presented, and they have found widespread use in a variety of sectors. Many studies have used process capacity indices to determine process quality levels in line with the Six Sigma concept. Existing PCIs based on Six Sigma, on the other hand, merely displayed a range of quality levels rather than a single quality level value. As a result, past studies have found insufficient and ineffective deployment of Six Sigma to process control and yield process.

2. PROCESS ACTUAL YIELD INDICES BASED ON SIX SIGMA – 6σ

According to Kane who presented the C_{pk} process capability index, which is defined as following

$$C_{pk} = Cp\left(1 - \frac{|T - \mu|}{U - L/2}\right) = \frac{U - L}{6\sigma}\left(1 - \frac{|T - \mu|}{U - L/2}\right)$$

(1)

where, L and U are the tolerance limits σ is standard deviation μ is the mean $T = (U + L)/2$ is the target $|\mu - T| = \delta\sigma (0 < \delta \le 1.5)$ variation coefficient and that the δ is equal to a constant value which is 1.5, Hence, based on Six Sigma concept, assuming the attendance of the idea of six Sigma, this means that the symbols are interpreted as follows $T = (U + L)/2, ; U - L = 2L\sigma, |\mu - T| = \delta\sigma (0 < \delta \le 1.5), \sigma = \frac{(U - L)/2}{6}$, thus C_{pk} can be extendedto SSC_{pk}, and the SSC_{pk} index can be computed as follows:

$$SSC_{pk} = \frac{2L\sigma}{6\sigma}(1 - \frac{2\delta\sigma}{2L\sigma} = \frac{L - \delta}{3}$$

After that, many analyses of the yield process. According toBoyles, (1994); Chen et al., (2003); Perakis & Xekalaki, (2003); Vännman & Albing, (2007);Wang (2013) the Cp, Cpk have the relationship with rate : %Y ≥ 2ϕ(3C$_i$)-1 Where $C \in (Cp, Cpk)$ Furthermore Cp, Cpk the Possess, have a rate relationship that is one-to-one, which represents the true values that are generated by the process. $Y \ge 2\Phi(3C_i) - 1$ Where $Cs \in (Cp, Cpk)$

Process yield Y is the most prevalent quality standard in manufacturing. The index determines yield. This allows these indices to accurately reflect yield characteristics and serve as an external product quality reference and quality control employees. Chen et al., (2016) Process yield Y equals the proportion of product units that meet standards as the equation (3):

$$Y = \int_{LSL}^{USL} 1 \, dF(x)$$

Where a cumulative distribution function F(x). Process yield states that each product within control boundaries is certified and has the same quality criteria. Loss happens when a product doesn't fulfill quality criteria.

Equations (2) and (3) demonstrate the link between process yield and Cpk index for different, where process yield is substituted by PPM non-conformities. Process yield cannot be predicted using Cpk. 1986 saw Motorola's Six Sigma Strategy. The term "six sigma process" stems from the idea that the upper and lower specification limits are two times six standard deviations apart, (USL–LSL) = 12.

In 1986, Motorola launched a quality improvement effort under the direction of engineer Bill Smith [14–16] to address product quality issues. Smith advocated that products be built more precisely to specification and set the following goal: To achieve higher accuracy, the tolerance interval limits (L and U) should be $\pm 6\sigma$ new from the centered procedure mean. The former accuracy (equivalent to a minimal capacity $C_{pk} = 1.33$ assuming tolerance limitations were only $\pm 4\sigma$ old off the process average. The statistical quality control 3 sigma rule states that no problems occur outside the interval $\pm 3\sigma$ of the average. The ratio of the domain outside the tolerance range without defects (beyond $\pm 3\sigma$ compared with mean) then the tolerance interval will increase 25% (result from the ratio $\sigma_{old} / 4\sigma_{old}$ to 50% (result from $\pm 3\sigma_{nww} / 6\sigma_{nww}$ (Boroiu et al., 2023). Hence, the safety zone is doubled.

Figure 1 shows key components of process precision: The picture shows two value distributions—the initial one (precision $4\sigma_{old}$) and the new one (precision $6\sigma_{NEW}$) because quality is improved by increasing process precision, not tolerance interval.

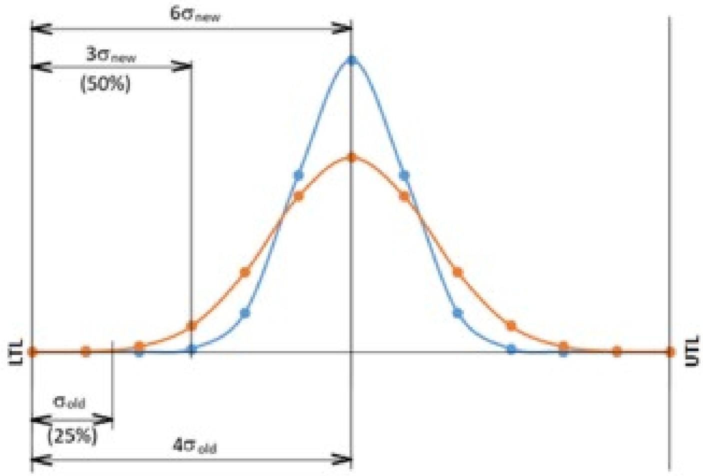

Figure 1. Process precision improvement: 6σ versus 4σ

Even Michael Harry, who implemented Bill Smith's proposal and is connected with the newly concept and other authors who portray the notion's beginnings (Raval & Muralidharan, 2016) don't emphasize this. Montgomery Montgomery, (2009)agrees that improving accuracy improves quality. "Variability: The root of defects," Bass, (2007)says. Nevertheless, This is the optimum situation, which may be true immediately after modifying the process, short-term performance, where the fraction of non-conformities is 2·F(6) =2, 0.0001= 0.0002 PPM, where F(x) integral Laplace function. (Boroiu et al., 2023). But, with time, the process will wander from its original location. Based on this hypothesis, Bill Smith advocated using the 1.5 σ process drift depicted in Figure 2. This process drift value was chosen without much scientific justification, supposing that a specific cause caused it.

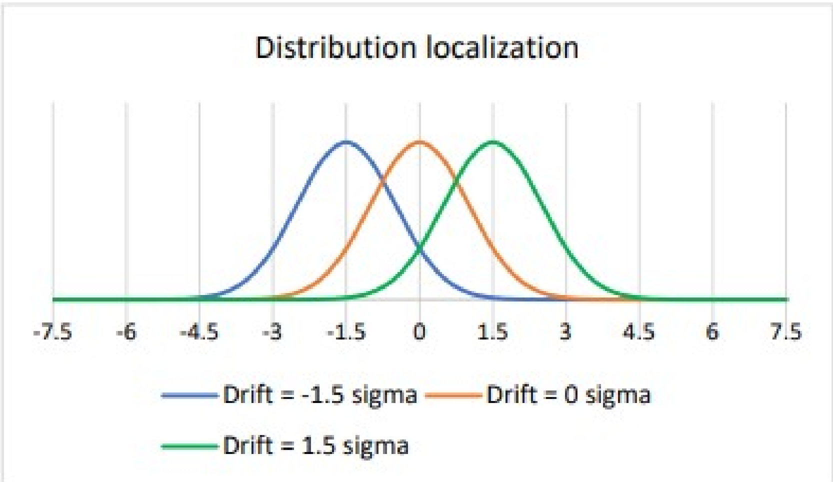

Figure 2.1.5 Shift process distribution

In this case, the level sigma process is six if specification limits interval is twice $U - L = 2L\sigma$ and $T - \mu = \delta = 1.5$,then the $C_{pk} = 1.5$ .also according to Six Sigma, $C_{pk} = 2$ if sigma=6 and $T - \mu = \delta = 0$. This analysis assumes that $\delta = 1.5$ has a stable value of 1.5 (constant value) and the level sigma = 6. Additionally, process centering μ can estimate: $T + 1.5\sigma \geq \hat{\mu} \geq T - 1.5\sigma$ thus, the level of the Sigma can be calculated according to the following equation

$$L_c = \hat{L}\sigma = \min\left[\frac{1-\delta}{\lambda} + 1.5, \frac{1+\delta}{\lambda} + 1.5\right]$$

Where,

$$\hat{\lambda} = \frac{((U-L)/2)/6}{(U-L)/2} = \frac{\sigma}{d}, \hat{\delta} = \frac{|\mu - T|}{d} = \frac{1.5\sigma}{d}$$

According to Equations (3) and (4)Assuming Motorola and Six Sigma, process yield can be calculated:

$$SSY = \int_{L^*}^{U^*} N(\hat{\mu}, \hat{\sigma})dx = \Phi(1.5+L_C) - \Phi(1.5-L_C)$$

Where $U^* = U + 1.5\sigma = \hat{\mu} + 4.5\ \hat{\sigma}_{ss}^2 / \sqrt{n}$,

$L^* = (L - 1.5\sigma) = (\hat{\mu} - 4.5\ \hat{\sigma}_s^2) / \sqrt{n}$,

Φ $(\cdot)$ is the cumulative distribution of the standard normal random variable,

$T - 1.5\sigma \leq \hat{\mu} \leq T + 1.5\sigma$. $\hat{\sigma}_{Si} = \frac{S\,i}{C_4(V)}$ and

$\hat{\sigma} = \frac{(U-L)/2}{6}$ also There are different ways to estimate standard deviation $\hat{\sigma}$ but the best way can be defined as a mathematical expression: $\hat{\sigma}_{Si}$ is used for S.D estimation. Here $V = \sum_{i=1}^{q} n - q + 1$, and $Si = \sqrt{\frac{1}{n-1}(Xij - \bar{x}i)^2}$ are unbiased.

According to equations 2 and 3, the yield process is:

$$2\Phi(3SS\hat{C}pk) - 1 \leq SS\hat{Y} \leq \Phi(3SS\hat{C}pk) \quad (6)$$

When $SS\hat{C}_{pk}$, $L\sigma$ and SSY are have one to one relationship. In light of value $SS\hat{C}_{pk}$ index, there is a guideline to interpreting the results of this index and the yield process. For example, if $SS\hat{C}_{pk} = 0.5$ the process is capable and guarantees that the level sigma equals there sigmaand when $SS\hat{C}_{pk} = 1.5$, the process is super and guarantees that the yield process will be not less than 0.999996602268 equivalently not more than 3.5 defect per million opportunities DPMO.. Six Sigma estimates process yield in two ways:

$$\left.\begin{aligned} &\text{way (A) } SS\hat{Y} == \Phi(1.5 + L\hat{\sigma}) - \Phi(1.5 - L\hat{\sigma}), \\ &\text{way (B) } SS\hat{Y} = 2\Phi(3SS\hat{C}pk) - 1 \leq SS\hat{Y} \leq \Phi(3SS\hat{C}pk)\ . \end{aligned}\right\}$$

Boyles (1994) proposed the yield index Spk. The index Spk establishes a relationship between process performance and tolerance limits to accurately evaluate yield process, and it is defined as follows:

$$Spk = \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\Phi(\frac{U-\mu}{\sigma}) + \frac{1}{2}\Phi(\frac{\mu-L}{\sigma})\right]$$

where Φ $(\cdot)$ is the cumulative distribution. The relationship between yield (Y) and index Spk is:

$$Y = 2\Phi(3Spk) - 1$$

By use Equations (7), (8), and (9) can be expanded S_{pk} to $SSSpk$ as follows:

$$SSSpk = \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\left(\Phi(3SS\hat{Y})\right) + 1\right]$$

The SSS_{pk} is a useful tool for estimating the yield process at the 6 sigma level. It has a one-to-one correspondence with the yield process, in a similar way to the index S_{pk}, the following relationship describes how the two are related:

$$SS\hat{Y} = 2\Phi(3SSSpk) - 1$$

In this study's the indes SSS_{pk} is connected to process yield by six sigma since Equations (7), (10) and (11) may be rearranged as follows:

$$\text{way (A) } SSSpk = \frac{1}{3}\Phi^{-1}\left(\frac{1}{2}[\Phi(1.5 + L\hat{\sigma}) - \Phi(1.5 - L\hat{\sigma})] + 1\right)$$
$$= \frac{1}{3}\Phi^{-1}\left((\Phi(SS\hat{Y}) + 1)/2\right)$$
$$\text{way (B) } SS\hat{S}pk = 2\Phi(3SS\hat{C}pk) - 1 \leq SS\hat{Y} \leq \Phi(3SSCpk)$$
$$= \frac{1}{3}\Phi^{-1}\left((\Phi(SS\hat{Y}) + 1)/2\right)$$

$SS\hat{C}_{pk}$ index or $L\sigma$ and SSY have one to one relationship when $T - \mu = \delta = 1.5$ Follow this idea the yield processThis way generates a yield by $SSY = \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\Phi(3SSCpk) + 1\right]$ where $SSCpk = \frac{(L\sigma - 1.5)}{3} = (\frac{L\sigma}{3} - 0.5)$. Here for a process achieving the level of quality or $\hat{L}\sigma$ level of Sigma can be calculated as shown in equation 4 or $\hat{L}\sigma = \Phi^{-1}(SSY)$

3. THE METHODOLOGY OF THIS STUDY

This study uses Process Capability Indices (PCIs) and Six Sigma (SS) to improve industrial process performance evaluation. This research technique focused on finding current performance and then extensive examination of performance evaluation indices to develop performance. Measuring current process performance is vital to discover the process's capabilities and reasons of faults and variability. The industry should use data gathering, data characterization, statistical tests, and generic estimators to measure and improve process performance using Six Sigma. Figure 3 (Appendix) shows this study's methodological flowchart.

4. MEASUREMENT AND EVALUATION OF SIX SIGMA PROCESS PERFORMANCE IN ADEN REFINERY

The first thing that has to be done in order to ascertain the state of the process performance in any industry is to measure the present performance. There are a lot of different indicators that may be used to figure out how well the process is doing right now. The majority of these indicators are evaluated using a wide number of estimating techniques, each of which results in a unique set of findings. As a result, it is very necessary to make use of the right estimating methodologies and measuring instruments while evaluating the performance of the process. This is basically the primary focus of a great number of research, and the purpose of this study is to produce accurate indicators for monitoring and assessing the performance of processes in industrial settings. As a result, the purpose of this study is to provide a case study that measures and evaluates the process performance of an oil refinery in Yemen.

4.1. Data Acquisition and Collection

Controlling petrol properties requires similar density. Its physical liquid feature makes density important. Oil density should be between 0.70 and 0.73. Thus, density affects fuel quality. Density determines the kind, volume, and transport or distillation of fuel. Thus, if the density is over 0.73, the oil is kerosene, but below 0.70, it becomes vapors and gases. (Ali & Ahmed, 2017; Aden Refinery 2016). This method obtains density relative data: First, a hydrometer is used to randomly sample oil from the tank's upper, middle, and lower regions. Since tank density varies, the sample is mixed. After mixing, the material is examined for density in the lab. 50 product samples, each with four items, were taken at even intervals (every 8 h) after the random data was gathered to 200 size samples. Important statistical tests were done to validate the data for further study. It includes normality, stationary, autocorrelation, heteroscedasticity (autoregressive model), and process capacity tests. The gasoline characteristic tests for density, normalcy, and stationary showed no unit root. Also, the density characteristic data does not have autoregressive and the results indicate that the process is capable at density characteristic, so the results for density characteristic concluded that normality, stationary, not autoregressive, and capable that means the tested on density characteristic are statistically reliable for further analysis we implement the process actual yield indexes based on six sigma concept and the results are discussed in the next section

4.2. Results and Discussions

According to the calculated and the guide to interpret the output of the process yield index and level process of sigma are explained in Table (1). Here, it should be noted that, the existing PCIshad not considered the probability of a 1.5σ process mean change when assessing product or service quality. Many studies have used process capacity indices to determine process quality levels in line with the Six Sigma concept. Existing PCIs based on Six Sigma, on the other hand, merely displayed a range of quality levels rather than a single quality level value. As a result, past studies have found insufficient and ineffective deployment of Six Sigma to process control and yield process.This necessitates investigating indexes in this study based on Six Sigma idea to evaluate product quality characteristic for our results on an index evaluate and measure the process based on the idea of six sigmas as evidenced in the paragraphs under section 2 of the process actual yield indications based on six sigmas – 6σ.The result of the process yieldindex SSSPKfor the A and B cases of estimation, for density characteristic is the same results whereandalso for percentage of yield was achieved for density characteristic for A and B cases of estimation is the same results whereand . So, there is a one-to-one correspondence between the process yield index, level sigmaand yield processIn both cases the A and B the judge to interpret the outcomes of a process whenas following: if theis 1.5, then the sigma level is 6 and the yield percent is high at 0.999996681. According to the calculated cases, A and B provide a guide to interpret the outcomes of the process yield index,and Sigma levelsare explained in Table 1.

Table 1. Grading description for cases A and B with sigma levels

yield index value	Grading	levels Sigma
$SSS_{pk} < 0.5$	Inadequate	LS<2.5
$0.5 \leq SSS_{pk} < 0.833$	Capable	3 ≤ LS<4
$0.833 \leq SSS_{pk} < 1.17$	Satisfactory	4 ≤ LS<5
$1.17 \leq SSS_{pk} < 1.5$	Excellent	5 ≤ LS < 6
$SSS_{pk} \geq 1.5$	Super	LS ≥ 6

Aside from this, it has been clear during the course of the previous discussion and analysis that there is a correlation of one to one between the SSY_i yield and the $SSSpk$ yield index in both of the processes that are used to calculate yield.

Table 2. The comparison between process performance indices

Oil Quality Characteristic	Traditional indices		indices beads Sigma		
	C_{pk}	S_{pk}	SSC_{pk}	$L\sigma$	SSS_{pk}
Density	0.785	0.904	0.874	4.12	0.951

Based on Table 2 it can be seen that the indices SSC_{pk}, SSS_{pk} and $L\sigma$ reflect the results of the capacity, yield and sigma level of the process according to the idea of Six Sigma. Also based on Table 2, it can be seen that the proposed SSC_{pk}, SSS_{pk} indices, produced better results when compared to the traditional indices using the two different cases of estimation for the characteristic oil density, where the guideline for traditional indices C_{pk}, S_{pk} annotated in Table 1. Mean while the indices SSC_{pk}, SSS_{pk} provide a guide to interpret the output of the process: capacity indices, yield and level of sigma process are explained in the Table 2.

5. CONCLUSION

Six-sigma, a quality improvement technique, uses indices to measure sigma for a quality feature. The indicators help quality control and engineering staff identify sigma process levels. This study provided a statistical method using PCIs and SS to measure and improve industrial process performance evaluation. This industrial case study evaluates Aden's oil refinery process performance. To do this, density data from 200 random samples was gathered to measure process quality. Data normality, stationary, and non-autoregressive were found via density characteristic statistical tests. Table 3 shows that Six Sigma indicators outperformed conventional indicators. Process yield *SSY* matches performance index. SSC_{pk}, SSS_{pk}, *and* $L\sigma$ hence, when consumers require high process quality for a certain quality attribute, boost product process yield. Yield increases with performance index value and decreases with performance index value. These indices can accurately depict yield characteristics to provide a baseline for quality control or manufacturers and a product quality reference for outside parties. This study developed a viable way to analyze process yield that engineers in manufacturing or quality control may use to evaluate yield processes and quality.

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Appendix

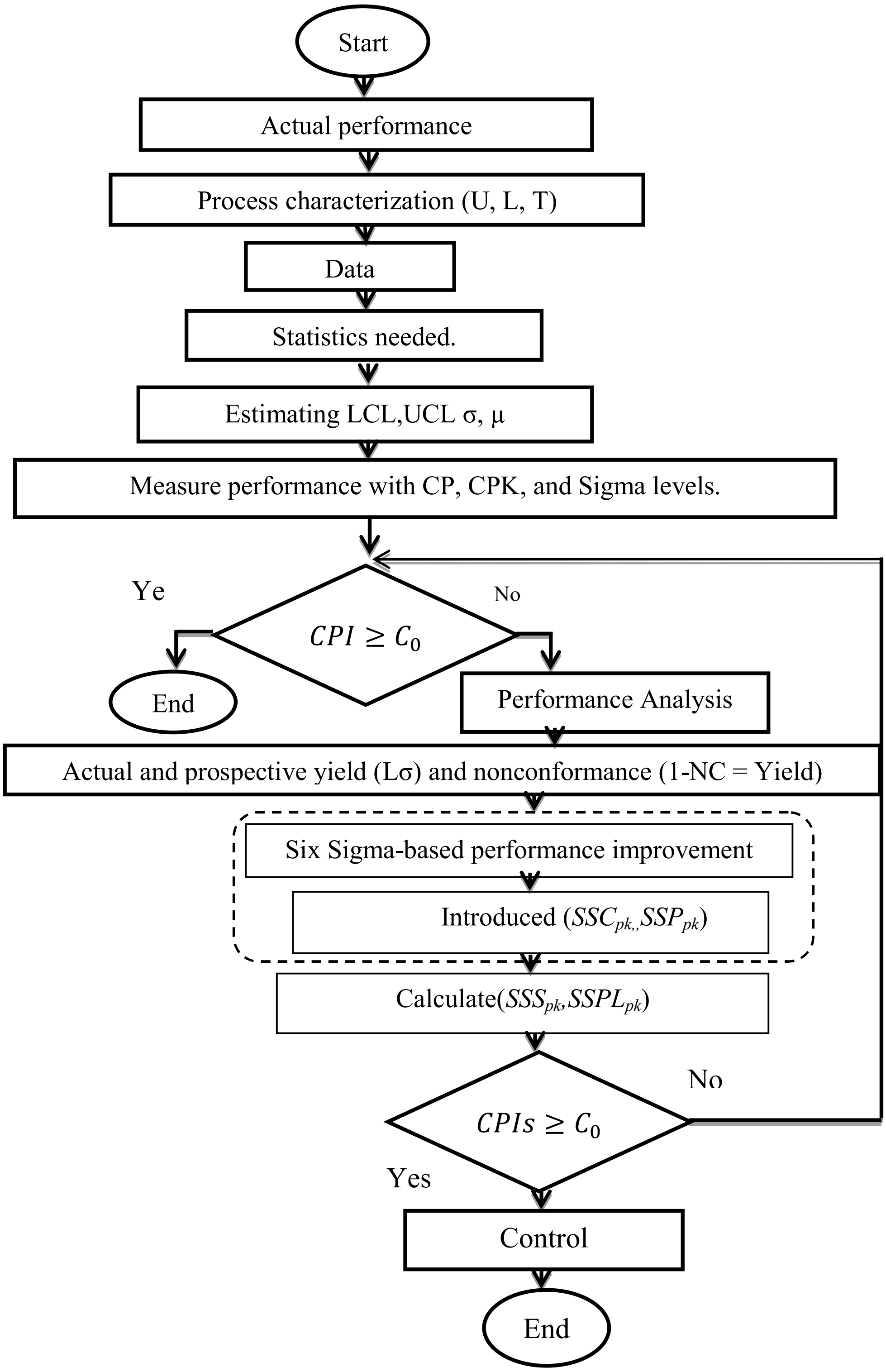

Figure 3. Methodology flowchart