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Process Capability Analysis to Assess Capacity of a Cleaning Liquid Product with Asymmetric Tolerances

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K E Y W O R D S

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A B S T R A C T

Process capability indices are a powerful tool used by quality control engineering to measure the degree to which the process is or is not meeting the requirements. This paper studies the application of process capability indices in the evaluation of a process with asymmetric tolerances. The analyzed collected data of the cleaning liquid "Zahi", was used to investigate the ability of the filling process to meet the requested specifications. Matlab software was used to plot $\bar{X} - \bar{R}$ *control charts, normal probability, and histogram of the data gathered from the production line and further performed statistical calculations. It was observed from the control charts that the filling process is under control. In addition, it was revealed by the process capability indices that the process of filling the cleaning liquid bottle is not fitted with the target value but it is adequate.*

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1. Introduction

The quality improvement process becomes a key factor to gain a competitive market position in today's industrial companies [1]. Manufacturing companies are required to align their products with respect to customer needs [2]. Variability in manufacturing processes is considered one of the most challenging problems facing industries. The sources of process variations can be categorized as random (or physical) and systematic (or functional) [3]. To reduce them, industries are required to develop effective quality improvement techniques. Among the most popular quality improvement techniques, control charts and Process Capability Indices (PCIs) are the two statistical tools that are employed to improve the quality of products when variations in the manufacturing process do not meet the process specifications or customer requirements [2, 4]. Control charts are used to monitor

production activities in terms of the detection of any out-of-control processes [5]. While PCIs compares the variability of the actual production process with its standard specified limit [6].
Various PCIs including C_p, C_{pk}, C_{pm}, and C_{pmk} have been developed in the literature to provide manufacturing companies quantitative measures of the process performance in terms of the process location regarding the target value and the process variation regarding the specified intervals. For example, index C_p measures the ratio between the desired specification limit and the actual process variation. This index is criticized for being unable to identify the scenario where the process is not centered in the middle of the limits of the specifications. Index C_{pk} was introduced to overcome this problem. However, these two indices are calculated independently of the target value of the process. For this reason, index C_{pm} was developed to take into account the actual process variation with respect to the target value in the assessment of process performance. Index C_{pmk} is proposed by combining indices C_{pk} and C_{pm} [7, 8, 18].
There are several fundamental assumptions that need to be met in order to get reliable decisions about process capability based on these traditional PCIs including normality of the collected data [9], and stability (process-in-control) [9, 10, 11]. However, it has been noticed in many industrial cases that the production process exhibits a non-normality distribution [12, 13]. As a result, alternative approaches to evaluate the capability of the production process are proposed. For example, Kovářík and Sarga are investigated the performance of nine approaches that was proposed to deal with non-normality processes [14].
Most of the published articles on the application of PCIs about measuring and improving the quality of manufacturing processes focus on the case when the process has symmetric tolerances [15]. In some cases, the target value of some processes is not located at the midpoint of the specified interval (asymmetric tolerances) due to different aspects such as functional requirements and economic considerations [16]. The objective of this research work is to illustrate the application of process capability indices in the evaluation of a process with asymmetric tolerances. The analyzed collected data of the cleaning liquid "Zahi", was used to investigate the ability of the filling process to meet the requested specifications. In practice, large deviations of the weight of the cleaning liquid bottle from a target value can result in dissatisfaction of the customer if deviations it is less than the target value, while it can be caused an additional cost to the company if deviations are more than the target value. This research was initiated by the company to measure the capability of the filling process and to bring down the defect level. Due to economic consideration, the upper and lower specification was set asymmetrically. Control charts, normal probability, and histogram of the data gathered from the production line and further are performed by the Matlab software was used.

2. Capability Measure for Asymmetric Tolerances

Assuming the quality characteristic of the process has a normal distribution, the most commonly PCIs are defined as follows [16]:

$$C_p = \frac{USL-LSL}{6\sigma} \quad (1)$$

$$C_{pk} = \min\left(\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}\right) \quad (2)$$

$$C_{pm} = \frac{USL-LSL}{6\sqrt{\sigma^2+(\mu-T)^2}} \quad (3)$$

where

USL	Upper Specification Limit.
LSL	Lower Specification Limit.
σ	Process Standard Deviation.
μ	Process Mean.
m	Specification Interval Midpoint, i.e. $m = (USL + LSL)/2$.
T	Target of the Product Characteristic.

The process capability C_p is used to compare the process width (variation) with the specified intervals (specification limits). But it does not give any information regarding the process mean location. To overcome this problem, the index C_{pk} was developed that includes the process mean. However, in some cases, the target value of some processes is not located at the midpoint of the specified interval (asymmetric tolerances) due to different aspects such as functional requirements and economic considerations. Therefore, C_{pm} index was introduced to include the target value in the calculation of the process capability. However, if the process mean (μ) and the process standard deviation (σ) are unknown and their value are estimated from samples of n measures $x_1, x_2, \dots, x_n$, then the estimated mean ($\bar{x}$) and the estimated standard deviation (s) can be obtained by using Eqs. (4 and 5) [9]:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (4)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \quad (5)$$

Substituting the process mean (μ) and the process standard (σ) by the estimated mean ($\bar{x}$) and the estimated standard (s) into Eqs. (1, 2 and 3) yields the following:

$$\hat{C}_p = \frac{USL-LSL}{6s} \quad (6)$$

$$\hat{C}_{pk} = \min\left(\frac{USL-\bar{x}}{3s}, \frac{\bar{x}-LSL}{3s}\right) \quad (7)$$

$$\hat{C}_{pm} = \frac{USL-LSL}{6\sqrt{s^2+(\bar{x}-T)^2}} \quad (8)$$

Where $\hat{C}_p, \hat{C}_{pk}$ and $\hat{C}_{pm}$ are estimated value of the actual value of indices C_p, C_{pk} and C_{pm}.

To check whether a given sample data is drawn from a given probability distribution, the Anderson-Darling test is used. The Anderson-Darling Test is a statistical test that was developed in 1952. The two hypotheses for the Anderson-Darling test for the normal distribution are presented below:

H_0: The data follows the normal distribution

H_1: The data do not follow the normal distribution

The Anderson-Darling statistic can be computed by the following formula [17]:

$$AD = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\left[\ln F(X_i) + \ln\left(1 - F(X_{n-i+1})\right)\right] \quad (9)$$

where

AD	Anderson-Darling statistic.
n	Sample Size.
$F(X)$	Cumulative Distribution Function.
i	i^{th} Sample when the data is sorted in ascending order.

The value of AD needs to be adjusted for small sample sizes as follows:

$$AD^* = AD\left(1 + \frac{0.75}{n} + \frac{2.25}{n^2}\right) \quad (10)$$

In order to calculate the $p - value$, it is given as follows [17]:

- If $AD^* \geq 0.6$, then

$p = e^{(1.2937-5.709AD^*+0.0186AD^{*2})}$

- If $0.34 < AD^* < 0.6$, then

$p = e^{(0.9177-4.279AD^*-1.386AD^{*2})}$

- If $0.2 < AD^* < 0.34$, then

$p = 1 - e^{(-8.318+4.2796AD^*-59.938AD^{*2})}$

- If $AD^* \leq 0.2$, then

$p = 1 - e^{(-13.436+101.14AD^*-223.73AD^{*2})}$

2. Case Study: Cleaning Dishes Liquid Capacity

The procedure of applying the estimated PCIs to evaluate the quality of a filling process is given via a practical application in an industrial case study. The State Company for Vegetable Oils Industry in Iraq (SCVOI) is an Iraqi company that focuses on the development and production of a variety of edible fats and oils, soaps, detergents, and cosmetics.

(**a**) (**b**)

Figure 1: Weighting a. Empty bottle b. Full bottle

The cleaning liquid bottle name (Zahi) was selected for a case study in this research to analyze the capability of the operational line to manufacture this type of product. Weight is the selective parameter for this product. According to the operational design of the company, the target value of the net weight was (2000 gm), the (USL=2025gm), and the (LSL=1950 gm). By adding the empty bottle weight (132gm) as shown in Figure 1. The standard specification will be equal to (Target = 2132 gm), (USL=2157gm), (LSL=2082gm), and (Middle point = 2119.5 gm). Table 1 summarizes the specification characteristic of the cleaning liquid bottle e. To assess the production process, (25) samples (k) randomly were taken during the manufacturing process. Each sample consisted of four observations (m). The weight was measured by using a scalar with accuracy (0.1g) and scale range (0-7kg). The calculation for each ($\bar{X}$,R, and σ) is included as shown in Table 2 for the k samples. The next step was to check whether the production process is operating within statistical process control and the distribution is normal. The software package MATLAB was utilized to perform this step. In terms of checking the stability of the process, Figure 2 plots $\bar{X}, R$ and σ charts for the production process data. It can be observed from Figure 2 that all points are within the upper and lower control limits. This means that the process of producing water pump plastic cover is under control and stable. The normality checking was performed by using Normal probability plots, histograms, and the Anderson-Darling. Figure 3a plots the histogram and Figure 3b plots the normal probability of the collected data. It can be seen from these two figures that the sample data appears to be normal. In addition, $P-$ value in Table 3 from the Anderson-Darling test is 0.1104 which is greater than the critical value (0.05). Having checked the stability and normality of the collected data, the PCIs can now be applied to evaluate the process.

Table 1: Specification characteristic of the water pump plastic cover

Parameters	Value (gm)
USL	2157
LSL	2082
T	2132
m	2119.5

Table 2: ($\bar{X}, R, s$) calculation of the 4 observations of 25 samples

Samples (k)	Observations (m)				$\bar{X}$	R	s
	X_1	X_2	X_3	X_4			
1	2130	2121	2120	2120	2122.7	10	4.8563
2	2111	2133	2107	2120	2117.8	26	11.5289
3	2121	2110	2118	2129	2119.5	19	7.8528
4	2122	2118	2113	2128	2120.3	15	6.3443
5	2108	2120	2132	2118	2119.5	24	9.8489
6	2104	2109	2118	2119	2112.5	15	7.2342
7	2114	2120	2132	2110	2119.0	22	9.5917
8	2132	2133	2128	2112	2126.3	21	9.7425
9	2127	2123	2114	2128	2123.0	14	6.3770
10	2118	2121	2109	2115	2115.7	12	5.1235
11	2132	2101	2120	2108	2115.3	31	13.6473
12	2117	2131	2118	2109	2118.7	22	9.1059
13	2100	2121	2125	2129	2118.7	29	12.9196
14	2122	2120	2135	2117	2123.5	18	7.9373
15	2107	2115	2129	2124	2118.7	22	9.7425
16	2125	2117	2114	2125	2120.3	11	5.6199
17	2122	2122	2121	2120	2121.2	2	0.9574
18	2117	2101	2122	2111	2112.8	21	9.0323
19	2113	2122	2114	2119	2117.0	9	4.2426
20	2119	2113	2108	2120	2.115.0	12	5.5976
21	2121	2109	2114	2128	2118.0	19	8.2865
22	2120	2125	2115	2139	2124.8	24	10.3401
23	2118	2139	2112	2118	2121.8	27	11.8427

24	2120	2108	2107	2124	2114.7	17	8.5391
25	2120	2118	2117	2122	2119.3	5	2.2174

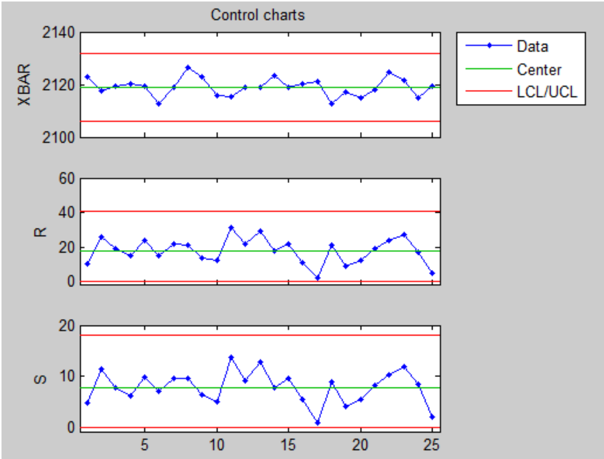
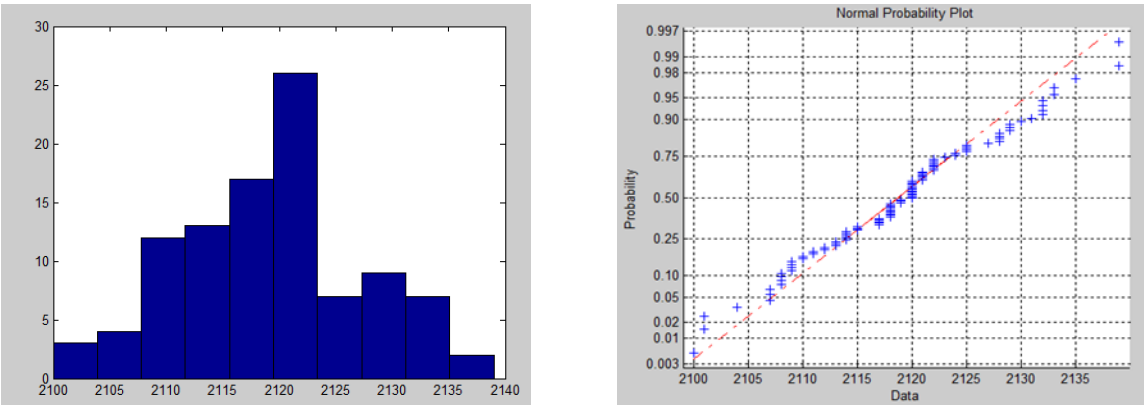


Figure 2: $\overline{X}, R$ and s charts

Table 3: Summary of Results for Calculations $\overline{\overline{X}}, \overline{R}, s$ and $P-value$

Parameters	Value
$\overline{\overline{X}}$	2119
$\overline{R}$	17.8800
s	7.9411
$P-value$	0.1104



(a) (b)

Figure 3: a. Histogram b. Normal probability plot

4. Results Analysis and Discussion

PCIs are used as metrics to know in which extend the process is able to achieve the tolerance limit or customer requirements [18]. Using a single PCI could be misleading. Therefore, appropriate PCIs need to be selected in order to get a good indication regarding the process performance. Khlil et al. [19] developed a procedure to interpret the values of the indices (C_p, C_{pm}) and decide whether a given process meets the capability requirement or not for the cases where the target located in the centre of the specification limits. In this paper, a modification of that procedure is used based on C_p and C_{pm} for the cases where the target is not located in the centre of the specification limits as shown in Figure 4.

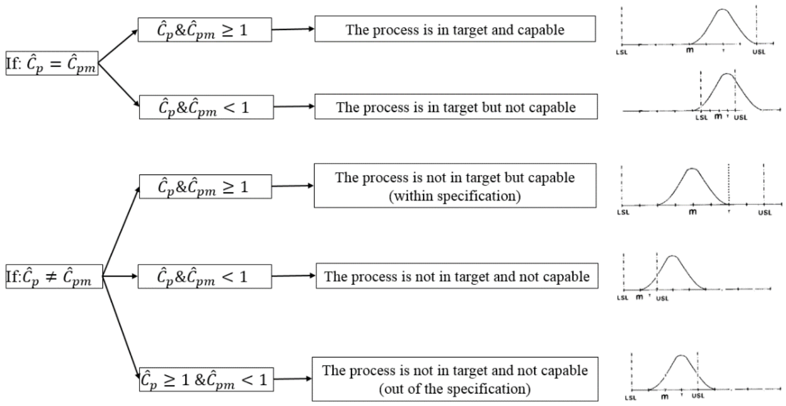


Figure 4: Decision making for testing $\widehat{C}_p$ and $\widehat{C}_{pm}$ (Source: adopted from [19]

Based on the Eqs. (6 and 8), the indices $\hat{C}_p$ and $\hat{C}_{pm}$ for the weight of the cleaning liquid bottle are calculated as 1.574 and 1.571 respectively. Table 4 summarizes the calculation results. From the value of the indices $\hat{C}_p$ and $\hat{C}_{pm}$, it can be seen that $\hat{C}_p \neq \hat{C}_{pm}$ and $\hat{C}_p$& $\hat{C}_{pm} > 1$. Therefore, based on Figure 4, it can be said that the process of filling the cleaning liquid bottle is not located in the target value but it is capable (within specification). As a result, the filling process is acceptable. The results of the study suggest that the mean of the process need to be shifted for further improvement of the filling process. The root causes need to find out for this shift in the process mean. One reason for this shifting could be the machining parameters such as over life use of tools.

Table 4: Summary of results for calculations $\widehat{C}_p$ and $\widehat{C}_{pm}$

Parameters	Value
$\hat{C}_p$	1.574
$\hat{C}_{pm}$	1.571

5. Conclusion

Process capability indices have already become an efficient tool adopted by many manufacturing companies in measuring product potential and performance to satisfy quality requirements. In this paper, a quality control analysis was conducted based on the process capability indices to investigate the ability of filling process of the cleaning liquid bottle name (Zahi), which is produced by the State Company for Vegetable Oils Industry in Iraq, to meet the prescribed specifications. The $\bar{X} - \bar{R}$ control charts of the collected data were confirmed that the process is in statistical control. Then, the normal probability and the histogram of the data gathered were proved that the process is normally distributed. Next, the estimated value of process capability indices for the critical volume of a cleaning liquid bottle was showed that the components produced are acceptable. The results of the study suggest that the mean of the process need to be shifted for further improvement of the filling process. The root causes need to find out for this shift in the process mean. One reason for this shifting could be the machining parameters such as over life use of tools.

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