Process Capability Analysis of a Turning Operation

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***Abstract*— Quality control helps industries for improvements of turning operation product quality and productivity. Process capability indices are effective tools for the continuous improvement of quality, productivity and managerial decisions. Statistical Process Control (SPC) techniques improve the quality in mass production. In this study, a process-capability analysis was carried out in the turning operation on department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna and Department of Industrial Technology Faculty of Science and Technology Chiang Mai Rajabhat University that produces machine and rice mill machine parts. For this purpose, normal probability plots and X bar- *R* charts were prepared and the process capability indices C_p, C_R, C_{pk}, C_{pm} and $\hat{C}_{pk}$ were calculated. It has shown that the process capability for the whole process was inadequate and turning operation the medium production was unstable. 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.**

***Index* Polished Cylinder, Statistical Process Control, Control Charts, Process Capability.**

I. Introduction

THE theoretical framework for accessing the capabilities of a process began with the development of the C_p index [1]. Process capability indices continue to be widely used tools for process engineers despite "a growing recognition that these tools are limited and, in particular, that standard capability indices are appropriate only with measurements that are independent and reasonably normally distributed" [2]. The popularity of process capability indices, along with the common understanding that in many cases these indices are flawed tools, has led continued research in this area. A recent summary of the state of theory and practice is presented [3]. The use of capability indices such as C_p, C_{pk}, and "Sigma" values are widespread in industry [4]. Therefore, the purpose of this paper is to generate the length of rice polished cylinder in different samples after turning was found to be out of tolerance limits asked by department of industrial engineering, faculty of engineering and department of industrial technology faculty of science and technology, the process capability found to be less than the standard value.

This required the idea of SPC implementation and the techniques has been practiced using process capability (C_p). If the process is not in statistical control, we are unable to use reliably on our estimates for spread and location. Hence, our formula are redundant. In order to assess whether or not a process is in statistical control, quality practitioners use control charts. The most frequently used form of control charts in operation today are those which have their derivation from the pioneering work of Dr. Walter Shewhart in the early 1920.s. In their basic form, these charts (e.g. X bar-R, X bar-S Chart) are sensitive to detecting relatively large shifts in the process [1]. SPC tools can be used by operators to monitor their part of production or service process for the purpose of making improvements [5]. For more information on these charts, the interested reader is referred to AIAG and Montgomery [6].

Quality may be defined as that characteristic which renders a product or service as having "fitness for purpose or use". There are different reasons why a product may have unsatisfactory quality. Statistical methods play a central role in quality improvement efforts and recognized as an efficient and powerful tool in dealing with the process control aspects [7].

A. Literature review

The use of statistical concepts in the field of quality emerged in the United States in the beginning of the nineteenth century. But its democratic use began only in the 1930s. W. Edwards Deming, who applied SPC methods in the US during the Second World War, was the one responsible for introducing this concept in Japan after the war ended. These methods were not used in France until the 1970s. The 1980s saw the SPC methods being used frequently, due to the pressure from large clients like automobile manufacturers and aircraft manufacturers [7],[8]. Companies who have been operating in the market

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for a while already have a quality control process in place. This process enables a company to meet four main objectives: higher quality, more effectiveness, optimum cost savings and greater rigor, and produces products of optimum quality [9].

SPC tools can be used by operators to monitor their part of production or service process for the purpose of making improvements [10]. Statistics is more applicable to measure and control variation from common cause (random) than from special causes [11].

II. METHOD EXPERIMENTAL PROCEDURE

A. Method

Process capability analysis using control chart the Normal distribution, one should note that there are an infinite number of distributions which may show the familiar bell-shaped curve, but are not Normally distributed. This is particularly important to remember when performing capability analyses. Therefore, these need to determine whether the underlying distribution can indeed be modeled well by a Normal distribution. If the Normal distribution assumption is not appropriate, yet capability indices are recorded, one may seriously misrepresent the true capability of a process. Consider the following simulation. Suppose the *USL* = diameter 25.45 and *LSL* = diameter 25.35 millimeters, and our target for this process is midway between analysis of the 100 observations. Firstly, considering the X bar and R control chart Refer to "(1)", this see that the distribution is stable over the period of study. To illustrate the use of a process capability to estimate process capability, consider Fig.1., which presents a process capability of the samples data of 20 sample. The samples data are shown in Table 1, the 95 % confidence interval on C_p and C_{pk}.

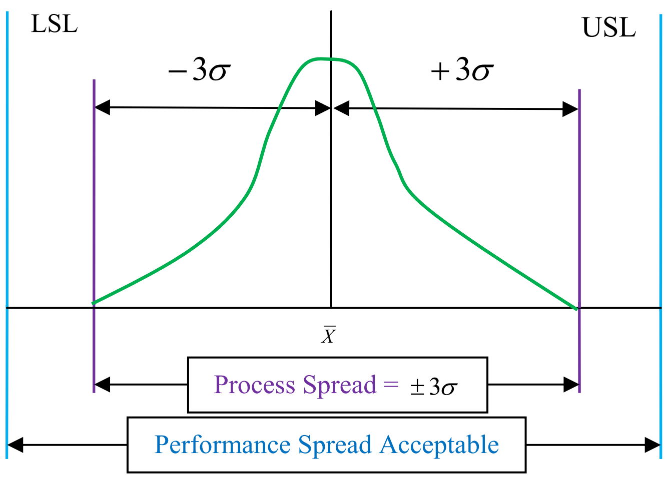

Fig.1. process capability

TABLE I
Polished Cylinder 20 Sample Data (Diameters, Millimeters, ± 0.05)

No.	X_1	X_2	X_3	X_4	X_5	$\bar{X}$	R
1	25.40	25.41	25.41	25.40	25.40	-	-
2	25.41	25.40	25.41	25.40	25.39	-	-
3	25.40	25.42	25.40	25.41	25.40	-	-
4	25.41	25.41	25.39	25.41	25.38	-	-
5	25.40	25.40	25.40	25.41	25.43	-	-
6	25.40	25.42	25.40	25.41	25.40	-	-
7	25.40	25.41	25.42	25.42	25.40	-	-
8	25.42	25.41	25.40	25.38	25.39	-	-
9	25.40	25.41	25.40	25.42	25.41	-	-
10	25.41	25.39	25.42	25.40	25.41	-	-
11	25.41	25.42	25.40	25.39	25.40	-	-
12	25.40	25.41	25.42	25.40	25.41	-	-
13	25.40	25.41	25.42	25.40	25.39	-	-
14	25.39	25.40	25.40	25.42	25.40	-	-
15	25.39	25.41	25.40	25.41	25.43	-	-
16	25.41	25.42	25.41	25.40	25.39	-	-
17	25.40	25.41	25.41	25.42	25.40	-	-
18	25.41	25.39	25.40	25.39	25.43	-	-
19	25.40	25.41	25.42	25.41	25.40	-	-
20	25.41	25.40	25.40	25.41	25.39	-	-

B. Experimental procedures

Process capability index relates the engineering specification (usually determined by the customer) to the observed behavior of the process. The capability of a process is defined as the ratio of the distance from the process center to the nearest specification limit divided by a measure of the process variability. Some basic capability indices that have been widely used in the manufacturing industry include C_p, and C_{pk}, explicitly defined as follows. : [12].

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$$
$$CL_{\bar{X}} = \bar{\bar{X}}$$
$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$$

$$UCL_R = D_4\bar{R}$$
$$CL_R = \bar{R}$$
$$LCL_R = D_3\bar{R} \qquad (1)$$

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

Capability Ratio, $C_R = 1 / Cp$ (3)

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Let, *CPU* and *CPL* are Upper and Lower Process

Often the process data is collected in subgroups. Let X_{ij}, i=1,…, m and j = 1,…, n represent the process data collected from the j^{th} unit in the i^{th} subgroup. Here, m equals the total number of subgroups, and n equals the subgroup sample size. The two most widely used capability indices are defined as:

$$C_{pk} = \min\left[\frac{USL - \overline{\overline{X}}}{3\sigma}, \frac{\overline{\overline{X}} - LSL}{3\sigma}\right] \quad (4)$$

$$C_{pm} = \frac{USL - LSL}{6t} \quad (5)$$

Where

$$t = \sqrt{\sigma^2 + (\overline{\overline{X}} - T)^2}$$

$$\hat{C}_{pk} = \pm z\sqrt{\frac{1}{9n} + \frac{\hat{C}^2{}_{pk}}{2n-2}} \quad (6)$$

Were $\overline{\overline{X}}$, the overall average, is used to estimate the process mean μ ,and $\hat{\sigma}_s$ and $\hat{\sigma}_{\overline{R}/d_2}$ are different estimates of the process deviation σ .

The estimate $\hat{\sigma}_{within}$ is

$$S_r = \sum_i \frac{\left(\dfrac{f_i r_i}{d_2(n_i)}\right)}{\sum_i f_i}$$

(7)

Where

$$f_i = \frac{(d_2(n_i))^2}{(d_3(n_i))^2}$$

The estimate $\hat{\sigma}_{overall}$ is the sample standard deviation

$$S = \sqrt{\frac{\sum_i \sum_j (X_{ij} - \overline{X})^2}{(\sum n_i) - 1}} \quad (8)$$

$\hat{\sigma}_{\overline{R}/d_2} = \overline{R}/d_2$ is an estimate derived using the subgroup ranges R_i, i=1,…,m.

The parameter d_2 is an adjustment factor needed to estimate the process standard deviation from the average sample range. Since d_2 is also used in the derivation of control limits for X bar and R control chart it is tabulated in standard references on statistical process control, such as the QS-9000 [5],[6],[13]. Large values of C_{pk} and C_{pm} should correspond to a capable process that produces the vast majority of units within the specification limits. However, Equation (4),(5) is used when the mean of process data is departure from the median of specification limits and Equation (6) is actually, an upper limit can also be had by replacing the minus sign with a plus above use z=1.645 to be approximately 95% sure that the real C_{pk} is above the limit. Where USL and LSL are the upper and the lower specification limits, respectively, X bar is the process mean, and σ is the process standard deviation(overall process variation). The index C_p measures the magnitude of the process variation relative to the specification tolerance and, therefore, it only reflects process potential. The index C_{pk} takes into account process variation as well as the location of the process mean, which is designed to monitor the performance of near-normal processes with symmetric tolerances. The index C_p is defined as the following, where M *or* T is the mid-point of the specification interval $sT = M = \frac{USL + LSL}{2}$. The calculation formulae presented in the Table I are right when the analyzed parameter is subject to a normal distribution or its distribution is close to the normal one. In such situations, there is obligatory the rule of three standard deviations according to which within the range X bar and R control chart see table 1 (i.e. within the range determined by a natural tolerance (1)). All possible realizations of the process should be contained (Fig.1). In this paper, we consider testing the most popular capability analysis C_p, C_R, C_{pm} and C_{pk} using process capability. We obtain the posterior probability (p) for which the process under investigation is capable, and propose accordingly a Bayesian procedure for capability testing. To make this Bayesian procedure practical for in-plant applications, we tabulate the minimum values of $\hat{c}_{pk}$ for which the posterior probability (p) reaches various desirable confidence levels. An application example to the workshops process is presented to illustrate the applicability of the proposed approach.

III. Implementation and Results

A. Sample size

Because process capability indices are determined from estimates of standard deviation, they are affected by sample size (degrees of freedom). As expected, the stability of estimates of the standard deviation increases with sample size (n) of 5 provide a very stable estimate of process capability. Even when n is 20 there is still substantial uncertainty in the estimator of C_{pk}. See Tables I provide estimates of 95% Confidence Bounds for C_{pk} (lower bound) and P_{pk} (two sided interval), assuming normality. The data were classified into 20 subgroup of five observation each by measuring the lengths of in each batch units. See Table II gives the 100 recorded data observations.

This type of capability study usually measures product functional performance, not the process itself. When the engineer can directly observe the process and can control the data collection methods this study is a “true process capability study” [14]. When historical data is used and direct observation of the process is not possible, Montgomery refers to this as a product characterization study. “In a product characterization study turning operation we can only estimate the distribution of the product quality characteristics; we can say nothing about the statistical stability of the process.” Histograms (or stem-and-leaf plots) require at 20 observations. If the data sequence is preserved,

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Mean Square of Successive Differences (MSSD) can be used to estimate the Short Term Standard Deviation (STSD). Or, an estimate of process standard deviation can be obtained from X bar and R control chart.

B. The results

The results of the preliminary analysis (the values of size parameters i.e. length see Table II, the empirical distribution Fig. 2 and especially the graphical test of normality Fig.2 indicate that the analyzed parameter is not subject to a normal distribution. In connection with it C_{pk} capability analysis have been determined. Fig.2. shows the corresponding X bar and R control chart and all points under control limits.

Analysis: Here in the above observation record, we have a number of variable measurement outcomes for the number of rice polished cylinder on a Turning Machine. To analyze the process capability, the statistical quality control chart techniques can be implemented in the following way:
The arithmetic average (mean) of range

$$\overline{R} = \frac{\sum R}{m} = \frac{0.52}{20} = 0.026$$

Where, A_2 = 0.577, D_2 = 2.326, D_3=0.00 and D_4=2.115 (from Table of SPC constants, for N = 5)
The control limits are,

$$UCL_R = D_4\overline{R} = 2.115(0.026) = 0.05499$$
$$CL_R = \overline{R} = 0.026$$
$$LCL_R = D_3\overline{R} = 0(0.026) = 0$$

Example subgroup No.1, and No.20 Range = [Highest value – Lowest value]
= 25.41-25.40 = 0.010
= 25.41-25.39 = 0.020

Average X bar (Process mean),

$$\overline{\overline{X}} = \frac{\sum \overline{X}}{m} = \frac{508.104}{20} = 25.4052 \quad mm.$$

The control limits are,

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$$
$$25.4052 + (0.577)(0.026) = 25.420 \quad mm.$$
$$CL_{\overline{X}} = \overline{\overline{X}} = 670.041$$
$$LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$$
$$= 25.4052 - (0.577)(0.26) = 25.3902 \quad mm.$$

As the X bar and R control chart indicate stability, even using all of the Western Electric rules [15]. We have some justification to use estimates of the overall process mean (σ) and the within subgroup (short-term) standard deviation (σ_{within}) from this course of study. Many practitioners mistrust the estimate of the overall standard deviation ($\sigma_{overall}$) as they question whether this window of inspection could truly estimate all of the possible realizations of special causes in the long term [4].

As we can observe from the X bar and R control chart, the diameters of all the components are out of the control limits, this means that process is capable of producing the diameters within specification limits. It is concluded that the process is now under control and capable of meeting the specific demand diameters of tolerances (±.0.05 millimeters).

TABLE II
POLISHED CYLINDER 20 SAMPLE DATA (DIAMETERS, MILLIMETERS, α 0.05)

No.	X1	X2	X3	X4	X5	$\overline{X}$	R
1	25.40	25.41	25.41	25.40	25.40	25.404	0.0100
2	25.41	25.40	25.41	25.40	25.39	25.402	0.0200
3	25.40	25.42	25.40	25.41	25.40	25.406	0.0200
4	25.41	25.41	25.39	25.41	25.38	25.400	0.0300
5	25.40	25.40	25.40	25.41	25.43	25.408	0.0300
6	25.40	25.42	25.40	25.41	25.40	25.406	0.0200
7	25.40	25.41	25.42	25.42	25.40	25.410	0.0200
8	25.42	25.41	25.40	25.38	25.39	25.400	0.0400
9	25.40	25.41	25.40	25.42	25.41	25.408	0.0200

TABLE II (continuous)
POLISHED CYLINDER 20 SAMPLE DATA (DIAMETERS, MILLIMETERS, α 0.05)

No.	X1	X2	X3	X4	X5	$\overline{X}$	R
10	25.41	25.39	25.42	25.40	25.41	25.406	0.0300
11	25.41	25.42	25.40	25.39	25.40	25.404	0.0300
12	25.40	25.41	25.42	25.40	25.41	25.408	0.0200
13	25.40	25.41	25.42	25.40	25.39	25.404	0.0300
14	25.39	25.40	25.40	25.42	25.40	25.402	0.0300
15	25.39	25.41	25.40	25.41	25.43	25.408	0.0400
16	25.41	25.42	25.41	25.40	25.39	25.406	0.0300
17	25.40	25.41	25.41	25.42	25.40	25.408	0.0200
18	25.41	25.39	25.40	25.39	25.43	25.404	0.0400
19	25.40	25.41	25.42	25.41	25.40	25.408	0.0200
20	25.41	25.40	25.40	25.41	25.39	25.402	0.0200

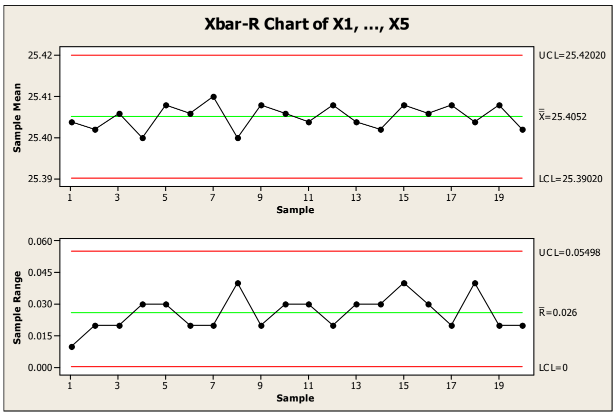

Fig. 2. X bar and R control chart for polished cylinder data

The capability analysis in Fig.3 shows that with the USL = 25.45 and LSL = 25.35 millimeters,. long-term performances are also indicated, namely that approximately 0.00 parts per million (*ppm*) for within performance would be nonconforming if only common causes of variability were present in the system, and approximately 0.00 *ppm* in the long-term.

Based on the data in see Table I, we calculate the following quantities: $\bar{\bar{X}} = 25.4052$, $\hat{\sigma}_{within} = 0.00309185$ *and* $\hat{\sigma}_{overall} = 0.00287096$. Since, in this example, the subgroup size equals five, d_2 = 2.326. Using the definitions (2-8) yields C_p = 5.39, C_{pl}= 5.95, C_{pu}=4.83, C_{pk}=min{5.95,4.83}=4.83, C_{pm}=2.80, P_p=5.81, Ppl=6.41, Ppu=5.20, P_{pk}=5.20. In this case, all the values are quite different, and, in fact, lie on different sides of the key cut off values 1.33 and 1.67 given in QS-9000. Which capability index is better in this example. As Refer to "(2-8)", the measures C_p, C_R, C_{pk}, C_{pm} and $\hat{C}_{pk}$ differ only in the estimate of the process standard deviation used in the denominator. As a result, to compare the seven capability measures turning operation process we need to compare the two standard deviation estimates $\hat{\sigma}_{within}$ *and* $\hat{\sigma}_{overall}$. There is one important differences between $\hat{\sigma}_{within}$ *and* $\hat{\sigma}_{overall}$. Since the range-based estimate $\hat{\sigma}_{\bar{R}/d_2}$ is calculated based on subgroup ranges, it uses only the variability within each subgroup to estimate the process standard deviation. The sample standard deviation- based estimate $\hat{\sigma}_{within}$ *and* $\hat{\sigma}_{overall}$, on the other hand, combines all the data together, and thus used both the within and overall subgroup variability. The total variation in the turning process is the sum of the within and overall subgroup variability. As a result, $\hat{\sigma}_{within}$ *and* $\hat{\sigma}_{overall}$ estimate the total variation present in the process within $\hat{\sigma}_{\bar{R}/d_2}$ estimates only the within and overall subgroup variation.

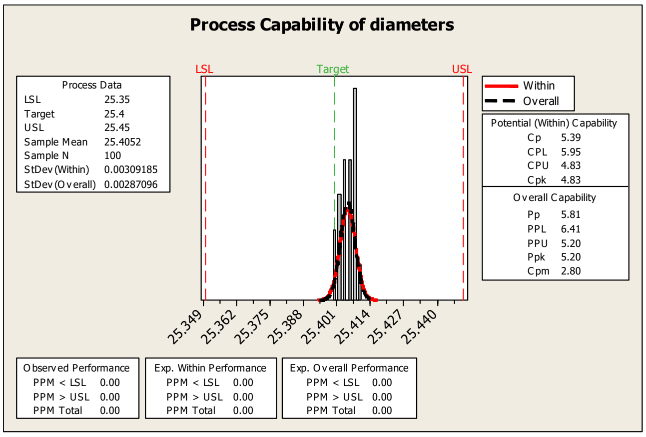

Fig. 3. graphical illustration of the polished cylinder data

In connection with it C_p, C_R, C_{pm}, C_{pk} and $\hat{C}_{pk}$ capability analysis have been determined according to adequate expression presented Refer to "(1), (2)," To determine the values $\bar{\bar{X}}$, $\bar{R}$, σ_{within} and $\sigma_{overall}$, there are used eight the computable method basing on knowledge of density function. The results are shown in see Table III.

TABLE III
Results- Capability Analysis

$\sigma_{overall}$	σ_{within}	C_p	C_R	C_{pk}	C_{pm}	$\hat{C}_{pk}$
0.28709	0.00309	5.39	0.19	4.83	2.80	4.83±1.295

Estimation of $\hat{C}_{pk}$:

$$\hat{C}_{pk} = \min\left\{\frac{USL - \bar{\bar{X}}}{3S}, \frac{\bar{\bar{X}} - LSL}{3S}\right\}$$

$$= \min\left\{\frac{25.45 - 25.4052}{3(0.009276)}, \frac{25.4052 - 25.35}{3(0.009276)}\right\} = \min\{4.83, 5.95\}$$

$$\hat{C}_{pk} = \pm z\sqrt{\frac{1}{9n} + \frac{\hat{C}^2{}_{pk}}{2n-2}}$$

$$= 4.83 \pm 1.645\sqrt{\frac{1}{9(20)} + \frac{(4.83)^2}{2(20)-2}} = 2.17 \pm 1.295$$

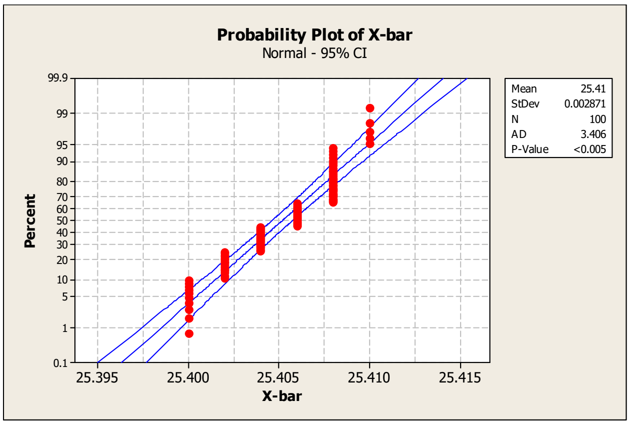

Fig.4. Normal probability plot of the polished cylinder data

From the Normal probability plot graph in Fig.4, the Normality test shows that we are unable to reject the null hypothesis, H_0: data follow a Normal distribution vs. H_1: data do not follow a Normal distribution, at the ≤ 0.05 significance level. This is due to the fact that the *p*-value test is 0.005, which is p-value less than 0.05 a frequently used level of significance for such a hypothesis test, as opposed to the more traditional 0.05 significance level.

The value of C_{pk} index achieved in analysis is not unfortunately an evidence of meeting the samples expectations (the required minimal value of C_{pk} index determined by the polished cylinder was 4.83 (A Highly Capable Process)).

Since, the value of process capability analysis, as required by the department, department of Industrial Engineering, Faculty of Engineering, RMUTL was greater than 2, and the process capability analysis we obtained after the implementation of SPC techniques is 5.39 which is greater enough than 2. Therefore, then can say that the process is under control now and capable of producing all the components under the given specification limits with the very low normal distribution and closely central limits. Process capability indices C_p and C_{pk} were calculated. It has shown that the process capability for the whole process was inadequate and turning operation process the mass production was unstable [16]. In order to satisfy the process-capability measures, it is necessary to improve the quality level by shifting the process mean to target value and reducing the variations in the process [16]. The most important problems in business, there are no trained employees to apply it and there is unsufficient investment. Consequently, SPC must be applied widely and continuously to achieve quality improvements [17]. [18] Identified a gap between how process capability analysis should be performed in theory compared to how it is actually preformed in practice, and stated that process capability analysis is often misused in practice. Furthermore, from [19] It is clear that there is a lack of well functioning capability tools in the cases when the output is non-normally distributed. Several references in these areas are given, but more research is needed to obtain tools that can be applied by practitioners.

IV. CONCLUSION

The results of process capability study of the given workshop process reveals turning operation process, graphical values of parameters approaches very nearer to the magnitude of the analytical values and hence graphical approach could be treated as equivalent to analytical method. Graphical approach can be used to study the variability of workshop process. It is one of the tools to convey the results through which it is easy to make inference on the data. The approach helps a worker (Students) in the workshop can make the assessment about the process parameters. Thus, it also helps to process management and identifies opportunities for improving quality and operational performance. The estimation of process capability is one of the basic tasks of the statistical process control (SPC). The values of C_p, C_R, C_{pk} and $\hat{C}_{pk}$ indices are very precise information on a process potential relating to the client's expectations. Correct determination of C_p, C_R, C_{pk} and $\hat{C}_{pk}$ indices values by counting requires identification of a distribution size, at least as a general settlement whether it is a normal distribution or not. If it is a normal distribution, for the estimation of C_p, C_R, C_{pk} and $\hat{C}_{pk}$ this can use a simple counting classic approach that is based on the rule of three standard deviations. If it is not a normal distribution, the application of a classic approach leads to wrong results. The process-capability analysis, which is a SPC technique, helps to determine the ability for manufacturing between tolerance limits and engineering specifications. The capability analysis gives information about the changes and tendencies of the systems during production. In this study, Control charts for variables are implemented to achieve a good control over the process. SPC technique was used to evaluate machines' capability (C_p) and process centering (C_{pk}) of manufacturing process to find whether the process is capable or not. The number of nonconforming part was determined in observed values, in short and long periods of time. After monitoring the process a significant improvement has been experienced in terms of increase in process capability indices and reduction in defective parts per million (*ppm*). The most important problems in business is that there are no trained employees to apply it and there is insufficient investment. Consequently, SPC must be applied widely and continuously to achieve quality improvements.

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