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# Estimating the PCIs for 10d Nail Production process in view of ASTM International Standards

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**ABSTRACT**

*With the ever-increasing demand for quality/standardized products and the desire for a local manufacturer of flat head 10d nails to push its product into the international market, there is a need to adopt its product specification into the more and widely accepted ASTM standard for nail length, in the production of flat head 10d nails. Process Capability Indices (PCIs) was used to estimate the ability of the 10d nail manufacturing process to meet the ASTM standard by collecting 250 samples of manufactured flathead 10d nails in sample sizes of 10 from the process. A digital vernier caliper was used to collect data, and the Minitab 20 statistical software package was used for data analysis. The PCIs such as the Cp (1.04), Cpk (0.36), and Cpm (0.46) and a process fall out of 13.45% indicates that the process is inadequate and requires improvement and proper centering to improve the process yield in view of ASTM standard. This requires targeted interventions, such as realigning the process mean to improve process yield and to design control charts for continuous process monitoring to detect unwanted process shift.*

## 1. Introduction

In modern production, meeting quality control standards and customer demands requires process optimization to guarantee consistent quality and efficiency [1-3]. Organizations that care about quality have come to understand that successful quality improvement projects depend on an understanding of processes and the ability to measure process performance [4]. Process capability indices (PCIs) have gained widespread use in measuring a manufacturing process's capability, thereby significantly enhancing quality [5-6]. The ability of a manufacturing process to create goods within predetermined tolerance limits is evaluated using these indices, which are essential indicators, by providing information on how process outputs are distributed in relation to the intended target and tolerance range [3].

In today's fast-paced business environment, a manufacturing organization can foster continuous quality improvement, operational excellence, and substantial advancement by improving its understanding of process capabilities and implementing targeted improvement projects. The strategic use of process capability indices in conjunction with continuous monitoring can lead to significant cost savings, improved product quality, and increased customer satisfaction. These indices also provide a foundation for setting reasonable improvement objectives and monitoring progress over time. Thus, it can be concluded that manufacturing companies seeking to maintain a competitive edge and meet high-quality requirements must estimate and analyze process capability indices of their manufacturing processes.

In light of the widely recognized American Society for Testing and Materials (ASTM) Standard specification for flat head 10d nail length production, which serves as the foundation for this study, a local nail manufacturing company wants its 10d manufacturing process to be examined using PCIs after receiving demand for 10d nails outside of the country and into neighbouring countries. Juran and Gryna created the first PCIs [7]. They created the capability index or Cp. The Taguchi capability index (Cpm), which calculated how close the process is to its target, was established by [8-9], while Kane [4] later created the real capability index (Cpk), which addressed the shortcomings of the Cp index. These indices were all developed to help ensure manufacturing processes stay within desired specification limits to meet regulatory standards [10-11], and also to improve customer satisfaction [12]. PCIs have been widely applied in diverse industries with great and astonishing results. It has helped improve the manufacture of vehicle parts [2]. It has helped to reduce defects and to improve the stability of products from a moulding machine [13]. PCIs have aided in the selection of equipment to meet product and process reliability [10], and reduce waste in manufacturing processes [6, 14], and also, to monitor and improve the filling process in a beverage company [15]. More information on the applications and uses of PCIs may be found in [5, 7], [16–19].

The study of Oludare et al. [20], through scientific investigation, confirmed that locally produced nails in Nigeria are of good quality and can compete favourably with imported nails. They also identified limitations in the Nigerian Institute of Standards (NIS) regarding nail tip length, and they went further to recommend the incorporation of the ASTM Standard into the NIS 118:1981 standard in future revisions as the ASTM standard is more widely accepted all over the world [21]. Therefore, the objective of this paper is to estimate the process capability indices for the 10d nail length production process in a local industry in view of ASTM International Standards.

## 2. Materials and Method

A nail manufacturing company wishes to push its fast-selling product, which is the 10d nails into the international market and as a result, requires the length of the 10d (76.2mm/3 inches) nail-making process to meet the ASTM international standard regarding length consistency. The length of flat head nails is required by ASTM standards, to be measured from under the head or shoulder to the tip of the nail and the length of 10d nails should fall within $(76.2mm \pm 2.38mm)$ [21]. A digital vernier caliper will be used to collect data and the Minitab 20 statistical software package will be used to carry out the data analysis. To achieve this, we must collect data from the process under normal operating conditions to reflect the true behaviour of the process. Secondly, we do a normality test and also, evaluate the stability of the process before estimating critical capability indices of the process and interpreting the results to identify improvement areas.

## 2.1 Data Collection and Sample size

From the 10d nail making machine, 10 samples were randomly collected, 30 minutes apart within 3 days of nail production. This gives us a total of two hundred and fifty (250) samples in sample sizes of ten (10). Minitab recommends a sample size of $n \geq 100$ [22-23]; therefore, a sample size of 250 is well sufficient for the study. Figure 1 reveals the dimension of one of the samples collected.


**Figure 1. Vernier caliper reading of Nail Length (74.16mm)**

## 2.2 X bar - S chart to test for process stability

The X bar- S chart is recommended for the testing of the process stability since samples were collected in group sizes of ten. These charts measure the mean or average change in the process over time from subgroup values [10], [16]. The control limits on the X-bar consider the sample's mean and centre, while the S chart measures the standard deviation of the process over time from subgroup values. It monitors the process standard deviation as approximated by the sample moving range. A detailed explanation of the design/construction of these charts may be found in [11-16], [24-25].

The following relation guide the X-bar chart:

$$UCL = X'' + A_3 S$$
$$CL = X'' \qquad (1)$$
$$LCL = X'' - A_3 S$$

The following relation guide the S chart;

$$UCL = B_4 S$$
$$CL = S \qquad (2)$$
$$LCL = B_3 S$$

Where:

$X''$ is the grand average of all subgroups mean (center line), $S$ represents the average of all subgroup's standard deviations (center line), UCL represents the upper control limit, and LCL the lower control limit. $A_3$, $B_3$ and $B_4$ represent control limit factor [24].

## 2.3 Process Capability Indices

Process capability indices are essential tools for assessing whether a process can consistently produce products that meet specifications [26]. Three capability indices—the Cp, Cpk, and Cpm—are widely applied in the manufacturing sector [3, 26]. They provide numerical metrics to assess how well a production process satisfies predetermined specification boundaries and are given as follows:

The Cp is an index which calculates the process yield when the process mean is ideally centered between the desired specification limits and is computed using the expression in equation 3.

$$C_p = \frac{USL - LSL}{3\sigma} \tag{3}$$

Using the expression in equation 4, the Cpk is an index that calculates the actual process capability of the manufacturing process by considering how far the process is operating from the center of the desired specification limits [5].

$$C_{pk} = \min\left\{\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right\} \tag{4}$$

And finally, the Taguchi capability index (Cpm)[27], which computes the capability of the manufacturing process around the desired target value is determined using the expression in equation 5.

$$C_{pm} = \frac{USL - LSL}{3\sqrt{\sigma^2 + (\mu - T)^2}} \tag{5}$$

where T is the target value, $\mu$ is the mean of the manufacturing process, σ is the process standard deviation, which also denotes process variability, and LSL and USL are the lower and upper specification limits, respectively.

## 3. Results and discussion

The dimensions of 25 samples of 10d nails in sample sizes of ten were collected using a digital vernier caliper and is presented in Table 1.

Table 1. Length of 10d Nails collected

| Sample Number | Length of 10d nails in twenty five samples of ten pieces per sample. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 74.16 | 74.93 | 73.82 | 74.33 | 73.58 | 75.14 | 75.25 | 74.91 | 74.19 | 74.20 |
| 2 | 75.07 | 74.44 | 73.42 | 74.97 | 74.51 | 74.79 | 74.92 | 74.76 | 74.37 | 74.93 |
| 3 | 74.71 | 73.61 | 74.80 | 74.52 | 74.97 | 74.09 | 73.84 | 74.96 | 74.87 | 73.27 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 75.60 | 73.98 | 74.44 | 77.06 | 74.96 | 74.56 | 74.13 | 75.27 | 74.71 | 74.89 |
| 5 | 74.33 | 75.28 | 75.19 | 73.86 | 75.66 | 75.29 | 75.02 | 74.61 | 75.47 | 74.08 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 74.22 | 73.78 | 74.28 | 74.22 | 74.53 | 74.45 | 74.01 | 75.35 | 74.28 | 73.85 |
| 7 | 73.50 | 74.93 | 74.71 | 75.28 | 74.71 | 74.16 | 75.83 | 74.71 | 74.61 | 75.69 |
| 8 | 73.95 | 74.19 | 75.24 | 73.30 | 76.28 | 75.72 | 73.65 | 74.35 | 74.73 | 73.87 |
| 9 | 75.42 | 74.28 | 73.06 | 74.26 | 75.97 | 73.94 | 74.87 | 75.45 | 74.55 | 74.85 |
| 10 | 75.63 | 74.61 | 76.05 | 74.59 | 74.91 | 75.01 | 74.46 | 73.73 | 74.66 | 74.87 |
| 11 | 74.48 | 74.29 | 73.48 | 75.85 | 76.60 | 75.12 | 75.01 | 73.72 | 74.44 | 75.37 |
| 12 | 75.53 | 73.98 | 75.71 | 73.49 | 73.91 | 74.00 | 74.80 | 74.24 | 74.35 | 74.95 |
| 13 | 75.51 | 74.26 | 74.34 | 74.34 | 74.61 | 74.65 | 76.04 | 73.21 | 74.75 | 75.00 |
| 14 | 74.84 | 74.54 | 74.07 | 73.65 | 74.52 | 73.52 | 74.74 | 75.58 | 73.34 | 74.77 |
| 15 | 75.07 | 73.34 | 74.90 | 74.32 | 75.25 | 74.82 | 74.33 | 74.38 | 73.37 | 74.82 |
| 16 | 74.74 | 74.75 | 74.85 | 74.60 | 74.73 | 74.45 | 74.35 | 73.90 | 75.05 | 75.36 |
| 17 | 75.19 | 75.19 | 73.38 | 73.68 | 74.01 | 76.14 | 75.27 | 74.34 | 74.16 | 75.87 |
| 18 | 75.50 | 75.41 | 75.45 | 73.53 | 75.01 | 74.36 | 74.90 | 73.72 | 74.86 | 74.65 |
| 19 | 73.82 | 74.40 | 75.07 | 74.49 | 74.55 | 75.65 | 73.33 | 74.69 | 75.43 | 76.28 |
| 20 | 73.23 | 74.86 | 72.77 | 74.49 | 75.21 | 76.09 | 74.70 | 74.71 | 75.21 | 74.86 |
| 21 | 74.47 | 74.10 | 75.43 | 74.75 | 75.10 | 73.09 | 73.71 | 75.06 | 75.70 | 74.22 |
| 22 | 74.64 | 74.83 | 75.62 | 74.22 | 74.34 | 74.61 | 74.55 | 76.12 | 75.18 | 73.40 |
| 23 | 74.45 | 74.38 | 74.61 | 73.95 | 76.35 | 75.87 | 75.31 | 74.98 | 75.37 | 73.66 |
| 24 | 74.34 | 73.90 | 74.16 | 75.87 | 74.74 | 72.97 | 75.89 | 73.39 | 74.64 | 75.98 |
| 25 | 73.78 | 75.11 | 74.79 | 74.05 | 74.95 | 75.35 | 74.80 | 74.75 | 75.37 | 73.01 |

### 3.1 Investigating Normality and Process Stability

The normal probability plot of the dataset presented in Table 1, is displayed in Figure 2. The dataset has a p – value of 0.561 which indicates that the collected data is normally distributed with a mean of 74.65mm and a standard deviation of 0.7474. The manufacturing process is off centered from the desired mean (Target) of 76.2mm as recommended by ASTM International.

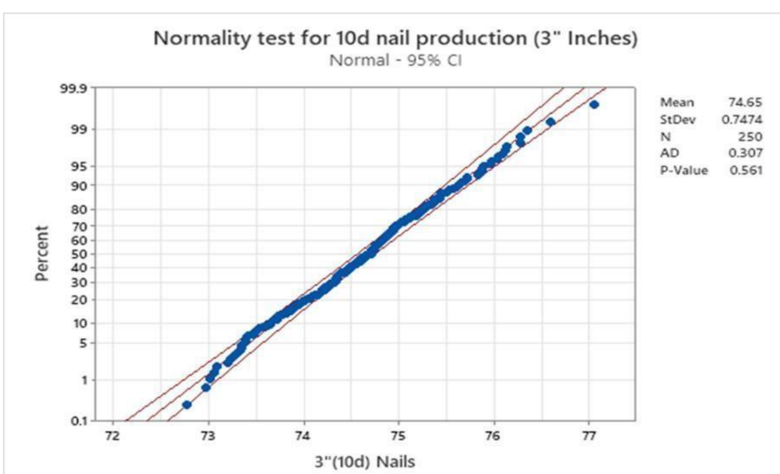


**Figure 2. Probability plot for cut rod from machine A.**

From the control charts (Figure 3), all the data points fall within the control limits, which informs us, that the process is stable and in control. There is no evidence of special cause variation, which means no unusual factors are affecting the process. The variations observed are likely due to common causes which are inherent in the process. However, the process as observed from the X bar chart shows that it is operating at a mean of 74.646mm instead of the expected 76.2 mm.

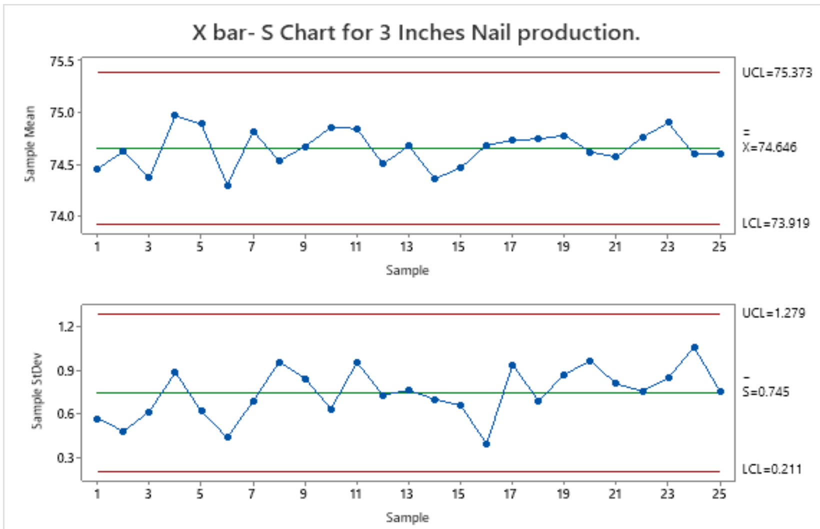


**Figure 3. Control charts for the case study data**

### 3.2 Process Capability Analysis for 10d nails in view of ASTM Standards

The process capability analysis for the 10d nail production process is shown in Figure 4. The capability indices value; Cp is 1.04 which suggests that the process is partially adequate[3], but requires strict control. The actual capability index (Cpk) is 0.36 which shows that the process quality condition is inadequate [3-5], [6], and the Taguchi index (Cpm) is 0.46 indicating that the production process is very inadequate and operating away from the desired target which can be seen in Figure 4 with the normal distribution for the production process operating between the lower specification limit (LSL) and the desired target.

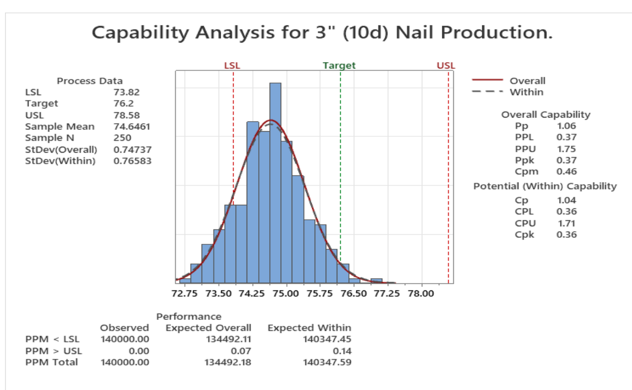


**Figure 4. Capability analysis for 3” (10d) nail production**

This proves that the quality assessment of the 10d nail manufacturing process to verify its capability to meet the ASTM international standard is lacking. The probability of the process to produce nails within the desired specification limits is 86.55%, and that of nails expected to fall outside the desired specification limits is 13.45% (134,492 PPM). The process capability indices were not very satisfying as the process is operating outside the desired target. Therefore, we can conclude that there is a need for improvement of the process centering to meet the target value, which will in turn improve the PCIs and also reduce the percentage of products that fall outside the ASTM international standard.

## 4. Conclusion

This study emphasizes how crucial it is for manufacturing companies to carry out process capacity analysis and put improvement plans into action To meet high standards of quality and keep a competitive edge. The output (items produced) of a manufacturing process must be rigorously assessed to confirm that it can produce goods that satisfy standards. We used statistical techniques and methodology in this work to show how important PCIs are for evaluating and enhancing process performance, especially in centring and variability reduction. To improve operational effectiveness and product quality, the company implements targeted interventions based on the insights gathered from this research. The manufacturing process needs to be properly centred to enhance the process yield beyond the existing 86.5% level. The manufacturing company should prioritize the centring of the manufacturing process as a top priority. This can be accomplished by regularly checking the process means and making the required modifications to keep it within the limits of the specification. Control charts and statistical process control techniques can be used for this. In order to systematically minimize process variability and defects, the Six Sigma approach should be implemented. Additionally, the data gathered from process capability analysis should be used to support decisions on quality management and process improvement methods

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