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# Measuring and Analyzing the Process Capability of Productivity – An Applied Study in the Al-Tahady Factory for the Production of Filters

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## Abstract

This study addressed concerns related to increased percentages of damaged and re-worked production, heightened demand for factory products, and lack of awareness of the approved Sigma (σ) level during manufacturing, and associated deviations in the manufacturing process. The primary research problem was to assess the manufacturing process's stability and capability to consistently produce conical filters that meet required specifications. The study followed a sample-based approach, where twenty samples, each containing four observations, were collected continuously over a period of seven days. For each sample, the mean ($\bar{X}$) and range (R) were calculated. The mean X-Double bar of 319.32 and the average range R-bar of 0.848 were obtained through data analysis. The main findings revealed that, on average, the manufacturing process was relatively close to the target value (X-Double bar = 319.32). However, the presence of several data points outside the control limits indicated potential variability in the process. The average range (R-bar = 0.848) highlighted certain variations in the manufacturing process, which might contribute to issues like damaged or re-worked production. The study identified the need for further investigation to determine the root causes of these variations, which could include machine malfunctions, material fluctuations, or operator errors. By addressing these concerns and reducing process variability, the factory can enhance product quality, decrease waste, and improve customer satisfaction. In conclusion, continuous process monitoring and improvement initiatives, such as Six Sigma, are essential for achieving greater process capability in conical filter manufacturing. This research contributes valuable insights into process performance and provides a basis for implementing corrective actions to ensure consistent product quality and meet customer demands.

## 1. Introduction

Al-Tahady Factory, operating under the Al-Zawra State Company, holds a significant position in the manufacturing industry, specializing in the production of filters. With an impressive annual production output of 500,000 filters, the factory plays a pivotal role in supplying essential components to ministries such as the Ministry

of Oil and Electricity, as well as various companies, fulfilling formal contracts and continuous process partnerships while adhering to stringent manufacturing specifications. Maintaining product quality and meeting customer requirements are paramount in any production process. However, like any manufacturing facility, Al-Tahady Factory may encounter deviations from specified upper and lower limits, which can impact overall efficiency and product reliability. This research aims to identify and address deviations from the upper and lower limits within the manufacturing process at Al-Tahady Factory. The primary objective is to identify the key factors contributing to these deviations and propose practical strategies to restore the manufacturing process within the required specifications. To achieve these objectives, the researcher conducted field visits to the factory and actively observed the manufacturing process. By immersing themselves in the production environment, the researcher sought to gain valuable insights into the intricacies of the process and identify areas where deviations are most likely to occur. Quantitative measurement and analysis of Process Capability will be conducted using Process Capability Indicators (PCIs). PCIs are widely used in manufacturing industries to assess a process's ability to consistently produce products within specified limits. By employing PCIs, the researcher aims to assess the capability of the existing process and identify potential areas for improvement. To gather crucial data for PCI calculations and detect patterns related to deviations, sampling during the manufacturing process was incorporated into the daily monitoring routine. By addressing deviations and optimizing the manufacturing process, Al-Tahady Factory can enhance production efficiency, reduce waste, and ensure its filters consistently meet the required specifications. Given the critical applications of these filters for various ministries and companies, ensuring their reliability and effectiveness is of utmost importance. The outcomes of this research will serve as a practical guide for the management of Al-Tahady Factory to implement targeted improvements. By effectively dealing with deviations and optimizing the production process, the factory can strengthen its reputation as a trusted and reliable supplier, enhancing its competitiveness in the market. This study contributes to the continuous improvement and success of Al-Tahady Factory in meeting customer requirements and fulfilling obligations under official contracts and partnerships. By maintaining strict adherence to manufacturing specifications, the factory can ensure the delivery of high-quality filters that meet the stringent standards of the industry and satisfy customers.

## 2. Theoretical Part

### 2.1. Process Capability Ratio

The process capability ratio proposal was first made by Juran (1974), who compared process fluctuations to process specifications as a quantitative indicator for assessing process capability [1]. Other measurable indicators that have emerged since then are based on process and specification fluctuations, such as Cp, Cpk, and Cpm. With the improvement of the processing level and the increasingly complex parts, the processing parts generally have multiple quality characteristics, and the assessment of process capability needs to consider multiple quality characteristics [2]. The Process Capability Ratio (PCR), which is a long-established measure for analyzing actual process performance, is of interest in this study to assess tolerance. As it is a statistical measure for making a comparison between the output of the process and the limits of the process specifications, the process whose results fall within the limits of the specifications is considered a capable process. The process ability ratio (Cp) helps them evaluate their performance. PCR can be defined by setting two new limits: the Upper specification limit (USL) and the Lower specification limit (LSL). These limits are specifications relevant to the quality characteristics one wants to analyses (such as process reliability) [3]. For a process to be capable, its values must fall within the upper and lower specifications. This usually means that the process capability is within (3) standard deviations of the process mean, since this range of values is (6) standard deviations the capable process tolerance, which is the difference between the upper and lower specifications, must be greater than or equal to inside the specification limit. The Process Capability Ratio Cp is calculated as follows. Eq (1) shows the mathematical expressions for the calculation of Process Capability (Cp).

$$Cp\ \frac{USL - LSL}{6\sigma}\ (1)$$

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

Cp: Process Capability
USL: upper specification limit
LSL: lower specification limit

According to the measurement, the process capability of CP describes as follows the state of the relationship between quality and process capability, Table (1) illustrates this relationship as follows [4]:

**Table (1).** The status of the relationship between quality and process capability ratio.

| NO. | Quality case | Process ability rate Cp |
|---|---|---|
| 1 | When the process ability ratio is greater than or equal to (2.00), this indicates that the quality of the process is very excellent. | Cp ≥ 2.00 |
| 2 | When the process ability ratio is less than (2.00) and greater than or equal to (1.67), this indicates that the quality of the process is excellent. | $1.67 \leq Cp < 2.00$ |
| 3 | When the percentage of process capability is less than (1.67) and greater than or equal to (1.33), this indicates that the quality of the process is satisfactory. | $1.33 \leq Cp < 1.67$ |
| 4 | When the process capability ratio is less than (1.33) and greater than or equal to (1.00), this indicates that the quality of the process is capable. | $1.00 \leq Cp < 1.33$ |
| 5 | When the process ability ratio is less than (1.00) and greater than or equal to (0.67), this indicates that the quality of the process is not appropriate. | $0.67 \leq Cp < 1.00$ |
| sixth | When the Process Capability ratio is less than (0.67), this indicates that the quality of the process is poor. | Cp < 0.67 |

Based on the foregoing in Table (1), the researcher considers that the process is capable, it must have a Process Capability (Cp) of not less than 1.0. If (Cp) is less than 1.0 the process is producing products or services that are outside the tolerance range, with (Cp) 1.0, 2.7 parts per 1000 is expected to be "out of specification". The higher the process capability ratio, the greater the likelihood that the process will be within the design specification. Figure (1) shows three important cases related to the specifications of the Process Capability Ratio.

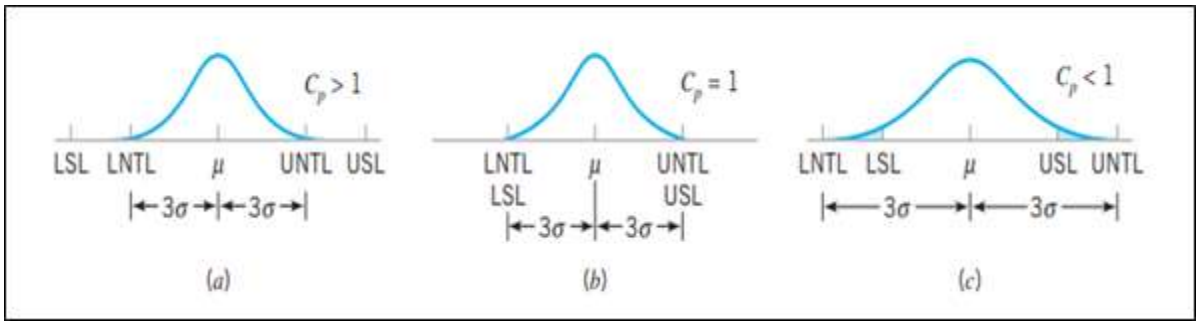


**Figure (1).** The repercussions of the operation and the percentage of the operation's ability Cp.

In Figure (1a) the PCR Cp is greater than Cp >1. This means that the process uses well below 100% of the tolerance range, and therefore relatively few non-conforming units will be produced through this process. Figure (1b) shows a process in which PCR Cp = 1; That is, the process uses all the tolerance range. For a normal distribution, that would mean about 0.27% (or 2,700 ppm) nonconforming units. Finally Figure (1c) shows a process in which the PCR Cp < 1; That is, the process uses more than 100% of the tolerance range. In this case, the process is very sensitive to productivity, and a large number of non-conforming units will be produced.

### 2.2. Process Capability Indices (PCIs)

The concept of Process Capability Indicators (PCIs) is a powerful tool widely used in many production and service industries to measure process performance. These indicators can be used to create a correlation between specified performance and predefined limits. These indicators are also used to find out critical information regarding a

process whether the process is capable of manufacturing products to the satisfaction of consumers. In recent years, the focus of research has been on PCIs in strict quality assurance [6]. Process capability indicators are commonly used tools for evaluating process performance in relation to design specifications [7]. Process Capability Indicator (PCI) is a unit-free quantitative measure that compares the behavior of manufactured process characteristics. Process Capability Indicators have been widely used in many fields for the purpose of process measurement and improvement. More explicitly, by using Process Capability Indicators, quality engineers identify what is going on in the production process on the ground with a single measurement value and the steps needed to improve the product [8]. Studies of the ability of the process to affect customer satisfaction through continuous examination of the quality and reliability of the supplier's products.

Data from a process under control can be used to calculate future performance of the process with the help of process capability indicators (PCI). Hence, the stability and capability of the manufacturing process are evaluated in two stages namely control charts and process capability indicators. The PCI scale has been widely used in the manufacturing industry to determine whether a production process is capable of manufacturing items according to predetermined quality requirements [8]**.**

Process Capability Indicators (PCIs) have become important and integrated tools in the statistical process control of all manufacturing industries. Process Capability Indicators can be used to check whether products meet their quality specifications. These indicators are numerical measures used to judge the accuracy, and performance of the manufacturing process. It is clear that PCIs can be used for continuous improvement of quality and productivity in manufacturing industries [9]. PCIs (PCIs) that correlate the buyer's stipulated specification requirements and the supplier's actual manufacturing process performance have been widely used to reveal accurate Process Capability information [10].

Acquired Process Capability Indicators (PCIs) to assess process acceptability means that PCIs are in widespread use. PCIs provide numerical metrics for checking whether a manufacturing process can reproduce items that meet quality requirements predetermined by an engineer or product designer. Using a statistical methodology with sample feedback, PCIs can be applied to determine the capability of processes, design an acceptance sampling plan, or select a satisfactory supplier. They also enable engineers to evaluate process performance and ultimately improve product quality. In addition to manufacturing yield, verifying that target customers' requirements are met is critical. This can be measured by examining quality loss, which occurs when a quality characteristic deviates from a customer's ideal target. (t) From the point of view of quality loss, the ability of a process to aggregate around a target is essential [11]. [10] defined Process Capability Indicators (PCIs) as a simple and quantitative way to show the process capability of a manufacturing process. The PCIs of (Cp), ((Cpk), (Cpm) and (Cpmk) have been widely used today to test whether a manufacturing process is capable or not.

Various process capability indicators have been introduced in the manufacturing industry to provide a mathematical measure of process capability and performance within specification limits. These indicators are used to adequately measure processes within the upper and lower specification limits. These indicators have been estimated through the following equations [12, 13, 14].

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

The process capability Indicator (Cpk) is used to relate process differences by showing how the process conforms to its specifications. This indicator is generally used to relate “normal tolerances (30)” to specification limits. The indicator (Cpk) describes well the inclusion of the process within the specification limits with reference to the average process [15]: Cpku represents the upper bound of Cpk and Cpkl represents the lower bound. Eqs (3 & 4) give that:

$$\mathbf{C_{Pku}} \frac{\mathbf{USL}-\boldsymbol{\mu}}{\mathbf{3\sigma}} \qquad (3)$$

$$C_{Pkl} \frac{\mu - lSL}{3\sigma} \quad (4)$$

The Cpk indicator gives information about the real capability of the process, and because μ, σ are often unknown, and as is the case when estimating process ratio indicators, we use $\overline{C}$ appreciation $\mu$ $\overline{R}$ /d₂ appreciation σ. This result estimates $\tilde{C}_{Pk}$, $\tilde{C}_{pkl}$, $\tilde{C}_{pku}$: Eqs (5, 6, and 7).

$$\tilde{C}_{Pk} = \min\left(\tilde{C}_{Pku}, \tilde{C}_{Pkl}\right) \quad (5)$$

$$\tilde{C}_{Pku} \frac{USL - \overline{X}}{3(\overline{R}/d_2)} \quad (6)$$

$$\tilde{C}_{Pku} \frac{\overline{X} - LSL}{3(\overline{R}/d_2)} \quad (7)$$

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

From samples ṅ measures $\chi_1, \chi_2, \ldots, \chi_n$, then the estimated mean $\bar{x}$ and the estimated standard deviation (s) can be obtained by using Eqs (8 & 9) [16].

$$\bar{\chi} = \frac{\sum_{i=1}^{n} xi}{n} \quad (8)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(xi-x)^2}{n-1}} \quad (9)$$

**3. Experimental Procedure**

The Al-Zawra State Company - Al-Tahady Factory for the manufacture of filters was chosen as an applied case for the study as a result of the increase in the percentage of damaged and re-worked production, the increase in the demand for factory products, the lack of interest and the factory's knowledge of the approved Sigma (σ) level during the manufacturing process and the deviations that accompany the manufacturing process. Therefore, a study was conducted that dealt with the use of process capability indicators.

Accordingly, (20) samples of size (4) were taken for each of them from the conical filter shown in Figure (2) All Dimension in mm the limits of specifications required in the manufacture and design of the conical filter, with continuous observation during manufacturing over a period of seven days. As shown in Table (2).

By using the data of Table (2), the researcher explains by calculating the rates and range for each sample and for all samples, for example for the first sample:

$\overline{X}$ = 335.87 + 336.54 + 335.88 + 336.57 /4 = 336.21
R = 336.57 - 335.87 = 0.7

The average of each sample (X) between the concentration of the process and the extent of each sample (R) shows the spread or dispersion of the process by representing the samples graphically. The center lines of the mean and range plots are the maximum average (meaning average rates for the samples) X is denoted by X-Double bar, R is denoted by R-bar. In this case:

X-Double bar = 6386.54 /20 = 319.32
R-bar = 16.96 /20 = 0.848

The calculation of the control limits is usually set at three standard deviations above and below the centre line and are commonly referred to as limits $\pm 3\sigma$. The upper and lower control limits for the mean and range plots are calculated as follows:

USL = 319.32 + (2.282) (0.848) = 319.32 + 0.0636 = 321.25
LSL = 319.32 – (0) (0.848) = 319.32 - 0.0636 = 319.32

**Table (2).** Calculation of the 4 observations of 20 samples.

| Net For Conical Filter | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | Net Inside | | | | | | | Standard (C) |
| | X1 | X2 | X3 | X4 | $\bar{X}$ | R | s | |
| 1 | Thirty Three Thousand And Five Hundreds Eighty Seven | 336,54 | 335,88 | 336,57 | 336.21 | 0.7 | 0.39281 | 335 |
| 2 | 336,40 | 335,75 | 336,55 | 335,56 | 336.06 | 0.99 | 0.483632 | 335 |
| 3 | 336,59 | 335,60 | 335,90 | 336,56 | 336.16 | 0.99 | 0.49196 | 335 |
| 4 | 335,90 | 336,57 | 336,55 | 336,58 | 336.15 | 0.68 | 0.511143 | 335 |
| 5 | 336,58 | 335,56 | 336,54 | 335,54 | 336.05 | 1.04 | 0.58341 | 335 |
| 6 | 335,50 | 336,56 | 335,54 | 336,56 | 336.04 | 1.06 | 0.600666 | 335 |
| 7 | 336,58 | 335,75 | 336,59 | 336,55 | 336.36 | 0.84 | 0.412017 | 335 |
| 8 | 335,75 | 336,55 | 335,57 | 335,55 | 335.85 | 1 | 0.471982 | 335 |
| 9 | 335,60 | 335,58 | 336,54 | 336,57 | 336.07 | 0.97 | 0.557337 | 335 |
| 10 | 336,57 | 336,59 | 335,40 | 336,56 | 336.28 | 1.19 | 0.586799 | 335 |
| 11 | 336,56 | 335,55 | 336,59 | 335,55 | 336.06 | 1.04 | 0.591911 | 335 |
| 12 | 336,56 | 335,60 | 335,90 | 335,56 | 335.90 | 0.96 | 0.462277 | 335 |
| 13 | 335,88 | 336,56 | 336,58 | 336,54 | 336.39 | 0.7 | 0.340392 | 335 |
| 14 | 336,55 | 335,55 | 335,50 | 336,56 | 336.04 | 1.06 | 0.595035 | 335 |
| 15 | 336,90 | 336,58 | 336,40 | 336,55 | 336.35 | 0.68 | 0.315 | 335 |
| 16 | 336,55 | 335,50 | 336,55 | 335,55 | 336.03 | 1.05 | 0.592136 | 335 |
| 17 | 336,54 | 336,58 | 336,56 | 336,56 | 336.56 | 0.04 | 0.01633 | 335 |
| 18 | 335,54 | 335,75 | 336,56 | 336,54 | 336.09 | 1.02 | 0.529552 | 335 |
| 19 | 335,87 | 335,60 | 336,55 | 335,55 | 335.89 | 0.95 | 0.460317 | 335 |
| 20 | 336,53 | 336,53 | 336,55 | 336,53 | 336.21 | 0.7 | 0.39281 | 335 |
| Total | | | | | 6386.54 | 16.96 | | |

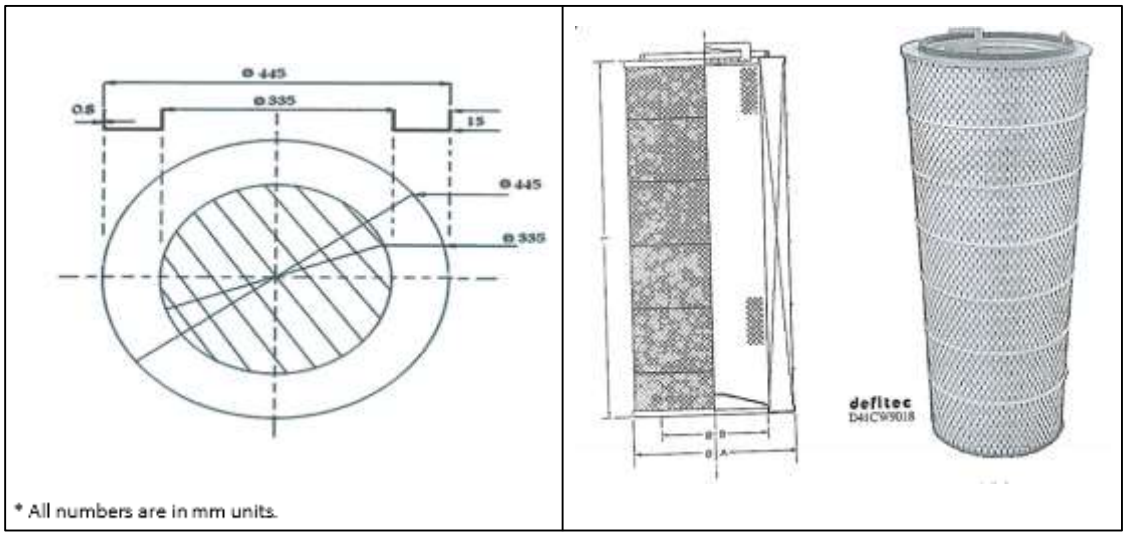


**Figure (2).** Conical filter design and specifications specified in the manufacturing process.

## 4. Results and Discussion

The study aimed to investigate the process capability of the manufacturing of conical filters at the Al-Zawra State Company - Al-Tahady Factory. Twenty samples, each containing four observations, were collected over a seven-day period. The following are the key results obtained from the data analysis:

- The mean ($\bar{X}$) and range (R) were calculated for each sample, resulting in a mean X-Double bar of 319.32 and an average range R-bar of 0.848.
- The control limits for the mean plot were established at ±**3σ**, leading to an upper specification limit (USL) of 319.27 and a lower specification limit (LSL) of 319.25.
- Several data points were found to be outside the calculated control limits, indicating potential points of concern and variability in the manufacturing process.

The process capability analysis revealed that the mean of the manufacturing process (X-Double bar) is 319.32, indicating that, on average, the process is relatively close to the target value. However, the control chart identified data points outside the control limits, suggesting that the process is not entirely stable or predictable. Process Variability: The average range (R-bar) of 0.848 indicates that there is a certain degree of variation in the manufacturing process. While the process might be centred on the target value, the variation could potentially lead to issues such as damaged or re-worked production. Out-of-Control Points: The existence of data points beyond the control limits suggests special causes of variation in the process. Further investigation is required to identify the root causes of these variations and take appropriate corrective actions. These out-of-control points could be due to factors like machine malfunctions, material variations, or operator errors.

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## 5. Conclusions

Based on such an applied study, you might draw several conclusions: Evaluation of process performance: By applying statistical tools such as process capability indicators (eg, Cp, Cpk), the study is likely to assess how well the plant's operations are performing relative to upper and lower specification limits, The study investigates whether plant operations are able to consistently produce filters within the required quality range, Recommendations for improvement Based on the results, the study proposes recommendations to improve productivity and practical ability, These recommendations may include changes to workflows, technology upgrades, employee training, or other operational improvements. Risk Mitigation By understanding process capability, a plant can proactively mitigate risks associated with production changes, defects, or delays.

**Conflict of Interest:** The authors declare that there are no conflicts of interest associated with this research project. We have no financial or personal relationships that could potentially bias our work or influence the interpretation of the results.

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