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AN OVERVIEW OF EXISTING STATISTIC METHODS FOR SELECTING OPTIMAL PROCESS PLANNING

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Abstract: *The fast development of technology and the rapidly changing market requirements nowadays are putting more and more pressure on production optimization. Analyzing and selecting the optimal process planning to ensure quality, cost efficiency and high productivity, is of paramount importance to companies and still represents a daunting task for them. This review paper discusses the existing methods for selecting optimal process planning by using the statistical indices Cp, Cpk, Pp, Ppk, Cm and Cmk to evaluate its capability. An overview is made between them, the information they provide about the process and their application is introduced. An algorithm for the evaluation of process capability for process planning is proposed, which synthesizes the methods for the evaluation of process capability.*
Key words: *Process capability, Cpk, Cp, Ppk, Pp, Cm, Cmk, Capability Indices.*

1. INTRODUCTION

In the last decades, many industries have continuously tried to improve the quality and reliability of their products, based on the concept introduced in the 1920s by Walter Shewhart and W. Edwards Deming [1]. Achieving a high quality and process capability leads to many positive outcomes for manufacturing such as: reduced waste and scrap, reliability, quality and cost-effectiveness of manufactured products, increased productivity, and competitive advantage and increased market share.

One of the most important stages of production is process planning. The final product must not only meet the specified parameters but also have to be manufactured with the required quality, be cost-effective and produced in the shortest possible time. That is why, when choosing from the different process planning variants, it is important to select the most optimal one for production requirements and for customer specifications. In most cases, this proves to be a difficult task for specialists trying to take into consideration all of these:

- The process parameters: the production programme, the available equipment and special equipment;
- The features of the production itself, such as: the stability, serialization and complexity of operations;
- Economic value:
  - prices of raw materials, equipment and tools;
  - costs for labor and training;
  - cost of energy, etc.

The selection of optimal process planning involves a comparative analysis of several process variants. For this purpose are used, input data for the part and various techno-economic characteristics.

Input data includes drawing of the manufactured part, technology, information about equipment and tooling, annual production program, etc. By comparing the process selection criteria, i.e., cost, productivity, and quality, helps to select its optimal variant.

The main difficulties for selecting optimal process planning are related to the lack of quantitative correlations between the parameters which characterize the accuracy, productivity and efficiency of operations, and the factors affecting them.

The use of statistical methods for selecting optimal process planning as well using them, during production is an effective way to guarantee and maintain the good quality of production.

The purpose of this paper is to present in a systematic form the methods for selecting the optimal process planning while highlighting the differences between them and their application, in order to be of assistance in creating new process planning and selecting the optimal one among them.

The overview of the methods in this publication is presented to be accessible and understandable to those working in the field, but with insufficient experience in their evaluation.

The proposed algorithm in this paper is a innovation in terms of combining the methods and providing a comprehensive assessment of process capability when designing new process planning.

2. STATISTICAL PROCESS CONTROL – SPC

One of the most common methods used to control process planning by analysing measured data obtained during the production process is statistical control - SPC.

In 1924, Walter Shewhart developed the concept of statistical process control - SPC, which involves the use of statistical methods to monitor, control and improve the quality of manufacturing processes. He laid the foundations for "control charts" that are still used today. They analyse data using statistical methods to track whether a process is stable, sufficiently controlled and provide us with information about its current condition [1].

According to SPC, there are two types of variation in any process: variation from an ordinary cause, which are common and expected to occur in the proces, and variation from special causes, which occurs as a result of unusual events or factors [2].

The implementation of SPC involves two phases, Fig.1. Phase I focuses on understanding the process and evaluating its capability, while Phase II aims to identify the causes of variation and bring the process under control [3].

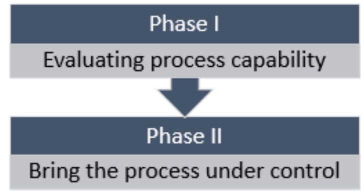


Fig.1. SPC implemented in two phases

2.1 Process Capability and Process Performance

Process capability and process performance are two important concepts for SPC and are providing useful information for process evaluation and control. Process capability evaluates and analyses the process to what extent it produces parts or products falling between specification limits - upper specification limit and lower specification limit [4].

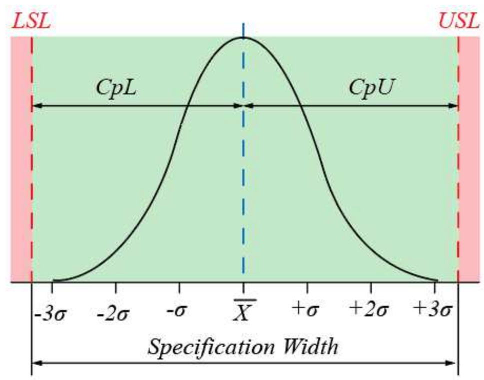


Fig.2. Process capability presented by Gaussian curve for normal distribution

The main tools for determining the quality and capability of process planing are the statistical indices:

- Process Capability Indices (PCI): Cp. Cpk;
- Process Performance Indices (PPI): Pp and Ppk.

Fig.2. shows the normal distribution curve with the help of which, the calculated statistical indices are plotted and analysed. The presented process is stable because it falls within the area enclosed by the limits. If some of the workpieces falling below the normal distribution curve are in the red areas, or the normal distribution curve falls within them, then the process must be placed under immediate control to find and

remove the cause of manufacturing unsuitable parts and the process is considered unstable [5].

Statistical indices are parameters that evaluate the stability and capability of the analysed process, to produce suitable products that both meet the set specifications and satisfy customer needs. By using them we can analyse the state of the process capability, and to decide to improve it or create a new one. Analysing and optimizing the process planning has a huge impact on the quality of production, reduces the variations that occur in the process and helps to achieve optimal results.

Systematizing the statistical indices and their main advantages can be point out:

- Deliver information about the state of the process capability, whether it is capable of producing quality output;
- Compare several processes variants and make a choice for the most optimal one based on their values;
- Predict the possible future appearance of problems in relation to observed variations;
- Support process monitoring and troubleshooting of special causes.

2.2 Relations and differences between Process Capability and Process Performance indices

The two concepts - Process capability and Process performance are often mistaken as they are referred to by the common name - Process capability, but it should be kept in mind that as close as they are from a purely conceptual point of view, they are also so different [6].

The main difference between process capability and process performance is the calculation of the standard deviation that is used to evaluate their statistical indices. In Table 1 the equations for the calculation of Cp, Cpk, Pp and Ppk are presented, from where we can make a conclusion of the main differences between them, what information each of the indices provides us about the state of the process and their application.

Table 1

Equations of statistical indices for determining Process Capability.

	Process Capability (Short term)		**Process Performance (Long term)**	
Indices	**Cp** capability index	**Cpk** centering capability index	**Pp** performance index	**Ppk** performance centering index
Equations for Cp/Cpk and Pp/Ppk [2,12]	$Cp = \left(\frac{USL - LSL}{6\hat{\sigma}}\right)$	$Cpk = \min(CpU, CpL)$	$Pp = \left(\frac{USL - LSL}{6\sigma}\right)$	$Ppk = \min(PpU, PpL)$
Equations for: $\hat{\sigma}/\sigma$, CpU/CpL and PpU/PpL [2,12]	$\hat{\sigma} = \frac{\overline{R}}{d_2}$	$CpU = \frac{(USL - \bar{x})}{3\hat{\sigma}}$ $CpL = \frac{(\bar{x} - LSL)}{3\hat{\sigma}}$	$\sigma = \sqrt{\sum \frac{(x_i - \bar{x})^2}{n - 1}}$	$PpU = \frac{(USL - \bar{x})}{3\sigma}$ $PpL = \frac{(\bar{x} - LSL)}{3\sigma}$
Application	Used when process is under statistical control.	Process is stable. (Used in mass production stage)	Used when process is initially starting out.	Used when process is new. (Used in starting development stage)

where:
USL – upper specification limit; LSL – lower specification limit; $\hat{\sigma}, \sigma$ – both standard deviations, but calculated in different ways; $\overline{R}$ – average of R; d_2 – constant; n – sample size;
x_i – individual values from the batch; $\bar{x}$ – average.

In different literature reviews, the names "Short term" and "Long term" are quite often associated with the consumed time for collecting the measurable data. Short term capability indices - Cp and Cpk, use randomly selected subgroups of measured details over time for each of them the spread R is calculated. Then all the collected n-number of subgroups are averaged for all the calculated ranges - R, Fig.3.

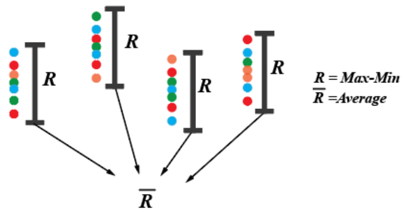


Fig.3. Calculating R̄, by using subgroups

Unlike "short term indices", "long term indices" - Pp and Ppk use all measured data for the process under consideration to calculate the standard deviation [7].

Table 1 also systematizes the applications of the indices themselves. Cp and Cpk are mostly used in processes that are already established, have been worked with for some time and are under statistical control. With them, we can successfully monitor the state of the process and make predictions about possible future problems in its implementation. On the other hand, Pp and Ppk provide information about the capability of the process up to the present moment or for past periods [8-9].

2.3 Stable process vs Capable process

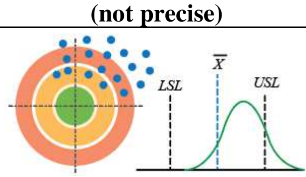
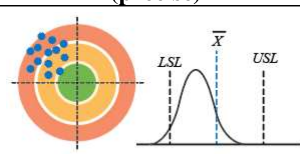
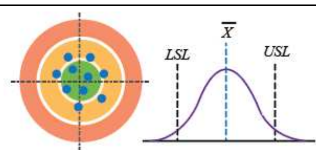
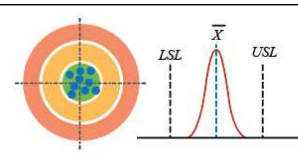
The statistical indices consider the number of variations outside the set limits - LSL and USL. A significant difference between the indices is the centering factor. The calculation of Cp and Pp does not provide information on whether the process is centered in relation to $\overline{X}$. The notations of Cpk and Ppk, in which "k" stands for "centering factor", and these indices more accurately are defining the capability and the accuracy of the process [10].

In Table 2, the difference between the different process states and the behavior of the normal distribution with versus to the data variability, is shown. It can be clearly seen that in certain cases, the process may be stable but not accurate Table 2 - b). We can also observe a process where all the data may fall within the limits and at the same time it may not be stable due to large variations of the data Table 2 - c). The most optimal process, appears to be the last one - Table 2 - d). In this process we observe low data variations and their spread is small. All fall within the specification limits and the distribution curve is centered [11].

Capability represents how close the measured value is to the specification limits and defines the capability of the detail. Stability, on the other hand, provides information on consistency, repeatability and how much variation occurs in the measured data. Both capability and stability are important to ensure a reliable, capable and high-quality process.

Table 2

Stable process vs Capable process

Process state:	**Not stable (not precise)**	**Stable (precise)**
Not capable (not accurate)	 **a)** The process is off the center and has high spread. The data have high variance, and the normal distribution curve is shifted to the right. The process is both not stable and not capable.	 **b)** This process is off the center, but his spread is low. Measured data have very low variance and because of that the process is considered stable but not capable.
Capable (accurate)	 **c)** The process is centered but has high spread. The data have high variance, and the normal distribution curve is in the centered. The process is capable, but not stable.	 **d)** This process has a high centering and low spread. Measured data have very low variance, and the normal distribution curve is centered. The process is both capable and stable.

2.4 Machine capability indices – Cm and Cmk

Two other important indices are the indices assessing the stability of the production machine - Cm and Cmk. Similar to the statistical indices discussed so far for evaluating Process capability, Cm measures the overall variation, while Cmk measures the shift of the process relative to the mean. Table 3 presents the equasions that are used to evaluate the Machine capability indices - Cm and Cmk, there are also a lot of similarities with the evaluation of Cp, Cpk, Pp and Ppk and their standard deviation [12].

Table 3

Equations of statistical indices for determining Machine Capability.

Cm	Cmk
$\mathrm{Cm} = \left(\frac{\mathrm{USL} - \mathrm{LSL}}{6\sigma}\right)$	$\mathrm{Cmk} = \min(\mathrm{CpU}, \mathrm{CpL}$
$\sigma = \sqrt{\sum \frac{(x_i - \bar{x})^2}{n-1}}$	$\mathrm{CmU} = \frac{(\mathrm{USL} - \bar{x})}{3\sigma}$ $\mathrm{CmL} = \frac{(\bar{x} - \mathrm{LSL})}{3\sigma}$
Criteria for machine capability : **1.33 – 1.67**	

When a process is analysed, it is affected by different types of factors that can cause variations during its execution. When evaluating the indices Cp, Cpk, Pp and Ppk, six types of variations are influencing:

- Machine;
- Material;
- Measurement;
- Environment
- Operator;
- Method

Each of them can affect the performance and quality such as when a variation occurs caused by the operator, it can be due to experience, inattention, shift change, etc [13]. To avoid the influence of these factors during the selection of an optimal process planning, it is necessary to determine the Cm and Cmk indices. They ensure that the measurements and results are the most accurate and precise, because their measurement data are taken from 30 to 50 consecutive parts over a continuous period of time, thus ensuring that the influencing factors do not affect the result. Although unlikely, Machine capability indices can be equal to Process capabilities. It is important to note that Cp, Cpk, Pp and Ppk can never have values greater than those of Cm and Cmk.

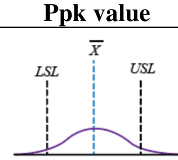
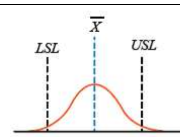
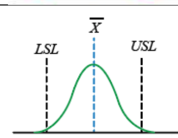
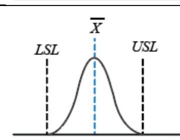
Observing these indices from the beginning allows us to analyse and better understand the specific characteristics and capabilities of the machine itself, also to conclude whether it is a good selection for the machine of the process under analysis.

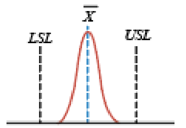
2.5 Criteria for establishing Cpk and Ppk

There are numerous international standards and regulations [5], [14-16] that are used by industries to evaluate process capability.

Table 4

Commonly used Process Capability criteria requirement.

σ level	Cpk / Ppk value	Process yield	Defects per million opportunities DPMO	Normal distribution according Cpk / Ppk value	Capability rating
1	>0.33	68.27%	691462		The process capability falls significantly short of the desired level and is **highly insufficient.**
2	0.33 – 0.67	95.45%	308538		
3	0.67 – 1.00	99.73%	66807		The process capability is below the desired standards and is considered **insufficient**.
4	1.00 – 1.33	99.9936%	6209		While the process capability falls short of being truly satisfying, it is still considered **acceptable.**
5	**1.33 – 1.67**	**99.99994%**	**232.6**		**The process capability meets the desired requirements, providing a satisfying process capability.**

6	> 1.67	99.999998%	3.40		The process capability exceeds expectations -process is **excellent**.

Most of them, recommend Cpk and Ppk values to exceed 1.33. This is considered ideal for a process that produces products that meet the set specifications.If the index values are below 1.00, then there are serious inconsistencies between the set limits and the measured results. Under these conditions, the cause must be immediately identified and removed. If this occurs when integrating a new process, then it must be investigated, modified, or replaced with another.

Table 4 provides the recommended values of the statistical indices Cp and Cpk, the behavior of the normal distribution curve with reference to each of them, and what is the process state for each value [5], [14-16]. It is observed that for high values of Cpk/Ppk, the normal distribution curve is narrower and concentrated around the mean value. For lower values of Cpk/Ppk, the normal distribution curve becomes wider and more spread around the mean value, indicating greater process variation and the possibility of producing products that do not meet specifications [17].

After analysing the results obtained by the statistical indices for evaluating the process capability, as well as their application to the normal distribution curve, it can be evaluate how well the process meets the specifications, and if needed, measures can be taken to improve the production quality.

2.6 Non-normal distributed data

In evaluating the statistical indices, it is assumed that the data are normally distributed. In not a few cases however, this turns out not to be the situation and the data do not always follow the normal distribution. This may lead to misleading results, inaccurate evaluation, or potential risks in the future. To prevent these issues, it is important to determine the actual distribution of data. If the data are not normally distributed, one possibility is to transform the data to achieve a normal distribution. When applying this type of transformation, the specification limits must be adjusted correspondingly. Some of the most used methods are:

- Square root transformation;
- Box-Cox transformation;
- Johnson data transformation;

Another commonly used method to solve the data normality problem is the one described in ISO-22514-1 , also called the percentile method. Values of the statistical indices are calculated as following [15]:

- Process Capability:

$$\mathrm{Cpk} = \min(\mathrm{CpU}, \mathrm{CpL}) \tag{1}$$

$$\mathrm{Cp} = \frac{\mathrm{USL}-\mathrm{LSL}}{X_{99.865\%}-X_{0.135\%}} \tag{2}$$

- Process Performance:

$$\mathrm{Ppk} = \min(\mathrm{PpU}, \mathrm{PpL}) \tag{3}$$

$$\mathrm{Pp} = \left(\frac{\mathrm{USL}-\mathrm{LSL}}{X_{99.865\%}-X_{0.135\%}}\right) \tag{4}$$

,where

$$\mathrm{CpU} = \frac{(\mathrm{USL}-X_{50\%})}{X_{99.865\%}-X_{0.135\%}};\ \mathrm{CpL} = \frac{(X_{50\%}-\mathrm{LSL})}{X_{99.865\%}-X_{0.135\%}};$$

$$\mathrm{PpU} = \frac{(\mathrm{USL}-X_{50\%})}{X_{99.865\%}-X_{0.135\%}};\ \mathrm{PpL} = \frac{(X_{50\%}-\mathrm{LSL})}{X_{99.865\%}-X_{0.135\%}};$$

$X_{0,135\%}$, $X_{99,865\%}$ - quantile of the distribution of the product characteristic;

$X_{50\%}$ - 50 % - distribution quantile;

In scientific circles, these methods have been object of research in order to compare one method with another with regard to their efficiency and application in processing non-normally distributed data. In their study of various methods for non-normal distributions, the obtained results of Tang and Than [18] show that the Box-Cox method, performs better than the Johnson method. In another study by Hosseinifard et al [19] concluded that the root transformation method provides a better estimate of the process capability for non-normal distributed data compared to Box-Cox and the percentile method.

Another well-known method that is widely used by industries to deal with non-normal distributed data is Clements'. Despite its popularity, the study of Wu et al. [20] shows that this method cannot give accurate information about the values of statistical indices when the data distribution is skewed.

Despite the significant number of studies in the field, the choice of method depends on the specific characteristics of the data and the nature of the process. Consultation with statistical experts in the field or the use of specialized software can help determine the most appropriate method for evaluating process apabilities when data is non-normally distributed.

After the reviewed researches, it is recommended to check the normality of the data, before using the statistical indices, trying to normalizing the data or using percentile methods. By using graphical methods such as: Histograms and Q-Q plot, allows a visual representation of the data distribution and analysing her for normality.

3. ALGORITHM FOR SELECTING OPTIMAL PROCESS PLANNING

After the review of statistical methods for process capability evaluation, as well as the review of their differences and applications, an algorithm is proposed that aims to support the evaluation and analysis of process capability Fig.4.

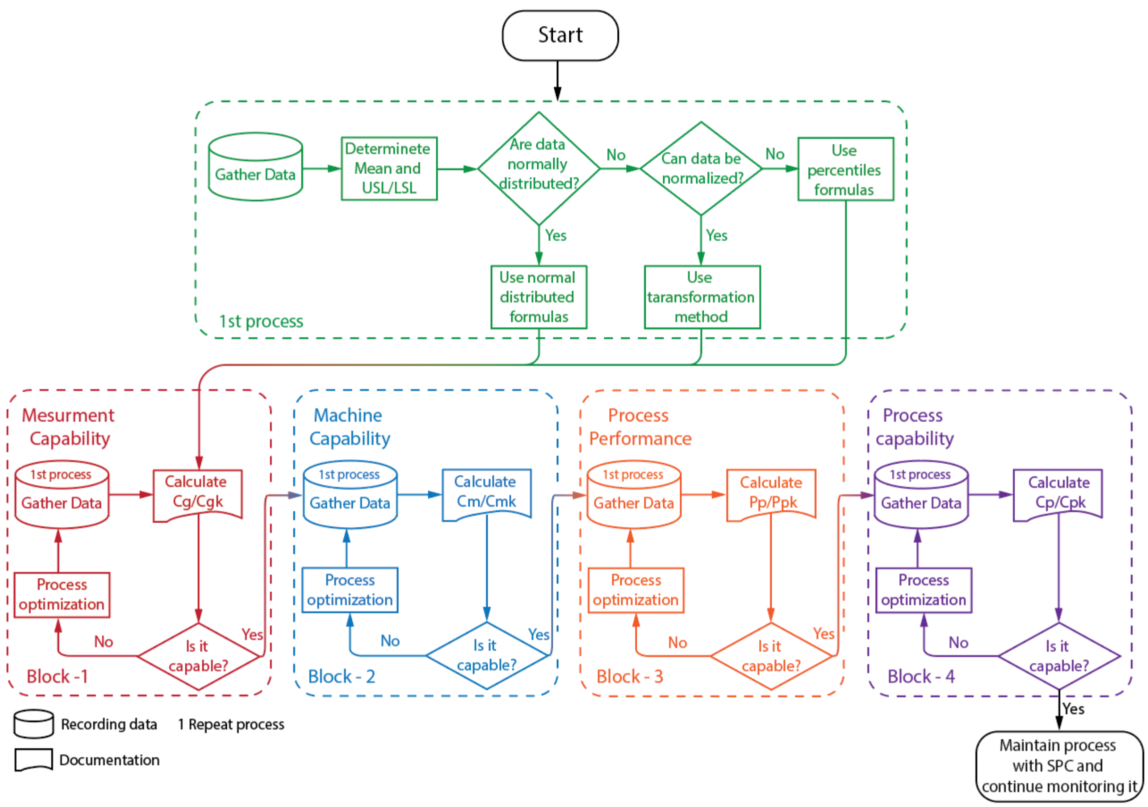


Fig.4. Algorithm for process capability evaluation for different stages of process planning

It provides a framework and sequencing between the different methods, leading to a detailed analysis on the capability and stability of the process under analysis. The algorithm covers and systematise the process evaluation methods reviewed so far and offers a structured approach to their use.

3.1 Gather data

Gathering data is an important step in analysing process capability. It needs to be planned and tailored to the different information provided by the statistical methods.

Table 5 presents the minimum recommendations for the number of samples for different methods to determine process capability [21-22]. The values set are recommended and should not be taken as absolute. These values can be increased in order to obtain more comprehensive results. This step is represented on the algorithm as "1st process" in Fig.4. In this step, the data is analysed to check if it is normally distributed, and a further decisions are made on possible steps for normalising the data.

Table 5

Data collection requirements.

Indices	Data gathering
Cm/Cmk	**n ≥50** consecutive parts (measurements)
Cp/Cpk	At least **25 subgroups** with **n ≥ 5** (parts/measurements)
Pp/Ppk	**n ≥125** (parts/measurements)

3.2 Evaluating process capability

In this step the actual calculation of the statistical indices is performed and a conclusion is drawn about the result obtained. In case of results that not corresponded by Table 3 and Table 4, the process has to be examined and the reason for the unsatisfactory result has to be analysed. Once the cause has been eliminated, the algorithm should again be carried out to evaluate the capability of the process. In case of positive results, the process analysis should continue to the next step.

The algorithm provides the ability to track, analyse and evaluate the technological process at different stages of its implementation.

- Maintaining existing processes.

When maintaining processes that are already under statistical control, the use of block 4 of the algorithm is recommended. This block provides with sufficient information about the state of the process and is particularly useful in case of possible consistent process variations. The use of block 4 allow to predict outliers in the process, which gives the opportunity to take correction measures at this point before serious deviations or problems occur.

- For new process planning;

When introducing new process planning in production, it is recommended to use block - 2 followed by block - 3 of the algorithm. The application of these blocks ensures that the results obtained will be the most accurate. This is achievable because the Cm and Cmk indices are not affected by external factors, allowing us to get an idea of the process state immediately, after running 50 samples. If the process does not meet the specifications at that time, we can update the process by taking appropriate adjustment measures. If the results of block - 2 are good, proceed to block - 3. This block gives an overview of the process and its status, which allows us to draw conclusions about the capability of the process and its ability to produce quality products. Using blocks 2 and 3 in combination provides a systematic and controlled approach to integrating new process technologies. This approach enables to measure and evaluate process efficiency and quality, detect and correct potential problems at an early stage, and achieve stable, high-quality production.

Blocks 3 and 4 also provide an opportunity to explore several process variants and make a comparative analysis between them in order to select the most optimal one.

For a comprehensive analysis of the process and to achieve a high degree of control and management, it is recommended to go through all blocks 1 to 4 of the algorithm. This provides a systematic and comprehensive approach that includes evaluating statistical characteristics of the process, analyzing potential variables and variations, predicting undesirable changes, and taking corrective action.

4. CONCLUSION

Following the review of process capability evaluation methods, their application and the information they provide differ from each other. Statistical indices are a tool that provide information for process capability evaluation. Performing a qualitative analysis of process capability evaluation, requires a good knowledge and correct application of the reviewed indices, otherwise errors may occur or incorrect information may be provided.

Cp and Cpk, analyse the state of the process by using subgroups and enable us to predict what the eventual state of the process will be in the future. They are used when the process is under statistical control and to monitor its behavior.

Pp and Ppk are also used for an overall analysis of the process status or to provide information on the process behavior for past periods or up to the present. They are used also in processes that are new and in starting development stage. When integrating a new process planning into the production program, as well as a pre-analysis of its behavior, it is recommended to start with the calculation of the machine index - Cm and Cmk. Then proceed to Pp and Ppk for an overall analysis of the process state.

An algorithm is provided to ensure an objective and systematic evaluation of process capability, which helps in making an informed decision regarding its status. Using it to compare several variants of a new process, a comparative analysis can be made between the calculated statistical indices and the most optimal process can be selected. This ensures that choices are made based on the quality and the capability of the process and minimizes future technological problems when implementing the new process.

The proposed algorithm not only allows the evaluation of process capability but is also flexible by providing blocks that can be used by themselves to analyze and monitor individual process characteristics such as: measurement capability, machine capability, process performance, and process capability. This allows monitoring the behaviour of the new process planning in his implementation in the production and and afterwards.

To summarize the presented overview of statistical methods for evaluating the process capability and selection of the optimal process planning, allows specialists - technologists to quickly and easily choose the suitable methodology for their specific case without the need to spend unnecessary time searching for reference information. The developed algorithm can be applied in different types of production such as batch production and fields like: automotive, mechanical engineering, shipbuilding, aircraft construction, etc.

The scientific team presenting this paper is working in this area, running experiments, and preparing future publications related to the selection of an optimal process planning, and the approbation of the proposed algorithm in real production.

5. REFERENCES

[1] Shewhart, W. A., & Deming, W. E. *In Memoriam: Walter A. Shewhart, 1891–1967*. The American Statistician, 1967. 21(2), 39-40. DOI:10.1080/00031305.1967.10481808

[2] Montgomery, D. C. *Introduction to Statistical Quality Control, 7th Eddition*, Wiley, Hoboken. 2013

[3] Chakraborti, S., Human, S. W., & Graham, M. A. *Phase I Statistical Process Control Charts: An Overview and Some Results.* Quality Engineering, Vol. 21, No. 1, pp. 52-62. 2008

[4] Kiran, D. R. *Total Quality Management: Key Concepts and Case Studies*. BSP Books Pvt. Ltd. Published by Elsevier Inc., pp. 257-259. 2017

[5] ISO - International Organization for Standardization. *Statistical methods in process management — Capability and performance — Part 2: Process capability and performance of time-dependent process models*. 2017. https://www.iso.org/standard/71617.html

[6] Ramirez, J. G., & Ramirez, B. S. *Douglas Montgomery's Introduction to Statistical Quality Control, A JMP Companion.* United Kingdom: SAS Institute.2018

[7] Mcneese, B. *Cpk Vs. Ppk: Who Wins?: SPC for excel*. 2014 https://www.spcforexcel.com/knowledge/process-capability/cpk-vs-ppk-who-wins. Accessed on May 15, 2023.

[8] Arcidiacono, G., & Nuzzi, S. *A Review of the Fundamentals on Process Capability, Process Performance, and Process Sigma, and an Introduction to Process Sigma Split.* International Journal of Applied Engineering Research, 12(14), 4556-4570. ISSN 0973-4562. 2017

[9] Rezaie, K., Rabbani, Z., Taghizadeh-Yazdi, M., & Bakhtiar, O. *Process Capability and Process Performance*. The 36th International Conference on Computers & Industrial Engineering. 2006

[10] Kapadia, M. (n.d.). *Measuring your Process Capability.* Symphony Technologies.https://www.symphonytech.com/articles/pdfs/processcapability.pdf. Accessed on May 17, 2023.

[11] Quality knowledge base. *Machine- and Process Capability*. http://www.qmindset.com/index.php?page=machine_and_process_capability. Accessed on May 15, 2023.

[12] Quality Management in the Bosch Group. (n.d.). *Technical Statistics, Booklet No. 9, Machine and Process Capability*. https://assets.bosch.com/. Accessed on May 15, 2023.

[13] Six sigma-materials. *Machine capability*. https://www.six-sigma-material.com/Cmk.html. Accessed on May 12, 2023.

[14] International Organization for Standardization. *ISO 9001:2015 Quality management systems Requirements*. Geneva, Switzerland. 2015 https://www.iso.org/iso-9001-quality-management.html. Accessed on May 15, 2023.

[15] International Organization for Standardization. *Statistical methods in process management — Capability and performance — Part 1: General principles and concepts.* 2014 https://www.iso.org/standard/64135.html. Accessed on May 12, 2023.

[16] ASTM International. *Standard Test Method for Process Capability and Performance Measurement.* West Conshohocken, PA. 2018. DOI:10.1520/E2281-15R20

[17] Six sigma-materials. *Process Capability indices*. 2020. https://www.six-sigma-material.com/Cpk.html. Accessed on May 17, 2023.

[18] Tang, L. C., & Than, S. E. *Computing process capability indices for non-normal data: a review and comparative study*. Qual Reliab Eng Int, 15, 339–353. 1999.

[19] Hosseinifard, S. Z., Abbasi, B., Ahmad, S., et al. *A transformation technique to estimate the process capability index for non-normal processes*. Int J Adv Manuf Technol, 40, 512–517. 2009. https://doi.org/10.1007/s00170-008-1376-x

[20] Wu, H. H., Wang, J. S., & Liu, T. L. *Discussions of the Clements based process capability indices*. CIIE National Conference, Chang-Hua, Taiwan. pp. 561–566. 1998.

[21] Quality Management in the Bosch Group. (n.d.). *Technical Statistics, Booklet 10 Capability of Measurement and Test Processes.* https://assets.bosch.com/. Accessed on May 13, 2023.

[22] Quality Management in the Bosch Group. (n.d.). *Technical Statistics, Booklet 7 Statistical Process Control - SPC.* https://assets.bosch.com/. Accessed on May 13, 2023.

Prezentare generală a metodelor existente pentru selectarea planificării optimale a procesului de fabricație

Dezvoltarea rapidă a tehnologiei și cerințele pieței în schimbare rapidă și permanentă din zilele noastre pun din ce în ce mai multă presiune asupra optimizării producției. Analiza și selectarea planificării optime a procesului pentru a asigura calitatea, eficiența costurilor și productivitatea ridicată, este de o importanță capitală pentru companii și reprezintă încă o sarcină costisitoare pentru acestea. Această lucrare de revizuire discută metodele existente pentru selectarea planificării optime a procesului prin utilizarea indicilor statistici Cp, Cpk, Pp și Ppk pentru a evalua performanța planificării. Se face o analiză comparativă între ele, evidențiind avantajele și dezavantajele relevante pentru a face o alegere optimă pentru planificarea procesului, în funcție de tipul de fabricație.

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