RESSALVA

Atendendo solicitação da autora, o texto completo desta tese será disponibilizado somente a partir de 05/07/2026.

UNIVERSIDADE ESTADUAL PAULISTA – UNESP

"Júlio de Mesquita Filho" - Guaratinguetá

MARIANA CRISTINA DE OLIVEIRA

THE np_x CHART: when the parameters are known and unknown

Guaratinguetá

2024

MARIANA CRISTINA DE OLIVEIRA

THE np_x CHART: when the parameters are known and unknown

Thesis presented to the Graduate Program in Engineering of the University of State of São Paulo (UNESP) to obtain the title of Doctor in Engineering.

Area: Production.

Advisor: Prof. Dr Marcela Aparecida Guerreiro Machado

Co-advisor: Prof. Dr. Subhabrata Chakraborti

Co-advisor: Prof. Dr. Felipe Schoemer Jardim

Guaratinguetá

2024

Oliveira, Mariana Cristina

O48n THE ***npx*** CHART: when the parameters are known and unknown / Mariana Cristina Oliveira – Guaratinguetá, 2024.

140 : il.

Bibliografia: f. 81-84

Tese – Universidade Estadual Paulista, Faculdade de Engenharia e Ciências de Guaratinguetá, 2024.

Orientadora: Profª. Drª. Marcela A.Guerreiro Machado

Coorientadores: Prof. Dr. Subhabrata Chakraborti

Prof. Dr. Felipe Schoemer Jardim

1. Controle de processos. 2. Estatística. 3. Gráficos (Engenharia). 4. Desempenho - Avaliação. I. Título.

CDU 658.511.3(043)

Luciana Máximo

Bibliotecária CRB-8/3595

POTENTIAL IMPACT OF THIS RESEARCH

In the thesis, statistical tools were suggested for monitoring processes in real-world scenarios where parameters like mean and variance are estimated. These tools were found to be more cost-effective, simpler, and, depending on the sample size, more efficient than existing methods.

IMPACTO POTENCIAL DESTA PESQUISA

Na tese, foram sugeridas ferramentas estatísticas para monitorar processos em cenários do mundo real, onde parâmetros como média e variância são estimados. Essas ferramentas mostraram-se mais econômicas, simples e, dependendo do tamanho da amostra, mais eficientes do que os métodos existentes.

UNIVERSIDADE ESTADUAL PAULISTA
CAMPUS DE GUARATINGUETÁ

MARIANA CRISTINA DE OLIVEIRA

ESTA TESE FOI JULGADA ADEQUADA PARA A OBTENÇÃO DO TÍTULO DE
"DOUTORA EM ENGENHARIA MECÂNICA"

PROGRAMA: ENGENHARIA MECÂNICA
CURSO: DOUTORADO

APROVADA EM SUA FORMA FINAL PELO PROGRAMA DE PÓS-GRADUAÇÃO

Documento assinado digitalmente
MARCELA APARECIDA GUERREIRO MACHADO DI
Data: 24/07/2024 11:02:36-0300
Verifique em https://validar.iti.gov.br

Profª. Drª. Marcela Aparecida Guerreiro Machado de Freitas
Coordenadora

B A N C A E X A M I N A D O R A:

Documento assinado digitalmente
MARCELA APARECIDA GUERREIRO MACHADO DI
Data: 24/07/2024 10:58:56-0300
Verifique em https://validar.iti.gov.br

Profª. Drª. MARCELA APARECIDA GUERREIRO MACHADO DE FREITAS
Orientador – UNESP

Documento assinado digitalmente
PEDRO CARLOS OPRIME
Data: 22/07/2024 11:26:20-0300
Verifique em https://validar.iti.gov.br

Prof. Dr. PEDRO CARLOS OPRIME
UFSCAR

Documento assinado digitalmente
NILO ANTONIO DE SOUZA SAMPAIO
Data: 17/07/2024 12:25:32-0300
Verifique em https://validar.iti.gov.br

Prof. Dr. NILO ANTONIO DE SOUZA SAMPAIO
UERJ

Documento assinado digitalmente
MESSIAS BORGES SILVA
Data: 22/07/2024 15:04:23-0300
Verifique em https://validar.iti.gov.br

Prof. Dr. MESSIAS BORGES SILVA
UNESP

Documento assinado digitalmente
PALOMA MARIA SILVA ROCHA RIZOL
Data: 16/07/2024 11:31:17-0300
Verifique em https://validar.iti.gov.br

Profª. Drª. PALOMA MARIA SILVA ROCHA RIZOL
UNESP

JULHO de 2024

To my beloved parents, Antonio Carlos de Oliveira and Sylvia Julieta de Oliveira.

ACKNOWLEDGMENTS

Firstly, I would like to thank God and Nossa Senhora Aparecida for granting me health and resilience on this journey.

I am immensely grateful to my parents, Antonio Carlos and Sylvia whose unwavering love, support, and encouragement have been the bedrock of my achievements. This achievement is as much theirs as it is mine. Thank you for for believing in me, always.

I would like to thank my doctoral advisor Prof. Marcela Aparecida Guerreiro Machado for her guidance, patience and kindness, guiding me through the challenges of research and academic writing.

I am deeply grateful to my co-supervisor, Prof. Subha Chakraborti, for not only welcoming me to the United States but also for his invaluable experience, patience, and guidance. His insightful feedback and encouragement have been invaluable in guiding me through the challenges of research and academic writing.

To Prof. Felipe Schoemer Jardim, my co-supervisor, I thank you from the bottom of my heart for your dedication, generosity and guidance over the years. His guidance was fundamental to the success of my research.

I extend my eternal gratitude to my sister, Natália Cristina de Oliveira, for her unwavering support, love, and encouragement. Her belief in me has been a constant source of inspiration.

To the Poitons, who graciously welcomed me into their home in the United States, I am deeply thankful for their support and hospitality, which made my stay memorable.

I extend my sincere gratitude to the University of Alabama for welcoming me and providing resources and facilities that facilitated my research efforts.

This work was carried out with the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) – Financing Code 001.

This work was supported by:
CAPES - Coordenação de Aperfeiçoamento de Pessoa de Nível Superior

ABSTRACT

Control charts are powerful tools used by many industries to monitor some quality characteristics and detect special causes of variation. If it is impractical to numerically represent the quality characteristic, attribute control charts, such as the np chart, are often used to monitor the number of nonconforming units. Attribute control charts are considered simpler, faster, and cheaper than variable control charts (such as the $\overline{X}$ chart) because they do not require the measurement of some quality characteristic; instead, professionals only need to count the number of nonconforming units in a sample. For this reason, the np control chart is also used to monitor not only the number of nonconforming units, but also the process average. The np_x control chart was introduced by Wu et al. (2009)(WU et al., 2009) to monitor the mean of a continuous variable using attribute inspection. The authors evaluated the performance of the np_x graph without considering the practical case where the parameters (such as p), necessary to calculate the control limits, must be estimated. The present work focuses on evaluating the performance of the np_x control chart when the parameters are estimated. Despite the initial fascination of the np_x chart for its perceived advantages over variable control charts – such as simplicity, speed and cost-effectiveness – inconsistencies in the results presented by Wu et al. (2009)(WU et al., 2009) are revealed. By addressing these inconsistencies, we offer alternative insights into the effectiveness of the np_x graph. Through an extensive investigation, involving derivations and numerical analysis, the scenarios in which the bilateral and unilateral np_x graphs outperform the $\overline{X}$ graph were determined. With this background, now with the corrected np_x graph, the impacts on parameter estimation were analyzed in detail. It was found that performance is affected mainly when the standard deviation of the process is estimated (cases KU and UU), presenting itself significantly different from what is nominally expected if the estimation of the parameters is not taken into account in the design of the graph. The number of reference samples needed to mitigate this effect makes the application of the np_x graph unfeasible. Therefore, adjustments to the UCL and k_w parameters are necessary. Such adjustments were investigated and proved to be efficient, enabling the np_x graph to offer equal or better performance to the $\overline{X}$ graph using numbers of usual reference samples. This work contributes significantly to a more nuanced understanding of the comparative advantages of different control chart methodologies, for variable and attribute data.

KEYWORDS: Attribute control charts; Parameter Estimation; Average Run Length; False Alarm Rate.

RESUMO

As cartas de controle são ferramentas poderosas usadas por muitas indústrias para monitorar algumas características de qualidade e detectar causas especiais de variação. Se for impraticável representar numericamente a característica de qualidade, gráficos de controle de atributos, como o gráfico np, são frequentemente usados para monitorar o número de unidades não conformes. As cartas de controle de atributos são consideradas mais simples, rápidas e baratas do que as cartas de controle variáveis (como o gráfico $\overline{X}$) porque não exigem a medição de alguma característica de qualidade; em vez disso, os profissionais só precisam contar o número de unidades não conformes em uma amostra. Por esse motivo, o gráfico de controle np também é utilizado para monitorar não apenas o número de unidades não conformes, mas também a média do processo. O gráfico de controle np_x foi introduzido por Wu et al. (2009)(WU et al., 2009) para monitorar a média de uma variável contínua usando inspeção de atributos. Os autores avaliaram o desempenho do gráfico np_x sem considerar o caso prático onde os parâmetros (como p), necessários para calcular os limites de controle, devem ser estimados. O presente trabalho tem como foco a avaliação de desempenho do gráfico de controle np_x quando os parâmetros são estimados. Apesar do fascínio inicial do gráfico np_x pelas suas vantagens percebidas sobre os gráficos de controle variável – como simplicidade, velocidade e custo-benefício – inconsistências nos resultados apresentados por Wu et al. (2009)(WU et al., 2009) são reveladas. Ao abordar essas inconsistências, oferecemos insights alternativos sobre a eficácia do gráfico np_x. Através de uma extensa investigação, envolvendo derivações e análise numérica, foram determinados os cenários em que os gráficos np_x bilaterais e unilaterais superam o gráfico $\overline{X}$. Com esse pano de fundo, agora com o gráfico np_x corrigido, foram detalhadamente analisados os impactos na estimação dos parâmetros. Verificou-se que o desempenho é afetado principalmente quando o desvio padrão do processo é estimado (casos KU e UU) apresentando-se significativamente diferente do que é nominalmente esperado se a estimação dos parâmetros não for levada em consideração na concepção do gráfico. O número de amostras de referência necessárias para atenuar esse efeito torna a aplicação do gráfico np_x inviável. Dessa forma, ajustes no parâmetros UCL e k_w se fazem necessários, tais ajustes foram investigados e mostraram-se eficientes, possibilitando que o gráfico np_x ofereça desempenho igual ou melhor ao gráfico $\overline{X}$ utilizando números de amostras de referência usuais. Esta trabalho contribui significativamente para uma compreensão mais matizada das vantagens comparativas de diferentes metodologias de gráficos de controle, para dados de variáveis e atributos.

PALAVRAS CHAVE: Gráficos de controle por atributo; Estimação de parâmetros; Número médio de amostras; Taxa de alarme falso.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ATS	Unconditional Average Time to a Signal: ATS = E(CATS)
CATS	Conditional Average Time to a Signal
CFAR	Conditional False Alarm Rate
EQL	Extra Quadratic Loss
CEQL	Conditional Extra Quadratic Loss
Case KK	Case where both the mean and standard deviation are known
Case KU	Case where the mean is known, and the standard deviation is unknown
Case UK	Case where the mean is unknown, and the standard deviation is known
Case UU	Case where both the mean and standard deviation are unknown
SPC	Statistical Process Control
UCL	Upper Control Limit
IC	In Control

LIST OF SYMBOLS

$\overline{X}$	Sample mean
$\overline{\overline{X}}$	The grand mean of the m Phase I samples estimator
k_w	Coeficient
μ	Process mean
μ	In-control process mean
σ	Process standard deviation
σ_0	In-Control process standard deviation
Φ	Cumulative distribution function of a Standard Normal Random Variable
δ	Scaled shift of the mean
τ	Letra Grega Tau
m	Number of Phase I samples
n	Sample size
Y	Chi-square random variable
Z	Standard Normal Random Variable
μ	In-control process mean

CONTENTS

1 INTRODUCTION

This chapter provides context for the research by outlining its motivation, research questions, objectives, and the structure of the document.

1.1 CONTEXTUALIZATION

The quality of processes is undoubtedly of paramount importance in the field of business, so controlling and improving quality is an excellent strategy used by companies. The statistical process control area (SPC) provides a series of tools used to improve the process stability and reduce the variability. Control charts are one of the oldest tools in the area, used to monitor and detect changes in the process in order to keep it stable (AYKROYD; LEIVA; RUGGERI, 2019).

Processes based on qualitative characteristics, that is, by attribute, cannot be monitored with traditional control charts, as the popular $\overline{X}$, for example. In this cases, it is necessary to apply an attribute control chart: p, np and c are the most used to evaluate processes where the analyzed characteristics are difficult to be measured in a numeral scale (CASTAGLIOLA et al., 2014).

Monitoring processes through attributes offers advantages in terms of time and cost efficiency. Typically, the equipment required for attribute monitoring is less expensive than that used for variable monitoring. However, according to Montgomery, attribute monitoring is generally considered less efficient for tracking specific characteristics compared to variable monitoring, (MONTGOMERY, 2012). Therefore, it is essential to develop methods that enhance the reliability of attribute control charts for monitoring variable processes.

In 2009, Wu *et al.* developed an attribute control chart called np_x which employs an attribute inspection to monitor the process mean using a gage to classify the items as conforming or nonconforming (WU et al., 2009).

Due to the simplicity of the np_x control chart, many researchers have focused on its improvement. For example, Ho and Costa (HO; COSTA, 2011) examined the effects of wandering process means on the performance of the np_x chart. Sampaio, Ho, and Medeiros (SAMPAIO; HO; MEDEIROSC, 2014) proposed a combined np_x-$\overline{X}$ chart to monitor the process mean in a two-stage sampling situation, where the sample is divided into two sub-samples: n_1 and n_2. First, the sub-sample of size n_1 is evaluated by attribute inspection. If it is out of control, then the sub-sample n_2 is evaluated, and the mean is calculated. The process is considered out of control only if the mean exceeds the limit. For monitoring process variability based on the np_x chart, see Ho and Quinino (HO; QUININO, 2013), and da Silva et al. (SILVA; HO; QUININO, 2022b). Quinino et al. (QUININO; CRUZ; QUININO, 2021) proposed a control chart that combines attribute and variable inspections to monitor the process mean. In their method, the first sample undergoes variable inspection using the $\overline{X}$ chart, followed by k samples subjected to attribute inspection using the np_x chart. If neither chart signals a shift in the process mean, the cycle restarts with one sample for variable inspection and k samples for attribute inspection, continuing until a shift is detected by either chart. Additionally, Zhou et al. (ZHOU; YE; ZHENG, 2022) introduced the np_{CEV} chart to monitor the process mean using the conditional expected value (CEV) weighting method. Da Silva et al. (SILVA; HO; QUININO, 2022a) proposed a control chart for monitoring the process mean based on attribute inspection with sequential sample sizes.

The concept of using an attribute chart to monitor a continuous variable, as proposed by Wu *et al.* (WU et al., 2009), has made a notable impact on process monitoring literature. This drew attention to the fact that all work carried out to date considered the process parameters as known. Typically, these parameters are unknown and must be estimated from m historical samples, each of size n, collected when the process is presumably in control. This is known as Phase I analysis in Statistical Process Control (SPC). For an overview of Phase I, see Chakraborti *et al.* (CHAKRABORTI; HUMAN; GRAHAM, 2008) and Jones-Farmer *et al.* (JONES-FARMER et al., 2014).

Subsequently, the chart's control limits are established using these estimates for prospective process monitoring (Phase II), where samples (also of size n) are collected at regular intervals h. These samples are classified as conforming or nonconforming using a gauge, for example, and the number of nonconforming units in each sample is compared with the control limits. If the plotting statistic falls outside the control limits, it indicates a high probability that the process mean has changed, requiring the manager to identify and correct the potential problem.

Most research on the development and performance evaluation of Phase II control charts assumes that the in-control process parameters are known. This assumption simplifies both the design and performance evaluation of the chart, as the run length (the number of samples until an alarm) follows the well-known geometric distribution.

In practice, however, these parameters are usually unknown and must be estimated during Phase I. When estimates are used instead of known parameters, their variability can leads to chart performance that deviates from that of charts designed with known parameters. For example, the run length no longer follows a geometric distribution, and the actual false alarm rate (FAR) may exceed the desired nominal rate. Frequent false alarms result to unnecessary costs, such as wasted time for managers investigating non-existent issues, which disrupts operations and reduces productivity. Therefore, when designing a control chart, it is crucial for managers to consider the impact of parameter estimation on chart performance to avoid unnecessary costs.

When designing control charts with estimated parameters, four cases are possible:

1. Both the in-control process mean (μ_0) and standard deviation (σ_0) are unknown. This situation, known as "Case UU" (Unknown mean and Unknown standard deviation), is the most common in practice and considered the standard unknown case.

2. The process mean is known, but the standard deviation is unknown. This is "Case KU" (Known mean, Unknown standard deviation), where the standard deviation must be estimated during Phase I.

3. The in-control process mean is unknown and needs to be estimated during Phase I, while the standard deviation is known. This is "Case UK" (Unknown mean, Known standard deviation).

4. Both the in-control process mean and standard deviation are known. This is "Case KK" (Known mean and Known standard deviation), the simplest and most desirable case. Here, the perfor-

mance of the control chart can be easily studied and measured since the run length distribution is known.

The np_x chart is commonly used in quality control to monitor processes over time. Using estimated parameters instead of true parameters can significantly impact the performance of the np_x chart. Estimating parameters introduces uncertainty, which can affect the chart's sensitivity to detecting process shifts and its overall effectiveness.

Building upon this background, the current study will explore the impact on the average time to signal (for both in-control and out-of-control conditions) and extra quadratic loss considering a shift range in the process mean for the UU, KU, and UK scenarios of the np_x chart. This research aims to elucidate the compromises inherent in these scenarios and offer valuable insights for practitioners in quality control, emphasizing practical considerations for real-world applications.

1.2 RESEARCH OBJECTIVES

Clearly defined research objectives provide a roadmap for the entire research process, guiding decisions on study design, data collection methods, and analysis techniques (CRESWELL, 2008).

The general objective of this thesis is to investigate the effects of estimation of parameters (μ and σ) on an attribute control chart used to monitor the mean of a continuous variable.

In order to achieve the general objective of this research, this thesis has the following specific objectives

1. Review the available literature on attribute control charts used to monitor the mean of a continuous variable to highlight gaps in the literature;
2. Replicate the results of the control chart by attributes np_x to monitor the mean of a continuous variable.
3. Obtain the properties of the np_x control chart in the condition in which the parameters (μ and σ) are estimated.
4. Evaluate the performance of the np_x chart under the effect of parameters estimation;
5. Evaluate optimizing the np_x control chart considering the estimated parameters;
6. Propose future studies for the continuation of the study and contribution to the research field.

1.3 METHODOLOGY

The methodology employed in this research plays a pivotal role in ensuring the credibility and validity of the findings. As Creswell (CRESWELL, 2008) aptly stated, the methodology serves as the "blueprint" for the study, guiding the researcher in the systematic investigation of the research questions or objectives. By meticulously designing and implementing a robust methodology, this study aims to uphold the principles of rigor and transparency in academic research.

The initial stage involved conducting a preliminary examination of control chart literature to identify gaps requiring further study. Specifically focusing on control charts with estimated parameters, relevant papers were examined to understand the current state of research, including best practices, findings, and limitations from previous studies. Notably, it was found that no prior research had considered the estimation of parameters for np_x control chart.

Based on the initial step, certain decisions were made. It was presumed that the designed control chart would be utilized for normally distributed processes. The unconditional approach was chosen to estimate the process parameters (μ and σ), given its wide applicability and ability to represent a variety of users. Recognizing the estimated parameters as random variables following a normal distribution, the model requires adjustments to accommodate this randomness and the associated variability.

The effect of estimating limits on the np_x control chart's performance is examined separately for cases where either one or both of the process parameters, the mean and the variance are unknown. Precise formulas are obtained for the distribution of run lengths, the Average Run Length (ARL), and the extra quadratic loss (EQL). We assess these exact $EQLs$ and $ARLs$ across various scenarios. These findings offer practical understanding of how the np_x chart performs when parameters are estimated. Additionally, these derivations can serve as illustrative instances of probability and distribution calculations through conditioning.

The optimization of the np_X chart is also proposed. After the optimization study, an illustrative simulation study is presented to demonstrate the use of optimized parameters.

To perform all the calculations mentioned above, programs were written in the R language and are provided in the appendix section.

1.4 THESIS STRUCTURE

This thesis is structured into six chapters. Figure 1 shows the proposed thesis' structure and the alignment of the chapters with the specific objectives of the Thesis.

Chapter 1 presents the contextualization and research question, research motivation, research objectives, and the methodological release.

Chapter 2 presents the relevant theoretical background. The fundamentals of control charts and the types of control charts are presented. An overview of the literature on control charts with estimated parameters is also presented.

Chapter 3 presents the design of the np_x chart considering the parameters are known. The divergences on results and necessaries corrections are also presented.

Chapter 4 presents the precise formulas for the distribution of run lengths, the Average Run Length (ARL), and the extra quadratic loss (EQL) for each cases where one or both parameters are estimated.

Chapter 5 presents the proposal for the np_x control chart optimization and an illustrative simulation example.

Finally, Chapter 6 summarize this thesis's main contributions and provide suggestions for further research involving related topics.

Figure 1 – Thesis Structure.

Chapter 1 – Introduction	Contextualization
Chapter 2 – Control Chart	Specific Objective 1
Chapter 3 – The np_x control chart with known parameters	Specific Objective 2
Chapter 4 – The np_x control chart with estimated parameters	Specific Objectives 3 and 4
Chapter 5 – The np_x control chart optimization	Specific Objective 5
Chapter 6 – Conclusions	Specific Objective 6

source: Elaborated by the author.

6 CONCLUSION

For the np_x chart when parameters are known, the results founded reveal inconsistencies with Wu *et al.*'s findings (WU et al., 2009). The np_x chart requires a larger sample size than recommended by Wu *et al.* to match the performance of the $\overline{X}$ chart. Despite this, the np_x chart can be advantageous due to its potential for cheaper, faster, and easier attribute inspections in certain applications. Both one-sided and two-sided np_x chart designs can outperform the $\overline{X}$ chart, particularly with small sample sizes.

The np_x chart can monitor the mean more efficiently than the $\overline{X}$ chart, depending on inspection costs. Adjusting the sample size or sampling interval can enhance performance or reduce costs. Although the np_x chart's performance may not be as high as initially claimed by Wu *et al.*, it remains beneficial for monitoring a continuous variable's mean in some cases.

Parameter estimation proved to be detrimental to the performance of the np_x chart. The results revealed that the constraint of $ATS_0 = 370$ is not satisfied, and the EQL_{npx} increases, indicating that the chart's performance has worsened. This effect diminishes as the number of reference samples increases; the more samples used to estimate the mean and standard deviation, the closer the performance will be to that achieved when the parameters are known. This makes the practical use of the np_x chart with estimated parameters unfeasible, as satisfactory results were only obtained when at least 500 reference samples were used.

The impact on the performance of the np_x chart is more pronounced for the KU and UU cases. The results showed that the mean estimate (UK case) has little effect on the variation of ATS_0 and EQL_{npx}. In contrast, the process standard deviation estimate substantially affects both ATS_0 and EQL_{npx}. Since in practice both parameters are typically unknown (UU case), it is necessary to adjust the control chart limits to optimize performance.

The optimization of the np_x chart involves adjusting its UCL and k_w parameters. The results have proven valuable, as adjusting these parameters allows for achieving equal or superior performance for the np_x chart when parameters are estimated, compared to when parameters are known, considering 25 reference samples — a commonly used value in real-world scenarios. Therefore, parameter adjustment renders the use of the np_x chart feasible.

In summary, our study sheds light on the performance and practical considerations of the np_x chart in comparison to the $\overline{X}$ chart. Our findings challenge previous research by revealing inconsistencies in performance expectations, particularly concerning sample size requirements. Despite requiring larger sample sizes, the np_x chart offers advantages in cost and efficiency, especially for attribute inspections. However, parameter estimation significantly impacts the np_x chart's performance, rendering its practical use unfeasible in many cases. Nonetheless, by adjusting parameters such as UCL and k_w, it's possible to optimize the np_x chart's performance, making it a viable option even when parameters are estimated. This highlights the importance of careful parameter adjustment in implementing the np_x chart effectively in real-world scenarios.

REFERENCE

AYKROYD, R. G.; LEIVA, V.; RUGGERI, F. Recent developments of control charts, identification of big data sources and future trends of current research. **Technological forecasting and social change**, New York, v. 144, p. 221–232, 2019. ISSN 00401625. Available from: https://doi.org/10.1016/j.techfore.2019.01.005. Acess in: February, 2021.

BRAUN, W. J. Run length distributions for estimated attributes charts. **Metrika,** Heidelberg, v. 50, p. 121–129, 1999. ISSN 00261335.

CASTAGLIOLA, P.; WU, S. Design of the c and np charts when the parameters are estimated. **International journal of reliability, quality and safety engineering**, Singapore, v. 19, p. 1250010, 2012. ISSN 02185393.

CASTAGLIOLA, P. *et al.* Synthetic phase ii shewhart-type attributes control charts when process parameters are estimated. **Quality and reliability engineering international**, Chichester, v. 30, p. 315–335,2014. ISSN 10991638.

CHAKRABORTI, S. Run length, average run length and false alarm rate of shewhart x-bar chart: Exact derivations by conditioning. **Communications in statistics part B**: simulation and computation, New York, v. 29, p. 61–81, 2000. ISSN 03610918.

CHAKRABORTI, S. Run length distribution and percentiles: The shewhart x chart with unknown parameters. **Quality engineering**, New York, v. 19, p. 119–127, 2007. ISSN 08982112.

CHAKRABORTI, S.; GRAHAM, M. A. **Nonparametric statistical process control**. Hoboken: John Wiley Sons, 2019. ISBN 9781118890561. Available from: https: //onlinelibrary.wiley.com/doi/abs/10.1002/9781118890561.fmatter. Access in: December, 2022.

CHAKRABORTI, S.; HUMAN, S. W. Parameter estimation and performance of the p-chart for attributes data. **IEEE transactions on reliability**, New York, v. 55, p. 559–566, 2006. ISSN 00189529.

CHAKRABORTI, S.; HUMAN, S. W.; GRAHAM, M. A. Phase i statistical process control charts: An overview and some results. **Quality engineering**, New York, v. 21, p. 52–62, 2008. ISSN 08982112.

CHUKHROVA, N.; JOHANNSSEN, A. Improved control charts for fraction non-conforming based on hypergeometric distribution. **Computers and industrial engineering**, New York, v. 128, p. 795–806, 2019. ISSN 03608352.Available from: November, 2021.

COSTA, A. F. B.; EPPRECHT, E. K.; CARPINETTI, L. C. R. **Controle estatístico de qualidade**. 2.ed. São Paulo: Editora Atlas, 2005. 334 p.

CRESWELL, J. W. **Research design**: qualitative, quantitative, and mixed methods approaches. Third edition. Los Angeles: SAGE Publications, 2008. 270 p.

GODINA, R. *et al.* Improvement of the statistical process control certainty in an automotive manufacturing unit. **Procedia manufacturing**, South África, v.17, 2018. ISSN 23519789.

HO, L. L.; COSTA, A. F. B. Monitoring a wandering mean with an np chart. **Produção**, São Paulo, v. 21, p. 254–258, 2011. ISSN 19805411.

HO, L. L.; QUININO, R. C. An attribute control chart for monitoring the variability of a process. **International journal of production economics**, Amsterdam, v. 145, p. 263–267, 2013. ISSN 09255273.Available from: https://www.sciencedirect.com/science/article/pii/S0925527313002107?via%3Dihub Access in: July, 2021.

HO, L. L.; QUININO, R. C. Combining attribute and variable data to monitor process variability: Mix s 2 control chart. **International journal of advanced manufacturing technology**, London, v. 87, p. 3389–3396, 2016. ISSN 14333015. Available from: http://dx.doi.org/10.1007/s00170-016-8702-5.Access in: January, 2022.

HU, X. *et al.* Guaranteed in-control performance of the synthetic x chart with estimated parameters. **Quality and reliability engineering international**, Chichester, v. 34, p. 759–771, 2018. ISSN 10991638.

HUSSAIN, S. *et al.* On a class of mixed ewma-cusum median control charts for process monitorin **Quality and reliability engineering international** ,Chichester, v. 36, p. 910–946, 2020. ISSN 10991638.

JARDIM, F. S.; CHAKRABORTI, S.; EPPRECHT, E. K. X chart with estimated parameters: The conditional arl distribution and new insights. **Production and operations management**, Baltimore, p. 1 –13, 2019. ISSN 19375956.

JARDIM, F. S.; CHAKRABORTI, S.; EPPRECHT, E. K. Two perspectives for designing a phase ii control chart with estimated parameters: The case of the shewhart chart. **Journal of quality technology**, Milwaukee, v. 52, p. 198–217, 2020. ISSN 00224065. Available from: https://doi.org/10.1080/00224065.2019.1571345. Access in:March, 2021.

JENSEN, W. A. *et al.* Effects of parameter estimation on control chart properties: A literature review. **Journal of quality technology**, Milwaukee, v. 38, p. 349–364, 2006. ISSN 00224065.

JONES-FARMER, L. A. *et al.* An overview of phase i analysis for process improvement and monitoring. **Journal of quality technology**, Milwaukee, v. 46, p. 265–280, 7 2014. Available from: www.asq.org. Access in: September, 2020.

JONES, M. A.; STEINER, S. H. Assessing the effect of estimation error on risk-adjusted cusum chart performance. **International journal for quality in health care**, Oxford, v. 24, p. 176–181, 2012. ISSN 13534505.

KEYVANDARIAN, A. *et al.* Adaptive c-chart with estimated parameter. **Communications in statistics**: theory and methods, New York, v. 46, p. 87–103, 2017. ISSN 1532415X. Available from: http://dx.doi.org/10.1080/03610926.2014.985842. Access in: October, 2021.

MACHADO, M. A.; HO, L. L.; COSTA, A. F. Attribute control charts for monitoring the covariance matrix of bivariate processes. **Quality and reliability engineering international**,Chichester, v. 34, p. 257–264, 2018. ISSN 10991638.

MALEKI, M. R.; AMIRI, A.; CASTAGLIOLA, P. Measurement errors in statistical process monitoring: A literature review. **Computers and industrial engineering**, New York, v. 103, p.316–329, 1 2017. ISSN 03608352.

MALEKI, M. R.; AMIRI, A.; CASTAGLIOLA, P. An overview on recent profile monitoring papers (2008–2018) based on conceptual classification scheme. **Computers and industrial engineering**, New York, v. 126, p. 705–728, 12 2018. ISSN 03608352.

MEHMOOD, R.; QAZI, M. S.; RIAZ, M. On the performance of x control chart for known and unknown parameters supplemented with runs rules under different probability distributions. **Journal of statistical computation and simulation**, New York, v. 88, p. 675–711, 2018. ISSN 15635163.

MONTGOMERY, D. C. **Introduction to statistical quality control**. 7th. ed. Hoboken: John Wiley Sons, 2012. 754 p. ISBN 9781118146811.

NEZHAD, M. S. F.; JAFARIAN-NAMIN, S.; FARAZ, A. Expanded fraction defective chart using cornish-fisher terms with adjusted control limits to improve in-control performance. **International journal of industrial engineering and production research**, Tehran, v. 30, p. 477–488, 2019. ISSN 2345363X.

QUININO, R. C.; BESSEGATO, L. F.; CRUZ, F. R. An attribute inspection control chart for process mean monitoring. **International journal of advanced manufacturing technology**, London, v. 90, p. 2991–2999, 6 2017. ISSN 14333015.

QUININO, R. C.; CRUZ, F. R.; HO, L. L. Attribute inspection control charts for the joint monitoring of mean and variance. **Computers and industrial engineering**, New York, v. 139, p. 106131, 2020. ISSN 03608352.

QUININO, R. C.; CRUZ, F. R.; QUININO, V. B. Control chart for process mean monitoring combining variable and attribute inspections. **Computers and industrial engineering**, New York, v. 152, 2 2021. ISSN 03608352.

REYNOLDS, M. R.; STOUMBOS, Z. G. Control charts and the efficient allocation of sampling resources. **Technometrics**, Washington, v. 46, p. 200–214, 5 2004. ISSN 00401706.

SAMPAIO, E. S.; HO, L. L.; MEDEIROS, P. G. A combined npx x¯ control chart to monitor the process mean in a two-stage sampling. **Quality and reliability engineering international**, Chichester, v. 30, p. 1003–1013, 2014. ISSN 10991638.

SHEPHERD, D. K.; CHAMP, C. W.; RIGDON, S. E. Properties of the markov-dependent attribute control chart with estimated parameters. **Quality and reliability engineering international**,Chichester, v. 32, p. 485–498, 2016. ISSN 10991638.

SILVA, L. A.; HO, L. L.; QUININO, R. C. An approach for improvements on the attribute npx control chart. **Quality and reliability engineering international**, Chichester, v. 38, p. 3342–3356, 11 2022. ISSN 10991638.

SILVA, L. A.; HO, L. L.; QUININO, R. C. The use of npx-type attribute charts to monitor the variance. **Quality and reliability engineering international**, Chichester, v. 38, p. 877–886, 2022. ISSN 10991638.

SIMÕES, F. D.; COSTA, A. F. B.; MACHADO, M. A. G. The trinomial attrivar control chart. **International journal of production economics,** Amsterdam, v. 224, 6 2020. ISSN 09255273.

TESTIK, M. C. Conditional and marginal performance of the poisson cusum control chart with parameter estimation. **International journal of production research**, London, v. 45, p. 5621–5638, 2007. ISSN 00207543.

TIPLICA, T. Arl1 of the attribute c control chart with estimated parameter. **International journal of reliability, quality and safety engineering**, Singapore, v. 22, p. 1–24, 2015. ISSN 02185393.

VACHÁLEK, J. *et al.* Intelligent dynamic identification technique of industrial products in a robotic workplace. **Sensors**, MDPI AG, v. 21, p. 1–20, 3 2021. ISSN 14248220.

VAKILIAN, F.; AMIRI, A.; FARAZ, A. The guaranteed adaptive c-charts with estimated parameter. **Quality and reliability engineering international**,Chichester, v. 34, p. 1575–1589, 2018. ISSN 10991638.

WEESE, M. *et al*. Statistical learning methods applied to process monitoring: An overview and perspective. **Journal of quality technology**, Milwaukee, v. 48, p. 4–27, 2016. ISSN 00224065.

WU, S.; CASTAGLIOLA, P.; KHOO, M. B. Run rules based phase ii c and np charts when process parameters are unknown. **Communications in statistics: theory and methods**, New York, v. 45, p. 1182–1197, 2016. ISSN 1532415X.

WU, Z. *et al*. An np control chart for monitoring the mean of a variable based on an attribute inspection. **International journal of production economic**s, Amsterdam, v. 121, p. 141–147, 2009. ISSN 09255273. Available from: http://dx.doi.org/10.1016/j.ijpe.2009.04.021. Access in: February, 2021.

ZHANG, Y. *et al.* The synthetic x chart with estimated parameters. IIE Transactions (Institute of Industrial Engineers), v. 43, p. 676–687, 2011. ISSN 0740817X.

ZHOU, W.; LIU, N.; ZHENG, Z. A synthetic control chart for monitoring the small shifts in a process mean based on an attribute inspection. **Communications in statistics: theory and methods**, New York, v. 49, p. 2189–2204, 2020. ISSN 1532415X. Available from: https://doi.org/10.1080/03610926.2019.1568491. Access in: January, 2023.

ZHOU, W.; YE, Z.; ZHENG, Z. A new npcev chart for monitoring process mean shifts based on an attribute inspection. **Communications in statistics: theory and methods**, New York, 2022. ISSN 1532415X.