Revista NEYART
ISSN: 2992 - 7161

ANALYSIS OF THE FUNCTIONALITY OF TOOLS FOR IMPROVING THE INDUSTRY 4.0 IMPLEMENTATION PROCESS: PLANNING THE RESEARCH PROJECT

ANÁLISIS DE FUNCIONALIDAD DE HERRAMIENTAS PARA EL MEJORAMIENTO DEL PROCESO DE IMPLEMENTACIÓN DE LA INDUSTRIA 4.0: PLANEACIÓN DEL PROYECTO DE INVESTIGACIÓN

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DOI: https://doi.org/10.61273/neyart.v1i2.117 | **Recibido:** 07/06/2025 | **Aceptado:** 22/07/2025 | **Publicado:** 10/09/2025

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Abstract: The use of statistical analysis has been fundamental at the industrial level, as it improves decision-making, optimizes operations, and ensures high quality standards in production. Over time, different statistical methodologies have allowed companies to identify patterns, forecast trends, and reduce variability in manufacturing and operational management. Its implementation covers sectors such as production, logistics, quality control, and risk management, where data analysis helps reduce waste, improve efficiency, and increase profitability. With the rise of Industry 4.0, the implementation of statistical tools has become even more relevant. Digitization and automation have generated large volumes of data that require precise analysis. Technologies such as Big Data and Machine Learning have revolutionized the use of statistical tools, enabling effective decision-making. The combination of technologies with advanced statistical models allows companies to optimize operational management and minimize errors in production. Industry 4.0 not only demands intensive use of data, but also its correct interpretation through robust analytical models that drive digital transformation and strengthen industrial competitiveness.

Keywords: Utility, Efficiency, Effectiveness, Risk Management, Digitalization, Automation.

Resumen: El uso del análisis estadístico ha sido fundamental a nivel industrial, dado que mejora las decisiones, optimiza as operaciones y garantiza estándares altos de calidad en la producción. A lo largo del tiempo, diferentes metodológicas estadísticas han permitido a las empresas identificar patrones pronosticas tendencias y disminuir la variabilidad en la manufactura y la gestión operativa. Su implementación abarca sectores como la producción, la logística, el control de calidad y la gestión de riesgos, donde el análisis de datos ayuda a reducir desperdicios, mejorar la eficiencia y aumentar la rentabilidad. Con el auge de la industria 4.0 la implementación de herramientas estadísticas ha cobrado aún más relevancia. La digitalización y la automatización han generado grandes volúmenes de datos que requiere un análisis preciso tecnologías como Big Data o Machine Learning han causado una revolución en la utilización de las herramientas estadísticas, permitiendo una toma de decisiones eficaz. La combinación de tecnologías con modelos estadísticos avanzados permite a las empresas optimizar la gestión operativa, así como también minimizar errores en la producción. La industria 4.0 no solo exige un uso intensivo de datos, sino también su correcta interpretación a través de modelos analíticos robustos que impulsen la transformación digital y fortalezcan la competitividad de las industrias.

Palabras clave: Utilidad, Eficiencia, Eficacia, Administración del riesgo, Digitalización, Automatización.

INTRODUCTION

In the digital age, industries have been adopting a series of tools for data and information control. Statistical analysis has become a necessary pillar for decision-making, which is applied not only in engineering and science, but also throughout the entire process of good business management. Statistical tools allow large volumes of information to be transformed into additional knowledge, facilitating the identification of patterns, the prediction of trends, and the optimization of processes. The use and application of statistical tools guarantee the validity and reliability of the analyzed data, with the aim of increasing the quality and efficiency of good process execution. ("The Role of Statistical Methods in Modern Industry," 2023).

The role of statistical tools in industry is crucial, from product planning to testing. This allows companies to control the process of adapting to new technologies, especially those beginning the process of digital transformation and the new challenge of implementing Industry 4.0. In this context, methodologies such as regression analysis, time series, data mining, predictive models, Bayesian analysis, and multivariate analysis play a key role in the Industry 4.0 implementation process. The combination of these statistical tools with emerging technologies such as Big Data, artificial intelligence, and automation strengthens industries' ability to adapt to highly competitive environments.

BACKGROUND

This research continues the EVALUATION OF THE CRITERIA THAT IMPACT THE IMPLEMENTATION OF INDUSTRY 4.0 project, which was carried out in the industry in Ciudad Juárez, in the state of Chihuahua. This project identified the main factors for the implementation of Industry 4.0. These factors were technological, human resources, and process. An instrument was designed and validated, showing that these factors are interrelated in the control and optimal implementation of digital transformation in the local industrial sector.

With this context, the aim is to continue providing industries with control and optimization strategies to improve the Industry 4.0 implementation process. These strategies will be based on the results of a feasibility analysis using statistical tools. This project aims to link the education sector with the industrial sector to drive technological innovation by combining the use of statistical tools such as Bayesian, multivariate, and capacity analysis with technologies such as Big Data and Machine Learning.

Continuing this project also helps promote the development and adaptation of Industry 4.0 in the region, which is characterized by the implementation of advanced digital technologies in manufacturing and production processes. This transformation involves the adoption of cyber-physical systems, the Internet of Things (IoT), and the analysis of large volumes of data to improve efficiency. Statistical tools play a crucial role in this context, as they allow the analysis and exploitation of information generated by these emerging technologies.

In Industry 4.0, advanced analytics allows this data to be processed in real time, facilitating process optimization and the prediction of failures in production systems. For example, through machine learning, it is possible to identify patterns in data that help anticipate problems and improve operational efficiency. However, the exponential growth in data storage and exploitation faces significant limitations, especially in terms of data quality, which represents a challenge for both private and public organizations (García, 2022).

GENERAL OBJECTIVE

Conduct a functional analysis of statistical tools applied in industry to improve the Industry 4.0 implementation process in Ciudad Juárez.

Specific objectives

- Identify the level of progress in the Industry 4.0 implementation process for a selected sample of industries in Juárez.
- Conduct a functional analysis of various statistical tools applied in the Industry 4.0 implementation process.
- Develop strategies and propose them to local companies for the transition to Industry 4.0.

THEORETICAL FRAMEWORK

Bayesian analysis with industrial applications

Kumar et al. (2024) employ Bayesian Network (BN) methodologies to investigate the intricate interrelationships between Industry 4.0-related attributes and technologies. This analytical framework facilitates the assessment of dependencies and effects among various variables, enhancing the understanding of how Industry 4.0 technologies can support decarbonization initiatives in the manufacturing sector.

By merging BN with a multi-criteria decision-making (MCDM) framework, the research emphasizes prioritizing strategies that promote carbon neutrality, thus effectively leveraging the capabilities of Industry 4.0 technologies.

To examine machine vision systems in the context of Industry 4.0, a network-oriented Bayesian framework specifically designed for reliability assessment can be used. The incorporation of advanced technologies, such as the Industrial Internet of Things (IoT) and edge computing, stands out for its potential to improve performance.

However, it highlights a significant shortcoming regarding the emphasis placed on reliability in cases of component failure. Bayesian methodology facilitates the identification of defective components, ensuring rigorous quality control in industrial applications, thus addressing a fundamental dimension of reliability in Industry 4.0 implementations. (Gauttam et al., 2022)

Bayesian methodologies, when integrated with Kalman filtering techniques, allow for the simultaneous estimation of system states along with noise variations. This integration serves to dynamically mitigate both noise and instability, allowing for a more accurate estimation of the signal (Asadi and Sadati, 2024).

By incorporating the uncertainties associated with input and output data, Bayesian methodologies improve the regression capabilities of Gaussian processes, reducing predictive uncertainties and increasing the accuracy of signal estimation (Ye and Guo, 2023).

Bayesian methodologies refine uncertainty assessments in measurement science and successfully align them with intuitive interpretations and empirical validations. This consistency is vital for industrial applications requiring accurate measurement results (Meija et al., 2023).

In the context of gas production, Bayesian models effectively address uncertainty and provide clearer risk assessments and more reliable predictions than frequency models, especially in environments characterized by limited data availability (Sharma et al., 2023). Bayesian decision analysis is used to estimate occupational noise levels and provides a probabilistic framework that incorporates variability and uncertainty in exposure data, which is crucial to ensure safety standards are met (Massawe and Fayed, 2024).

Multivariable analysis with industrial applications

Multivariate analysis in Industry 4.0 involves the use of advanced statistical techniques to manage complex data characteristics that traditional Six Sigma methods struggle with. The incorporation of latent variable-based techniques, such as principal component analysis and partial least squares, enhances the

Six Sigma toolset, leading to the development of Multivariate Six Sigma. This methodology is particularly effective for process improvement in environments such as batch production in chemical plants, addressing the challenges posed by the data complexity of Industry 4.0. (Palací-López et al., 2020)

IMPACT OR BENEFIT

This project aims to demonstrate the use of statistical tools in optimizing production processes in Industry 4.0. However, it highlights the application of machine learning and data analysis techniques to improve production performance, suggesting that advanced analytical methods, including statistical tools, are essential for identifying patterns and predicting outcomes. These methodologies enable organizations to improve efficiency and proactively manage production challenges, ultimately contributing to optimization efforts in the context of Industry 4.0. This study aims to achieve the following benefits:

- Gather information from local companies on the current status of the Industry 4.0 implementation process.
- Promote the use of statistical tools in industrial processes, supporting local innovation and technological development.
- Identify the needs of industries to propose strategies for improving the Industry 4.0 implementation process.
- This project is a collaborative effort that reaffirms a strong connection with the local business sector in Cd. Juárez.

METHODOLOGY

In order to carry out this project, applied research has been proposed using a structured methodology with a systematic approach. This methodology seeks to generate and apply knowledge in the industrial context. It will be characterized by clear objectives oriented toward a practical solution, in this case, analyzing statistical tools, under a sequential and orderly process that will allow for replicable results.

This methodology has the flexibility and adaptability to adapt to the industry sector. The validation and verification of results will guarantee the effectiveness of the strategies proposed to the companies.

Materials

During the data collection stage, a measuring instrument will be required for decision-makers who are directly involved in the Industry 4.0 implementation process. During the feasibility analysis stage, a

desktop and/or laptop computer with sufficient capacity for the following software packages will be required: R, SPSS Version 22, and Amos Version 22 (all registered trademarks).

Method

The method proposed in this paper consists of four stages:

- Stage 1. Select industries from different sectors to verify their status in relation to Industry 4.0.
- Stage 2. Identify the level of progress of the industry 4.0 implementation process in a sample of industries in Juárez.
- Stage 3. Prepare a feasibility analysis of various statistical tools to be applied in the industry 4.0 implementation process. Propose strategies and tools for the transition to Industry 4.0 for the selected companies.
- Stage 4. Conclusions, recommendations, and future lines of research.

Stage 3 mentions the use of statistical tools (Table 1). These are fundamental in the implementation of Industry 4.0, allowing companies to process large volumes of data and detect hidden patterns. A prominent example is big data analytics (Oner & Oner, 2017), which drives predictive maintenance, reduces downtime, and improves resource management (Bhandari et al., 2023).

Likewise, advanced statistical techniques such as data envelopment analysis and fuzzy DEA models have been used to evaluate efficiency in Industry 4.0 implementations, helping organizations recognize opportunities for improvement (Sari & Ak, n.d.; Montoya et al., 2023).

On the other hand, statistical process control, integrated with technologies such as the Internet of Things, has evolved into a real-time monitoring system. This synergy provides instantaneous data on production, facilitating early detection of anomalies and rapid problem correction (Wolniak & Grebski, n.d.). Thus, statistical process control has evolved from a reactive tool to a proactive element in smart manufacturing.

In this context, using statistical tools alongside technological tools will allow:

- Improving decision-making through real-time data analysis.
- Optimizing processes by identifying patterns, trends, and anomalies in the implementation and control process.
- Reduce costs through failure prediction and preventive maintenance.
- Increase product quality through statistical process control.
- Increase efficiency by analyzing large volumes of data generated by sensors and connected machines.

Table 1. *Key Statistical Tools in Industry 4.0.*

Tool	Importance
Regression Analysis	Helps predict key variables and optimize processes.
Statistical Process Control	Monitors the stability of industrial processes and detects abnormal variations.
Statistical Simulation	Evaluates complex scenarios and reduces risks when implementing new technologies.
Time Series Analysis	Useful for predicting demand, equipment failures, and production trends.
Design of Experiments	Optimizes industrial processes by extracting valuable information from large databases to improve operational efficiency.
Data Mining	Enables the automation of decisions based on historical and real-time data.
Machine Learning	Helps predict key variables and optimize processes.

Linkage

This research project requires the collaboration of students from the various graduate programs in the Division of Graduate Studies and Research. These students work in manufacturing companies in the region, companies that are in the process of implementing Industry 4.0. There would be a direct relationship with the personnel of these companies involved in the implementation process.

Students will also participate by collecting data and supporting the feasibility study of the statistical tools that will be analyzed. The results obtained will be registered under intellectual property rights with INDAUTOR in the name of the Ciudad Juárez campus, and will subsequently be disseminated on other campuses.

The fundamental objective of the students' work is to improve the efficiency and effectiveness of processes, and consequently, increase profits. Part of the work involves the automation and semi-automation of production equipment, considering the determination of key process variables and the analysis of the large amount of data generated.

Project locations

The project will be carried out in Ciudad Juárez, Chihuahua, based in the Graduate Studies and Research Division of the TecNM/IT of the city. Juárez, information will be collected through visits to companies

in the region with management and middle management personnel currently pursuing postgraduate studies at the Autonomous University of Ciudad Juárez and at the IT Center of Ciudad Juárez.

Infrastructure

The cubicle and laboratory assigned to the project's lead researcher, located in the Graduate Studies and Research Division of TecNM / IT Cd. Juárez, is equipped with office furniture and equipment, a laptop with software, and internet access.

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