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Sistema integral de control de la calidad en un centro de distribución logístico

Operational curves to measure quality in a logistics distribution center

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ABSTRACT

Introduction: The purpose of this applied study is to analyze and control the behavior of a logistics distribution system, estimating the service threshold required to demonstrate significant variations in the Sigma Z level.
Methodology: A quantitative and rational methodology was used, establishing an evaluation model and measurement criteria based on operating curves and Six Sigma metrics.
Results: The evaluation of the logistics system and its processes revealed considerable variations in the Z quality levels, ranging from a minimum of 2.92 to a maximum of 5.58; that is, quality performance varies between Deficient and Excellent according to the established performance criteria. Furthermore, this variation impacts the number of defects per million opportunities (DPMO), the number of nonconformities (n), and process yield (Y). Finally, the analysis of the Average Run Performance (ARP) curves shows that processes such as distribution require a larger number of units to detect shifts between Zi and Zii.
Conclusions: It is demonstrated that integrating Average Run Performance (ARP) curve analysis and Six Sigma methodology into logistics systems optimizes operational quality, supports managerial decision-making, and systematically reduces nonconformities.

Keywords: average run performance; operating curves; quality; Six Sigma.

JEL Classification: H83, L32, L95, M15

RESUMEN

Introducción: El propósito de este estudio aplicado es analizar y controlar el comportamiento de un sistema de distribución logística, estimando el umbral de servicios necesarios para evidenciar variaciones significativas en el nivel Sigma Z.
Metodología: Se utilizó una metodología cuantitativa y racional, estableciendo un modelo de evaluación y criterios de medición basados en curvas operativas y métricas Seis Sigma.
Resultados: La evaluación del sistema logístico y sus procesos reveló variaciones considerables en los niveles de calidad Z, con valores mínimos de 2.92 y máximos de 5.58, es decir, el desempeño de calidad varía entre Deficiente y Excelente según los criterios de desempeño establecidos. Asimismo, la variación impacta en las cantidades de defectos por millón de oportunidades (DPMO), el número de no conformidades (n) y el rendimiento de los procesos (Y). Finalmente, el análisis de las curvas de rendimiento promedio de corrida (RPC) muestra que procesos como el de distribución requieren un mayor número de unidades para detectar el cambio entre Zi y Zii.
Conclusiones: Se demuestra que integrar el análisis de rendimiento promedio de corrida (RPC) y la metodología Seis Sigma en sistemas logísticos optimiza la calidad operativa, fundamenta la toma de decisiones gerenciales y reduce de forma sistemática las no conformidades.

Palabras clave: calidad; curvas de operación; rendimiento promedio de corrida; Seis Sigma.

Clasificación JEL: H83, L32, L95, M15.

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INTRODUCTION

The current competitive landscape requires organizations to constantly optimize their production processes and develop the capacity to generate and integrate knowledge, with the aim of enhancing their performance (Garcia Ramos & Pareja Huacausi, 2021; Robledo-Fernández et al., 2025). Quality, efficiency, and performance are fundamental pillars of success, and the pursuit of methods to optimize them is a strategic priority. The logistics services market—and each of

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its constituent processes—has undergone continuous development, with the demand for storage space steadily increasing. Logistics distribution centers require modern, flexible storage space that allows for easy reorganization and adaptation to market needs (Markowski & Bilski, 2021). To address the need for optimizing logistics processes, two tools stand out as key allies: Six Sigma metrics integrated with operating curves. This strategy is a comprehensive methodology that, through the measurement and diagnosis of process deviations, enables the identification and elimination of the root causes of defects (Gutiérrez et al., 2021). Its systematic approach seeks to reduce the likelihood of errors and optimize the quality of deliverables and services (Purba et al., 2021). Operating curves, meanwhile, are graphical tools that visualize the relationship between process variability and the probability of obtaining products that meet specifications. They allow for the evaluation of a production system's performance, facilitating informed decision-making to optimize its output (Sáenz et al., 2021). Nevertheless, despite the potential of these tools, gaps remain in their application within the context of logistics distribution. There is a need for models that can evaluate both the overall and specific performance of production systems by utilizing Six Sigma metrics (Delahoz-Domínguez et al., 2022).

The significance of this research paper lies in understanding and improving the operation of logistics distribution systems within dynamic environments, utilizing operating characteristic curves based on Six Sigma metrics. As a primary motivation, this research introduces a statistical quality control method for a logistics distribution center—structured around Six Sigma metrics and average run performance charts—which enables the identification and reduction of errors under shifting operational conditions. This contributes to enhancing procedural quality, ultimately fostering exceptional performance and an agile, reliable supply chain. Furthermore, the study analyzes the influence of Z-variability and system throughput on the quality performance of the system under investigation. This analysis provides insight into how the system functions under varying conditions, facilitating timely and relevant decision-making to improve quality in response to changing operational contexts.

Against this backdrop, the following questions arise to guide the course of this research: How can statistical control systems be established to measure the quality of logistics processes? How can the quality performance of a logistics distribution center be measured using Six Sigma metrics? How can quality performance be assessed and controlled effectively within dynamic environments? To address these research questions, the following objectives are defined—centered on the optimization of the Sigma (Z) level: 1) To structure a statistical control model for measuring the excellence of logistics processes. 2) To evaluate Six Sigma metrics within logistics system processes. 3) To develop average run performance charts to determine the number of units to be processed, thereby facilitating the detection of shifts between the Sigma (Z) levels of the system's processes.

Theoretical foundation

Quality in logistics distribution

Economic development is in a state of constant change, driven by market uncertainty and increasingly demanding customers (Benavides et al., 2026). Consequently, to meet high customer expectations, industries must commit to improvements in technological, administrative, and operational areas. This is particularly true for logistics distribution centers, where staying at the forefront of continuous innovation is essential for maintaining competitiveness and sustainability across all processes (Mendoza & Suarez, 2023). In this context, the distribution of goods should be viewed as a strategic link within the organization, focused on providing high-quality service to customers—a goal that requires the rigorous examination, assessment, measurement, and control of every element implemented within that process.

A key aspect of effectively satisfying customers is delivering products in the required quantity, at the right time, and to the correct location (Ascón et al., 2022). To meet these requirements, companies must seek and implement strategies that optimize operational performance based on criteria of excellence, economic efficiency, and adaptability, with the aim of facilitating effective decision-making (Mittal et al., 2019). Among the available solutions, there are various models and strategies that promote continuous optimization in logistics—most notably the statistical tool known as Six Sigma.

The Six Sigma methodology is highly applicable to logistics distribution processes due to its ability to identify issues related to variability and dispersion in specific indicators or requirements. It fosters process improvement by analyzing the root causes of defects, which are then brought under control. This contributes directly to the continuous refinement of a company, enhancing both its operational performance and its competitive standing (Ramírez Pérez et al., 2021). Therefore, Six Sigma control is highly effective for strengthening quality within logistics distribution. Six Sigma has proven to be a successful methodology in many organizations, yielding benefits that range from increased user satisfaction to the optimization of operating costs (Pano Nava et al., 2022). Furthermore, Six Sigma is particularly effective for optimizing logistics processes, supporting decision-making through statistical performance analysis, and ensuring continuous improvement at a low cost.

Six Sigma metrics for quality measurement

Six Sigma metrics have become fundamental tools for evaluating and improving the quality of industrial processes, significantly reducing the likelihood of defects (Bharath & Shankar, 2020; Fontalvo Herrera et al., 2026; Kumar & Khanduja, 2021). This innovative approach minimizes failures, waste, and process variability, with the goal of increasing both productivity and quality (Singh, 2020). Consequently, Six Sigma metrics are well-suited for optimizing logistics distribution centers, fostering success and enhancing an organization's competitive position (Kumar et al., 2020). Logistics distribution systems can be evaluated using Six Sigma metrics. A key metric is "defects per million opportunities" (DPMO), which measures operational performance and quality by quantifying the volume of failures relative to the total number of potential defect opportunities (Pinilla et al., 2021). Another metric is the number of non-conformities (N), which assesses any deviation of a product or service from quality standards—aiding in the diagnosis and mitigation of operational deviations—as well as process yield (Y), which measures the ability to generate outputs that conform to customer-defined limits or product specification parameters (Veena & Prabhushankar, 2020). Adopting Six Sigma-based quality tools and techniques in a logistics distribution center aims to optimize productivity and mitigate defects. By utilizing the model's core indicators—such as defects per million opportunities (DPMO), the calculation of deviations, and process yield rates—organizations can better understand and reduce operational failures, thereby facilitating continuous improvement. Furthermore, this control philosophy is grounded in the rigorous analysis of data and metrics aimed at reducing process variability and enhancing stability; consequently, its application yields significant advantages for a logistics distribution center and its ongoing processes (Sharma, 2020).

Fontalvo-Herrera et al. (2025) highlight that the Six Sigma methodology streamlines the identification of processes in urgent need of improvement, thereby facilitating a reduction in variation and greater stability, with the ultimate goal of achieving a specific quality standard. Moreover, academic research indicates that companies implementing Six Sigma initiatives experience substantial improvements in the efficiency of their production and/or service processes (Luna Amador, 2021). In this context, the new operating curves for Six Sigma metrics provide a powerful tool for evaluating and refining the performance of logistics distribution systems.

Average run performance curves

Six Sigma performance curves serve as key tools for evaluating process performance in dynamic environments. They facilitate the analysis of quality conditions across various production systems by utilizing Six Sigma metrics—such as defects per million opportunities (DPMO), non-conformities (N), and yield (Y)—generated during the production process (T. Fontalvo Herrera et al., 2024; T. J. Fontalvo Herrera et al., 2024). By plotting these curves, one can observe fluctuations in process capability relative to the Sigma quality level (Z), which aids in identifying both the optimal and minimum performance levels of a process. This, in turn, supports informed decision-making aimed at process improvement and the reduction of non-conformities (T. Fontalvo Herrera et al., 2024; T. J. Fontalvo Herrera et al., 2024).

In this context, Average Run Performance (ARP) curves are useful tools for assessing process stability and capability; they are also well-suited for optimizing logistics systems, thereby enhancing overall system productivity. When represented graphically, these curves provide a detailed view of process performance in terms of output (Balza Franco et al., 2019). In this research, the ARP curves are based on two fundamental approaches: the calculation of the "upper" ARP—the number of units required to detect a significant increase in Sigma values (higher Z and Y)—and the calculation of the "lower" ARP—the number of units required to identify a significant decrease in Sigma values (lower Z and Y)—based on the following model. Regarding the disparity between the larger RPC and the smaller RPC, this enables the calculation of the number of units to be produced (np) necessary to detect the shift from Zi to Zii,:

$$RPC = \frac{1}{1 - Y_i} = total\ de\ unidades\ a\ generar\ para\ lograr\ un\ rendimiento\ Y_i$$

$$Y_i = \%\ de\ productos\ de\ producto\ bueno$$

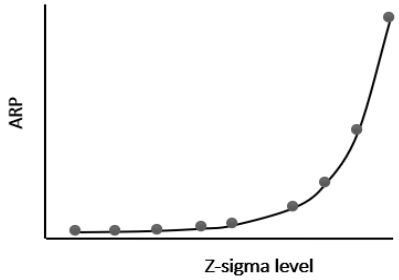
$$1 - Y_i = \%\ de\ productos\ defectuosos$$

$$Z_{i_{Mayor}} \rightarrow Y_{i_{Mayor}} = RPC_{i_{Mayor}} = \frac{1}{1 - Y_{Mayor}} = n_{i_{Mayor}}$$

$$Z_{i_{Menor}} \rightarrow Y_{i_{Menor}} = RPC_{i_{Menor}} = \frac{1}{1 - Y_{Menor}} = n_{i_{Menor}}$$

When evaluating the relationship between the ARP values for the various sigma (Z) levels, it is observed that they maintain a directly proportional relationship, represented graphically as follows:

Figure 1.
Operational representation of ARP for each Sigma (Z) level

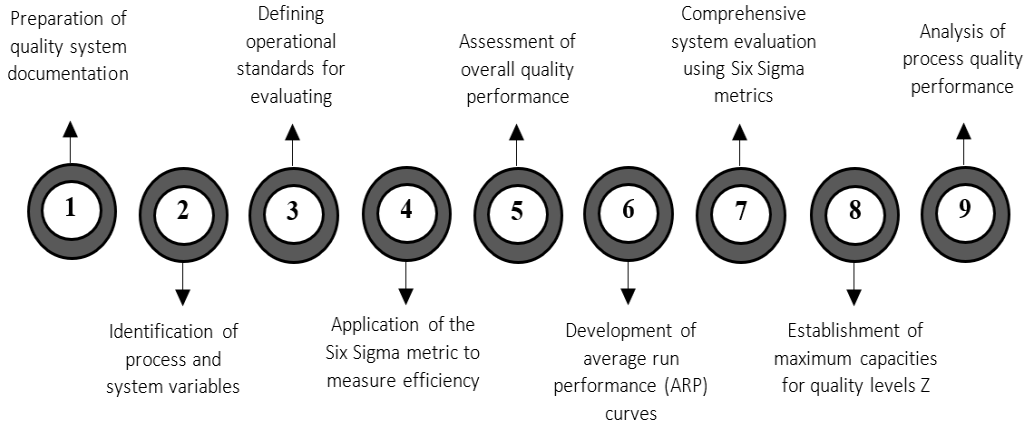


Source: own elaboration.

METHODOLOGY

This work was approached from the perspective of basic research, integrating concepts from statistical quality control, mathematics, and Six Sigma metrics. This integration enabled the establishment of a comprehensive quality control system designed to assess and manage the quality of a logistics distribution system and its associated processes, utilizing proposed operating characteristic curves and a system control dashboard. The study was conducted within a logical positivist paradigm, which—through a rational design approach—facilitated the development of a mathematical model of the logistics system for quality assessment. Subsequently, a sensitivity analysis—accounting for the operational conditions of the subject under study—was used to adjust the performance level (the system's and processes' Sigma Z-level). This process yielded the response variables, data, and primary information required to calculate the quality metrics and curves proposed in this research. These elements are incorporated into the methodology outlined in Figure 2, which consists of nine phases designed to achieve the objectives set forth in this study.

Figure 2.
Systematic process for the development of research



Source: own elaboration.

To analyze system performance, Six Sigma metrics were used; the details of these are specified in Table 1.

Table 1.
Six Sigma metrics for system performance

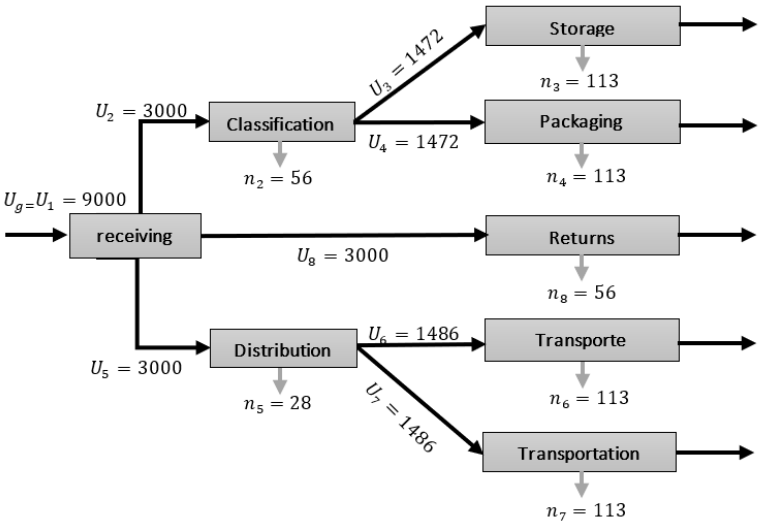
Metric	Description
DPMO	Defects per million opportunities for failure
U	Volume of critical units inspected in the process
O	Potential error events per unit evaluated
Z	Capability indicator or Sigma quality level
n	Non-conformities
Y	Process yield
ARP	Average process yield (Y)

Source: own elaboration.

To meet the requirements of the initial phase of the systematic process, the aforementioned metrics were applied to the logistics distribution system, which consists of eight distinct processes, as illustrated in Figure 2. The evaluation determined an overall sigma level (Zg), which indicates the number of defective units produced by the set of processes.

At the outset of the logistics system, the process and system variables were identified. Units were allocated to four of the eight processes involved. The allocated quantities were established as follows: 9 000 units (U1) were assigned to Process 1 (receiving); these were subsequently distributed among Process 2 (classification)—which received 3 000 units (U2)—Process 5 (distribution)—which received 3 000 units (U5)—and Process 8 (returns)—which received 3 000 units (U8). It should be noted that the allocation of units to Process 3 (storage) and Process 5 (distribution) is derived exclusively from the units exiting Process 2 (classification), while the allocation of units to Process 6 (transport) and Process 7 (delivery) is derived exclusively from the units exiting Process 5 (distribution).

Figure 3.
Diagram of the logistics distribution system



Source: own elaboration

It is essential to understand that the units within the various logistics processes are key to grasping the production flow in this system; they also have significant implications for performance evaluation based on the aforementioned metrics.

To measure the system's efficiency and evaluate its performance, an analysis was conducted regarding the number of defects generated in each process. This analysis began by calculating the total number of defective products generated by the system as a whole (ng), using the following formula:

$$n_g = \frac{DPMO \text{ x } U \text{ x } O}{1000000} \qquad (1)$$

DPMO is determined based on the overall sigma level (Zg), using the following formula:

$$DPMO = e^{\left[\frac{29.3-(z-0.8406)^2}{2,221}\right]} \qquad (2)$$

The calculation of DPMO, followed by its application in the formula for (ng), made it possible to determine the total number of defective products generated by the system. This value—along with the consideration of (ng), as the total sum of defects in the system—indicates that:

$$n_2 = \frac{1}{2}n_3 \qquad (3)$$

$$n_5 = \frac{1}{2}n_2 \qquad (4)$$

$$n_3 = n_4 = n_6 = n_7 \qquad (5)$$

$$n_8 = \frac{1}{2}n_3 \qquad (6)$$

As can be seen, all the formulas are related to n_3. Based on this, the general equation for calculating (ng) is defined as follows:

$$n_g = n_3 + n_4 + n_6 + n_7 + \frac{1}{2}n_3 + \frac{1}{2}n_3 + \frac{1}{2}\left(\frac{1}{2}n_3\right) \quad (7)$$

Solving the equation leads to the following expression:

$$n_3 = \frac{n_g}{(21 \div 4)} \quad (8)$$

After calculating the volume of non-conforming units associated with all the system's sub-processes, the number of units entering and exiting each sub-process was determined, with defective units being subtracted before moving on to the next stage. Likewise, the defects per million opportunities (DPMO) rates at each stage of the chain were evaluated using the following equation:

$$DPMO = \frac{n}{U \text{ x } O} \text{ x } 1000000 \quad (9)$$

Likewise, the corresponding sigma level was established:

$$Z = \sqrt{29.3 - 2.221 \text{ x } \ln\ (DPMO)} + 0.8406 \quad (10)$$

The value of and the remaining output units for each process were also calculated, using the following formulas:

$$U_g = U_2 + U_3 + U_4 + U_5 + U_6 + U_7 + U_8 \quad (11)$$
$$U_3 = \frac{(U_2 - n_2)}{2} \quad (12)$$
$$U_4 = \frac{(U_2 - n_2)}{2} \quad (13)$$
$$U_6 = \frac{(U_5 - n_5)}{2} \quad (14)$$
$$U_7 = \frac{(U_5 - n_5)}{2} \quad (15)$$

Having calculated the aforementioned metrics, the performance of each process and of the system as a whole was determined using the following formula:

$$Y = 1 - \left(\frac{n}{U}\right) \quad (16)$$

Finally, the average run performance for each of the individual processes and for the overall process was determined using the following formula.

$$RPC = 1/(1 - Y) \quad (17)$$

Additionally, operational standards were defined for evaluating the processes. Based on the established conditions, a sensitivity simulation was conducted by varying the Z-sigma levels between 3.0 and 5.1. This variation allowed for a comparison of the performance of individual operations and the overall structure, with the results to be evaluated using Table 2 as a reference.

Table 2.
Operational performance rating scale based on the Sigma (Z) level

Sigma Range (z)	Performance classification
Z < 3,0	Poor
3,0 ≤ Z ≤ 3,5	Acceptable
3,5 ≤ Z ≤ 4,6	Outstanding
Z > 4,6	Excellent

Source: own elaboration.

RESULTS

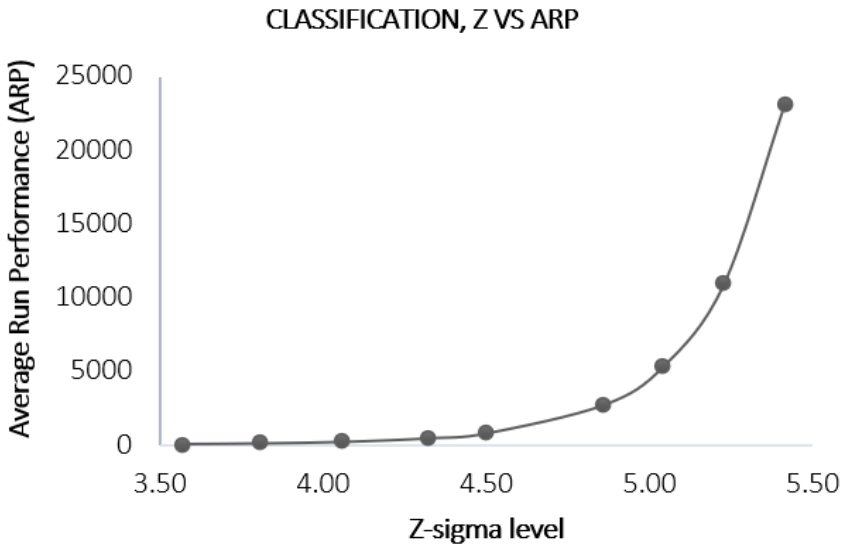
The following section details the results obtained during the analytical assessment of the logistics distribution system, with a focus on the implementation of the Six Sigma methodology. The first section analyzes the ARP curves for different

sigma levels (Z), allowing us to identify how processes behave under different levels of variability and quality control. Next, a control chart designed to monitor logistics operations is presented, along with key performance indicators. Finally, tables of results corresponding to the Six Sigma indicators determined for each phase of the distribution center are included, demonstrating improvements in efficiency and a reduction in errors.

Analysis - Average run performance (RPC) curves for each sigma (Z) level

In this analysis, the performance of processes within the logistics distribution system is evaluated through the implementation of Six Sigma metrics, focusing on the behavior of ARP curves, which make it possible to identify the variability and effectiveness of each process when operating at different sigma (Z) levels.

Figure 4.
Average run performance curve (ARP2) for each sigma level (Z2)



Source: own elaboration.

Figure 5.
Average run performance curve (ARP3) for each sigma level (Z3)

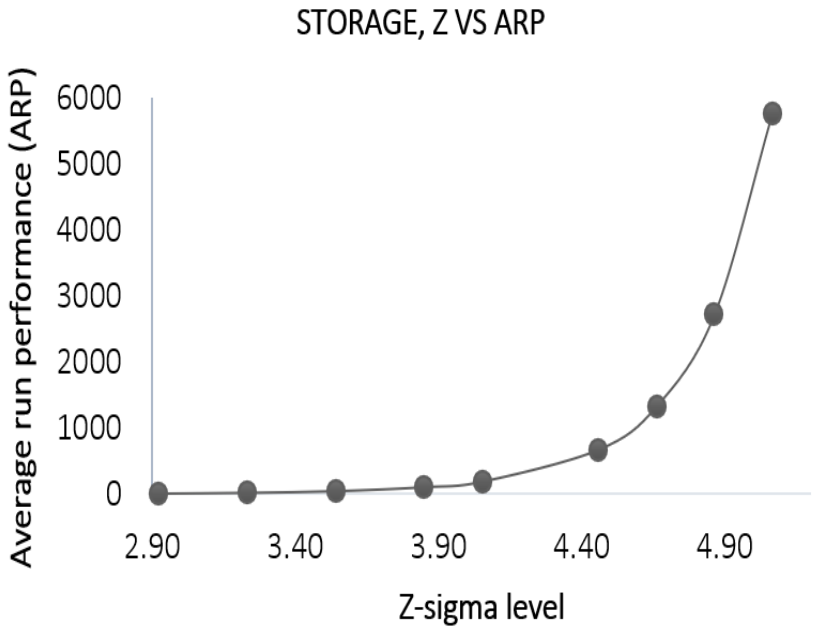


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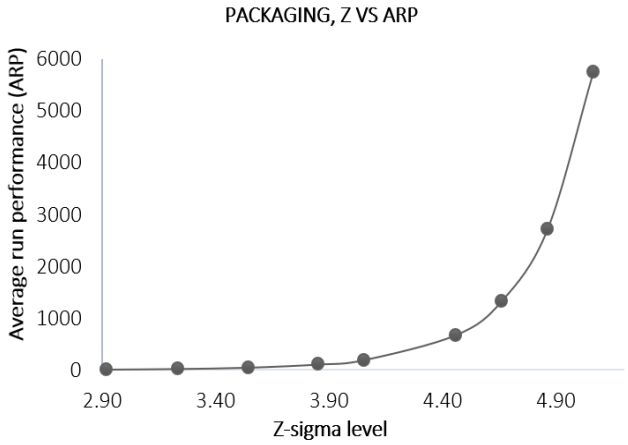
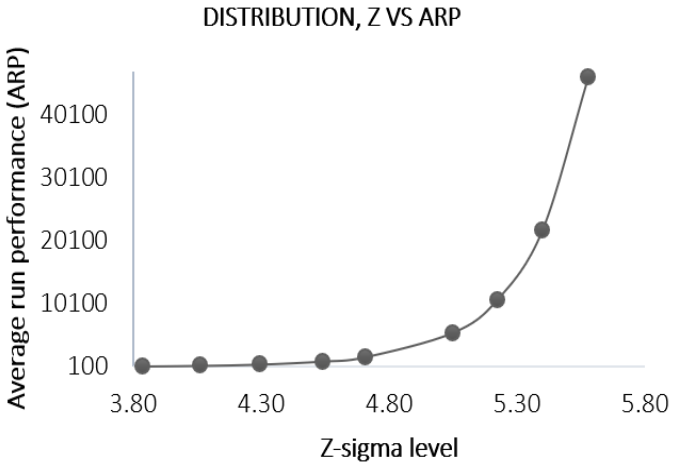
Figure 6.
Average run performance curve (ARP4) for each sigma level (Z4)



Source: own elaboration.

Figure 7.
Average run performance curve (ARP5) for each sigma level (Z5)



Source: own elaboration.

Figure 8.
Average run performance curve (ARP6) for each sigma level (Z6)

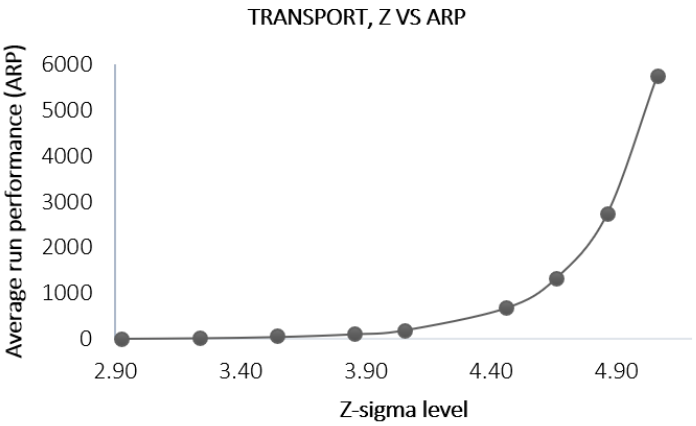


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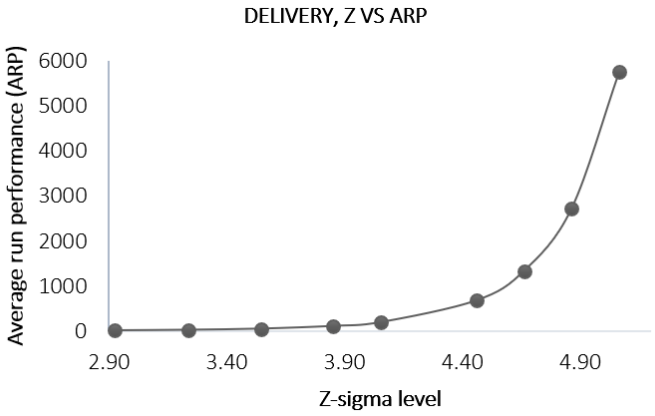
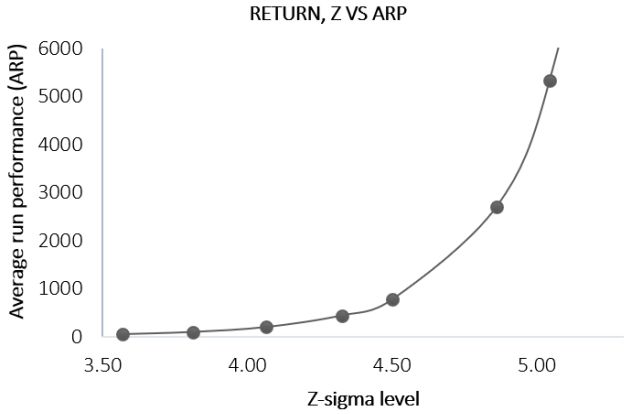
Figure 9.
Average run performance curve (ARP7) for each sigma level (Z7)



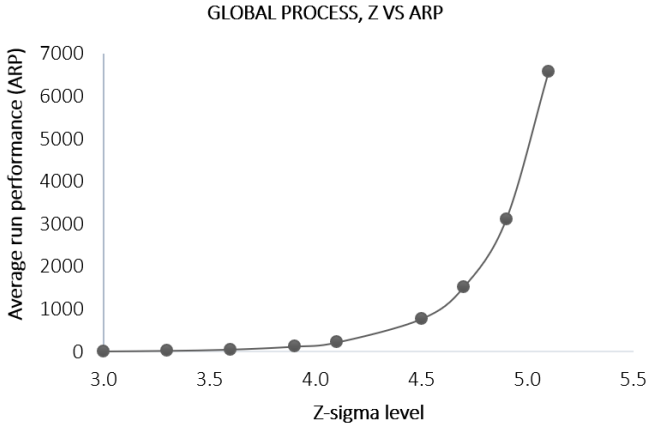
Source: own elaboration.

Figure 10.
Average run performance curve (ARP8) for each sigma level (Z8)



Source: own elaboration.

Figure 11.
Average run performance curve (ARPg) for each sigma level (Zg)



Source: own elaboration.

In the analysis of the processes within the logistics distribution system, it is observed that the Distribution process exhibits an ARP ranging from 107 to 46 064 units; this process shows the highest variability, requiring 45 957 units to Zii (excellent). Furthermore, the Classification and Returns processes show a similar ARL, with values ranging from 53

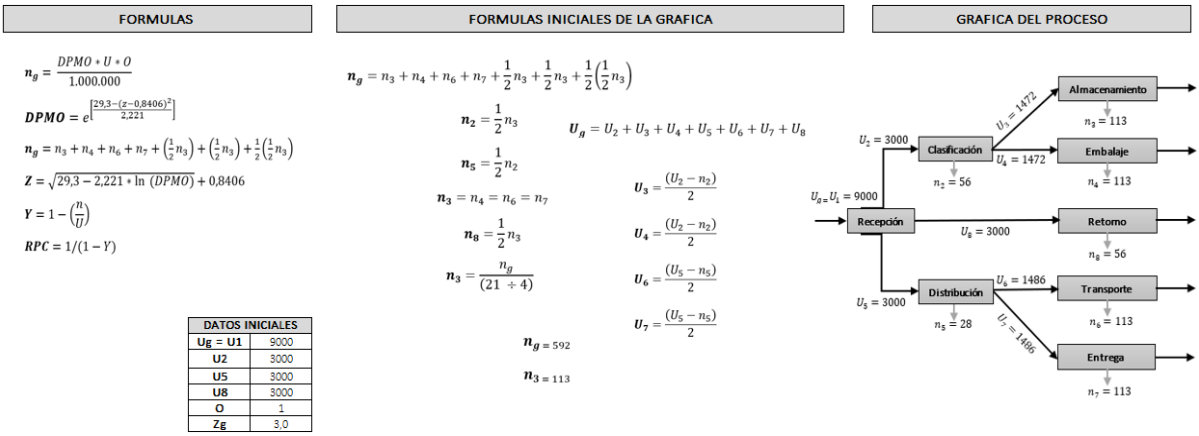
to 23 032 units, requiring 22 997 units to detect a shift between Zi (outstanding) and Zii (excellent) for these processes.

A similar pattern is observed in the Warehousing, Packaging, Transportation, and Delivery processes, which have an ARL ranging from 13 to 5 758 units—meaning 5 758 units are required to detect a shift between Zii (deficient) and Zii (excellent) in these processes. Finally, the overall process shows an ARL ranging from 15 to 6,581 units, requiring 6,566 units to detect a shift between Zii (acceptable) and Zii (excellent).

Logistics distribution operations system dashboard

Presented below is the control dashboard for the logistics distribution operations system, evaluated using performance indicators and charts based on Six Sigma metrics. These tools allow for the analysis of performance in terms of achieved quality, as well as the assessment of all processes under simulated Sigma-level (Z) scenarios—as illustrated in Figures 12 and 13. Furthermore, the calculations underlying these charts are presented, enabling an analysis of the following conditions.

Figure 12.
Operations dashboard



Source: own elaboration.
Note: the figure appears in its original language.

Figure 13.
Dashboard with graph calculations

TABLAS DE PROCESOS

PROCESO GLOBAL

n3	Zg	DPMOg	ng	Yg	RPC
112,6	3,0	65693	591	93,43%	15
60,3	3,3	35202	317	96,48%	28
29,8	3,6	17395	157	98,26%	57
13,6	3,9	7927	71	99,21%	126
7,7	4,1	4487	40	99,55%	223
2,2	4,5	1291	12	99,87%	775
1,1	4,7	656	6	99,93%	1525
0,6	4,9	321	3	99,97%	3111
0,3	5,1	152	1	99,98%	6581

CLASIFICACION

U2	Z2	DPMO2	n2	Y2	RPC
3000	3,57	18769	56	98,12%	53
3000	3,81	10058	30	98,99%	99
3000	4,06	4970	15	99,50%	201
3000	4,33	2265	7	99,77%	442
3000	4,50	1282	4	99,87%	780
3000	4,86	369	1	99,96%	2712
3000	5,05	187	1	99,98%	5337
3000	5,23	92	0	99,99%	10889
3000	5,41	43	0	100,00%	23032

ALMACENAMIENTO

U3	Z3	DPMO3	n3	Y3	RPC
1472	2,92	76514	113	92,35%	13
1485	3,23	40640	60	95,94%	25
1493	3,54	19979	30	98,00%	50
1497	3,85	9079	14	99,09%	110
1498	4,05	5135	8	99,49%	195
1499	4,46	1476	2	99,85%	678
1500	4,66	750	1	99,93%	1334
1500	4,86	367	1	99,96%	2722
1500	5,07	174	0	99,98%	5758

EMBALAJE

U4	Z4	DPMO4	n4	Y4	RPC
1472	2,92	76514	113	92,35%	13
1485	3,23	40640	60	95,94%	25
1493	3,54	19979	30	98,00%	50
1497	3,85	9079	14	99,09%	110
1498	4,05	5135	8	99,49%	195
1499	4,46	1476	2	99,85%	678
1500	4,66	750	1	99,93%	1334
1500	4,86	367	1	99,96%	2722
1500	5,07	174	0	99,98%	5758

DISTRIBUCION

U5	Z5	DPMO5	n5	Y5	RPC
3000	3,84	9385	28	99,06%	107
3000	4,06	5029	15	99,50%	199
3000	4,30	2485	7	99,75%	402
3000	4,54	1132	3	99,89%	883
3000	4,71	641	2	99,94%	1560
3000	5,05	184	1	99,98%	5424
3000	5,22	94	0	99,99%	10674
3000	5,40	46	0	100,00%	21778
3000	5,58	22	0	100,00%	46064

TRANSPORTE

U6	Z6	DPMO6	n6	Y6	RPC
1486	2,93	75789	113	92,42%	13
1492	3,24	40435	60	95,96%	25
1496	3,54	19930	30	98,01%	50
1498	3,85	9069	14	99,09%	110
1499	4,05	5131	8	99,49%	195
1500	4,46	1475	2	99,85%	678
1500	4,66	750	1	99,93%	1334
1500	4,86	367	1	99,96%	2722
1500	5,07	174	0	99,98%	5758

ENTREGA

U7	Z7	DPMO7	n7	Y7	RPC
1486	2,93	75789	113	92,42%	13
1492	3,24	40435	60	95,96%	25
1496	3,54	19930	30	98,01%	50
1498	3,85	9069	14	99,09%	110
1499	4,05	5131	8	99,49%	195
1500	4,46	1475	2	99,85%	678
1500	4,66	750	1	99,93%	1334
1500	4,86	367	1	99,96%	2722
1500	5,07	174	0	99,98%	5758

RETORNO

U8	Z8	DPMO8	n8	Y8	RPC
3000	3,57	18769	56	98,12%	53
3000	3,81	10058	30	98,99%	99
3000	4,06	4970	15	99,50%	201
3000	4,33	2265	7	99,77%	442
3000	4,50	1282	4	99,87%	780
3000	4,86	369	1	99,96%	2712
3000	5,05	187	1	99,98%	5337
3000	5,23	92	0	99,99%	10889
3000	5,41	43	0	100,00%	23032

Source: own elaboration.
Note: the figure appears in its original language.

Following the application of Six Sigma (Z) metrics to the processes within the logistics distribution system, it is evident that the Warehousing and Packaging processes exhibit defect rates—measured as defects per million opportunities (DPMO)—ranging from 76,514 to 174; these processes show the highest values on the model's deviation scale. The Distribution process recorded DPMO values ranging from 9,385 to 22, making it the operation with the lowest error rate in the entire system. Regarding the overall process, DPMO values vary between 65,693 (indicating a low-quality level, prone to errors) and 152 (representing a superior quality level, though still with room for optimization).

As for non-conformities (n), the Classification and Returns processes show the same range, varying between 56 and 0 non-conformities. A similar pattern is observed in the Warehousing, Packaging, Transportation, and Delivery processes, where the number of non-conformities ranges from 113 to 0. The Distribution process stands out for having the lowest number of non-conformities, ranging from 28 to 0. Finally, the overall process shows a number of non-conformities ranging from 591 to 1.

Regarding performance (Y), the Warehousing and Packaging processes initially showed performance values between 92.35% and 99.96%, representing the lowest performance levels within the system. Similarly, the Transportation and Delivery processes showed performance values between 92.42% and 99.98%. Subsequently, in the Classification and Return processes, better performance is observed, with values ranging from 98.12% up to 100%. Meanwhile, the Distribution process exhibits the best performance within the system, with values varying between 99.06% and 100% across the different Z levels. Finally, the overall process showed performance levels ranging from 93.43% to 99.98% (indicating a high level of performance, though with areas that still offer room for improvement).

Consolidation of results associated with the estimated Six Sigma metrics in the different phases of the logistics distribution center

Tables 3 and 4 are presented below, showing the relationship between various key variables of the logistics distribution system at different sigma (Z) levels. This information allows for an examination of the specific dynamics of operations and the consolidated structure, facilitating a deeper understanding of overall performance.

Given that the Receiving process (process 1) exhibits a complete absence of non-conformities (n), the concept of operating curves does not apply. Consequently, this process will not be included in analyses concerning operating characteristic curves for defects per million opportunities (DPMO), yield Y, and ARP for sigma (Z) levels.

Table 3.
Minimum operational capability thresholds by sub-process, based on Six Sigma metrics

Process	Z_i	$DPMO_i$	n_i	Y_i	ARP_i	Performance
Global	3.0	65693	56	93.43%	15	Acceptable
Classification	3.57	18769	56	98.12%	53	Outstanding
Storage	2.92	76514	113	92.35%	13	Poor
Packaging	2.92	76514	113	92.35%	13	Poor
Distribution	3.84	9385	28	99.06%	107	Outstanding
Transportation	2.93	75789	113	92.42%	13	Poor
Delivery	2.93	75789	113	92.42%	13	Poor
Returns	3.57	18769	56	98.12%	53	Outstanding

Source: own elaboration

Table 4.
Maximum operational capacity thresholds per sub-process based on Six Sigma metrics

Process	Z_{ii}	$DPMO_{ii}$	n_{ii}	Y_{ii}	ARP_{ii}	Performance
Global	5.1	152	1	99.98%	6581	Excellent
Classification	5.41	43	0	100.00%	23032	Excellent
Storage	5.07	174	0	99.98%	5758	Excellent
Packaging	5.07	174	0	99.98%	5758	Excellent
Distribution	5.58	22	0	100.00%	46064	Excellent
Transportation	5.07	174	0	99.98%	5758	Excellent
Delivery	5.07	174	0	99.98%	5758	Excellent
Returns	5.41	43	0	100.00%	23032	Excellent

Source: own elaboration

The findings derived from the implementation of Six Sigma statistical control within the overall logistics distribution structure indicate that Sigma Z quality levels vary considerably, ranging from a minimum of 2.92 to a maximum of 5.58—meaning that quality performance spans from "Poor" to "Excellent."

An individual analysis of the processes reveals similarities between the "Sorting" and "Returns" processes; these yielded Z-values ranging from 3.57 to 5.41, corresponding to a performance level between "Outstanding" and "Excellent." The "Warehousing" and "Packaging" processes show Sigma values between 2.92 and 5.07, with performance varying from "Poor" to "Excellent." The "Transportation" and "Delivery" processes have Sigma values ranging from 2.93 to 5.07, representing "Poor" and "Excellent" performance, respectively.

The "Distribution" process stands out, with Sigma levels between 3.84 and 5.58, corresponding to performance levels ranging from "Outstanding" to "Excellent." This variation affects the number of defects per million opportunities (DPMO), which ranges from 22 to 76,514; notably, this process exhibits the fewest deviations under this metric, recording a minimum of just 22 defects per million. Meanwhile, the Sigma levels for the overall process fluctuate between 3.0 and 5.1, representing "acceptable" and "excellent" performance, respectively. Furthermore, a significant reduction in the volume of non-conformities (n) has been observed across most processes. Specifically, the "Warehousing," "Packaging," "Transportation," and "Delivery" processes saw their non-conformities drop from a maximum of 113 to zero, effectively reaching the system's optimal capacity with zero defective units. Regarding the yield (Y) of the processes evaluated, a range of 92.35% to 100.00% is observed. The distribution process stood out by reaching a maximum yield of 100%; for the overall process, the yield ranges from a minimum of 93.43% to a maximum of 99.98%.

The findings indicate that the Sigma Z yield levels within the logistics distribution system show considerable variability, ranging from 2.92 to 5.58. This suggests that process performance varies from "deficient" to "excellent." Notably, the distribution process achieves a maximum Sigma (Z) level of 5.58, indicating "excellent" performance—a significant result given the specific subject of this study.

Furthermore, it has been identified that the number of defects per million opportunities (DPMO) in the distribution process is the lowest, at 22 DPMO. This highlights the effectiveness of this process compared to others—such as storage and packaging—which exhibit significantly higher defect rates, ranging from 174 to 76,514.

A positive correlation is also observed between system yield (Y) and the sigma level (Z), suggesting that as the sigma level (Z) increases, performance improves. Additionally, it is evident that as the sigma level (Z) rises, the number of non-conformities (n) decreases; this indicates that higher quality levels result in fewer non-conformities, with some processes reaching a state of zero defective units.

Ultimately, the examination of ARP curves demonstrates that the volume of units indispensable for detecting changes in performance varies between different processes. For example, the distribution process requires more units to detect the change between Z (outstanding) and Z (excellent), while others, such as packaging and delivery, require fewer. Table 4 and the corresponding ARP curves further reveal that the distribution process is the least sensitive when it comes to registering fluctuations in its Z-level performance. Conversely, the storage, packaging, transport, and delivery processes exhibit significantly greater sensitivity to variations in their quality parameters. In this context, the ARP curve provides criteria for prioritizing strategies aimed at optimizing the system under monitoring and control, based on its sensitivity to detecting changes in the Z-level of the process being analyzed.

DISCUSSION

Based on the results of this research and in alignment with the stated objectives, the relevance of a comprehensive statistical quality control system is evident; it enabled a thorough and specific evaluation of the various processes within the logistics system under study. Furthermore, this system revealed that distribution was the best-performing process, while storage, packaging, transport, and delivery were the lowest-performing areas. A significant contribution of this research lies in the developed method, which treats the logistics system as a whole. By employing an integrated dashboard—incorporating Six Sigma metrics, their corresponding operating characteristic curves, and ARP performance curves—the method allows for the systematic control and evaluation of the entire system. From the perspective of statistical quality control, this approach is innovative.

In the existing scientific literature, there are various studies on logistics across different organizational contexts. One specific example is the work of Şişman (2023), who applied the Six Sigma approach to improve logistics systems, optimizing the supply chain and significantly reducing transport costs and other expenses within the plastics industry. This resulted in both cost savings and a reduction in plastic waste. However, while the author focused on minimizing defects and expenses, the study did not analyze how Z-performance levels shift under varying conditions—an aspect addressed in the present research through the use of ARP curves for Six Sigma metrics. This approach enables not only

the measurement but also the control of variations in Z-performance levels across processes. Consequently, it facilitates the prioritization of improvement initiatives and allows for targeted interventions based on the sensitivity level of each process.

Similarly, research by Panayiotou & Stergiou (2023) aimed to develop a model to help identify improvements in the supply chain operations of a retail firm through the implementation of Six Sigma. Its purpose was to optimize commercial logistics flow, providing a comprehensive guide for applying Six Sigma within the retail sector—a field of great economic significance. Furthermore, by utilizing an integrated statistical control system and a balanced scorecard, this research offers a set of quantitative and graphical metrics—applicable to this operational system or any other employing this methodology—that enable quality managers within organizations to take action toward quality improvement. Likewise, the study provides tools to measure the maximum and minimum capabilities of each process, thereby allowing for the control of variations in the Z-level of quality.

The study by Ramires & Sampaio (2022) explores the benefits of applying Six Sigma and process mining to supply logistics, with the aim of identifying and correcting operational errors. Although this research does not use operating characteristic curves to evaluate the system, it differs from the present study by introducing the analytical power of process mining to raise quality standards within supply flows. Similarly, other authors, such as Samaranayake et al. (2024), evaluated the implementation of Six Sigma to address issues in logistics processes. This tool enabled the isolation and resolution of critical deviations within the distribution channel, resulting in the minimization of waste. However, a distinguishing feature of the current research—unlike the aforementioned studies, which primarily evaluate quality on a point-in-time or isolated basis—is the development of a comprehensive statistical monitoring framework. This framework integrates multiple univariate statistical process control tools to evaluate and monitor a logistics system from a holistic perspective, accounting for variable performance levels (Z-scores). This represents a novel contribution to the field and is replicable in any other operational system.

Furthermore, the very design of this study and the proposed method allow for the structuring of a statistical control system and the establishment of an overall assessment of defects within the system. This enables the evaluation of the system under study and its subsequent control through the statistical tools. This research bridges a gap by offering a new approach to using statistical control tools—moving beyond traditional methods, where quality techniques are typically applied to specific, individual characteristics or processes, rather than in the comprehensive and systematic manner proposed here.

CONCLUSIONS

As a theoretical contribution, this basic-applied research integrates concepts from logistics distribution center systems, Six Sigma parameters, and ARP modeling. This approach is designed to identify variations in the quality performance levels of logistics processes under changing conditions, thereby strengthening real-time decision-making, optimizing outcomes, and minimizing defects or errors—a critical aspect of this industry. Consequently, a methodology based on ARP is highly relevant in today's competitive environment for logistics distribution centers; these organizations operate in a landscape of constant change, where high-quality standards are required, necessitating tools, methods, and models that enable the effective evaluation of process performance.

As a practical and distinctive contribution, this research employs Six Sigma metrics and ARP curves to assess the capabilities of a logistics distribution center. By adjusting these to different Sigma (Z) levels, the study analyzes how the system responds to variable conditions. It calculates the number of service instances required to detect such variations, demonstrating an efficient and innovative methodology. This approach allows for the measurement of performance dispersion—both globally and at the individual process level—within a logistics distribution center, providing a clear advantage for decision-making.

Specifically, the application of the Six Sigma methodology and the analysis of ARP curves reveal that processes such as distribution require a larger number of units to detect a shift between Zi (outstanding) and Zii (excellent). In contrast, processes like packaging or delivery require fewer units to detect a shift between Zi (deficient) and Zii (excelente). (excellent). These findings confirm the validity of the methodology and its effectiveness in accurately measuring logistics processes.

As a potential limitation or requirement for replicating the proposed method in any other organizational context, it is important to establish a standardized data collection system so that the information used to evaluate the system is dimensionally integrated from a systematic perspective, in accordance with the mathematical model of the proposed statistical quality control system.

The scientific community is invited to utilize the ARP curves—introduced and analyzed in this research—in future studies and logistical contexts. These curves serve as a valuable tool for logistics distribution centers and various production systems where the measurement and control of defects are essential. They enable the assessment of a company's control system quality, providing a basis for making improvement-related decisions while accounting for the variable operating conditions of the system under analysis.

REFERENCES

Ascón, J. E. G., Natividad, R. o. S., Sotelo, J. F. A., Alegre, L. R. R., Pittman, J. A. A., Loza, A. D. M. B., & Tiznado, M. D. P. (2022). Six Sigma and improvement of the logistics process in the construction retail industry. *Proceedings Of The 20th LACCEI International Multi-Conference For Engineering, Education And Technology: "Education, Research And Leadership In Post-pandemic Engineering: Resilient, Inclusive And Sustainable Actions"*. https://doi.org/10.18687/laccei2022.1.1.789

Balza Franco, V., Paternina Arboleda, C., & Cardona Arbeláez, D. (2019). Prácticas colaborativas en la cadena de suministro: una revisión conceptual. *Saber, ciencia y libertad, 14*(2), 77-101. https://www.redalyc.org/articulo.oa?id=736980319005

Benavides, M. R. C., Cortés, J. A. Z., & Barrios, N. R. (2026). Models for risk management in the procurement process within organizational contexts: A systematic literature review. *Multidisciplinary Reviews, 10*(2), 2027101. https://doi.org/10.31893/multirev.2027101

Bharath, A. A., & Shankar, M. G. (2020). Developing a framework for economically improving the quality of a construction process by Six Sigma. *International Journal Of Six Sigma And Competitive Advantage, 12*(2-3), 294-312. https://doi.org/10.1504/IJSSCA.2020.110978

Delahoz-Domínguez, E., Zuluaga-Ortiz, R., Periñan-Luna, A., & Mendoza-Brand, S. (2022). Un enfoque de Seis Sigma para evaluar la calidad de la educación superior en Colombia. *Revista De Métodos Cuantitativos Para La Economía Y La Empresa, 33*, 386–407. https://doi.org/10.46661/revmetodoscuanteconempresa.5313

Fontalvo Herrera, T. J., Banquez Maturana, A. G., & Mendoza Villero, K. (2024). Performance of a concurrent parallel production system through new operating curves of Six Sigma metrics. *Production, 34*, e20230040. https://doi.org/10.1590/0103-6513.20230040

Fontalvo Herrera, T. J., Delahoz-Domínguez, E. J., & Barrios, N. R. (2026). Evaluation and Prediction Methods for a Steel Company Using Six Sigma Metrics, Capability Indicators, and Markov Chains. *Eng*, *7*(8), 383. https://doi.org/10.3390/eng7080383

Fontalvo Herrera, T., Mejia Zambrano, F., & Oyuela Rodríguez, G. (2024). Evaluación con curvas de operación de métricas seis sigma el desempeño de sistemas productivos mixtos. *Investigación E Innovación En Ingenierías, 12*(1), 1–12. https://doi.org/10.17081/invinno.12.1.6680

Fontalvo-Herrera, T., Morelos-Gómez, J., & Simancas-Caicedo, S. A. (2025). Evaluación del desempeño de un sistema de transporte de pasajeros y carga mediante curvas de operación, métricas Seis Sigma y un indicador de capacidad geométrico multivariable. *Saber, Ciencia y Libertad*, *20*(2), 343-373. https://doi.org/10.18041/2382-3240/saber.2025v20n2.13214

Garcia Ramos, K. E., & Pareja Huacausi, J. M. (2021). *Análisis de experiencias de la metodología Six Sigma en las organizaciones en los últimos diez años. Una revisión de la literatura*. https://hdl.handle.net/11537/27705

Gutiérrez, J. N. M., Saldivar, D. O., Chumacero, S. M. Q., Cuadros, M. J. L., Curo, G. G., & Dumont, J. R. D. (2021). Estrategia de mejora de procesos Six Sigma aplicado a la industria textil. *Revista De Investigación Científica Y Tecnológica Alpha Centauri, 2*(3), 72–90. https://doi.org/10.47422/ac.v2i3.45

Kumar, S., & Khanduja, D. (2021). Cost of poor quality reduction in auto sector: an exploration with Six-Sigma. International Journal of Six Sigma and Competitive Advantage, *13*(1-3), 271-288. https://doi.org/10.1504/IJSSCA.2021.120249

Kumar, S., Brahma, G., Kaur, P., & Gupta, B. K. (2020). A case study on quality improvement of connecting rod assembly line using Six Sigma DMAIC cycle. *International Journal Of Six Sigma And Competitive Advantage, 12*(2-3), 234-249. https://doi.org/10.1504/ijssca.2020.110982

Luna Amador, J. A. (2021). Implementación de la metodología Sigma Seis como herramienta de gestión en el proceso de manejo de equipajes en una aerolínea en la ciudad de Cartagena. *Revista De Jóvenes Investigadores AD Valorem*, *4*(2), 103–120. https://doi.org/10.32997/RJIA-vol.4-num.2-2021-3703

Markowski, T., & Bilski, P. (2021). Optimization of Autonomous Agent Routes in Logistics Warehouse. *International Journal Of Electronics And Telecommunications*, *67*(4), 559-564. https://doi.org/10.24425/ijet.2021.137846

Mendoza, L. P., & Suarez, E. V. (2023b). Lean Six Sigma como herramienta de apoyo en la logística empresarial. Una Revisión Sistemática de la Literatura. *Boletín De Innovación, Logística Y Operaciones, 5(2), 50–61*. https://doi.org/10.17981/bilo.5.2.2023.05

Mittal, S., Khan, M. A., Purohit, J. K., Menon, K., Romero, D., & Wuest, T. (2019). A smart manufacturing adoption framework for SMEs. *International Journal Of Production Research*, *58*(5), 1555-1573. https://doi.org/10.1080/00207543.2019.1661540

Panayiotou, N. A., & Stergiou, K. E. (2023). Development of a retail supply chain process reference model incorporating Lean Six Sigma initiatives. *International Journal Of Lean Six Sigma*, *14*(1), 209-251. https://doi.org/10.1108/ijlss-04-2021-0079

Pano Nava, C. M., Núñez Piña, F., Zapien Rodríguez, J. M., Lazcano Cortes, G., & Núñez Pérez, F. A. (2022). Lean six sigma para solución de problemas logísticos: caso real terminal de contenedores en Michoacán. *Ciencia Latina Revista Científica Multidisciplinar*, *6*(1), 511-529. https://doi.org/10.37811/cl_rcm.v6i1.1515

Pinilla, J. C., Navarrete, F. N., Vergara, K. L., Campos, J. G., Navarrete, T., & Acevedo, J. S. C. (2021). Aplicación de la metodología seis sigma para mejorar la calidad de la estimación de densidad básica de la madera en Acacia mearnsii. *Ciencia & Investigación Forestal, 27*(1), 19–42. https://doi.org/10.52904/0718-4646.2021.470

Purba, H. H., Nindiani, A., Trimarjoko, A., Jaqin, C., Hasibuan, S., & Tampubolon, S. (2021). Increasing Sigma levels in productivity improvement and industrial sustainability with Six Sigma methods in manufacturing industry: A systematic literature review. *Advances in Production Engineering & Management*, *16*(3), 307-325. https://doi.org/10.14743/apem2021.3.402

Ramires, F., & Sampaio, P. (2022). Process mining and lean six sigma: a novel approach to analyze the supply chain quality of a hospital. *International Journal Of Lean Six Sigma*, *13*(3), 594-621. https://doi.org/10.1108/ijlss-12-2020-0226

Ramírez Pérez, J. F., López Torres, V. G., Hernández Castillo, S. A., & Morejón Valdés, M. (2021). Lean six sigma e industria 4.0, una revisión desde la administración de operaciones para la mejora continua de las organizaciones: lean six sigma e industria 4.0 en la administración de operaciones. *UNESUM - Ciencias. Revista Científica Multidisciplinaria*, *5*(4), 151–168. https://doi.org/10.47230/unesum-ciencias.v5.n4.2021.584

Robledo-Fernández, J. C., del Carmen Angulo-Vásquez, M., & Cardona-Arbelaez, D. (2025). La Socialización Organizacional como Pilar para la Gestión del Conocimiento en Entidades Promotoras de Salud: Caso Mutualser EPS. *Saber, Ciencia y Libertad*, *20*(1), 315-338. https://doi.org/10.18041/2382-3240/saber.2025v20n1.13166

Sáenz, L., Aguilera, K., Heredia, R., Romero, T., Donoso, C., & Singaña, M. (2021). Fragilización de aceros inoxidables dúplex SAF 2205 y SAF 2507 sometidos a tratamientos térmicos de envejecimiento artificial. *Revista Ingeniería UC, 28*(1), 121–128. https://doi.org/10.54139/revinguc.v28i1.7

Samaranayake, P., McLean, M. W., & Weerabahu, S. K. (2024). Application of lean and quality improvement methods for improving operational performance in coal supply chains: a case study. *International Journal of Quality & Reliability Management*, *41*(6), 1594-1622. https://doi.org/10.1108/IJQRM-04-2023-0138

Sharma, J., Tyagi, M., Panchal, D., & Singh, R. P. (2022). Contemplation of food industry attributes confronted in smooth adoption of Lean Six Sigma practices. *International Journal Of Six Sigma And Competitive Advantage, 14*(1), 32-69. https://doi.org/10.1504/IJSSCA.2022.124294

Singh, M., & Rathi, R. (2020). Investigation of critical success factors associated with Lean Six Sigma implementation in MSMEs using best worst method. *International Journal of Six Sigma and Competitive Advantage*, *12*(2-3), 209-233. https://doi.org/10.1504/IJSSCA.2020.110976

Şişman, G. (2023). Implementing Lean Six Sigma methodology to reduce the logistics cost: a case study in Turkey. *International Journal Of Lean Six Sigma*, *14*(3), 610-629. https://doi.org/10.1108/ijlss-02-2022-0054

Veena, T., & Prabhushankar, G. (2020). Identification of Critical Success Factors for implementing Six Sigma methodology and grouping the factors based on ISO 9001:2015 QMS. *International Journal Of Six Sigma And Competitive Advantage, 12*(1), 1-19. https://doi.org/10.1504/IJSSCA.2020.107463

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