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Research Article

Performance of a concurrent parallel production system through new operating curves of Six Sigma metrics

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Abstract

Paper aims: This research establishes a method to evaluate a concurrent production system in parallel, through new operating curves of six sigma metrics.

Originality: Se proposes a novel method that provides criteria to monitor the performance of a production system in changing production conditions.

Research method: This research was approached from a logical positivist epistemological model, through a heuristic analysis and with a rational propositional approach to establish the characterization of the model, the evaluation metrics and propose the new operation curves.

Main findings: The results obtained show that as the sigma level increases in the global system (4.17), the level of defects per million opportunities decreases considerably and the performance increases at levels close to the main objective of Six Sigma, all this with a decrease of defects from 20.657 to 1.317, generating a high quality of 99.99% and achieving a good performance according to the established quality criteria.

Implications for theory and practice: This research provides a new tool where they articulate concepts of six sigma and operating curves to monitor a productive system, which allows in a practical way to determine the real capabilities in terms of quality performance of a system.

Keywords

Six sigma. Parallel production system. Quality. Performance.

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1. Introduction

Analyzing today the reasons why companies fiercely compete for markets involves delving into the business context and studying the landscape regarding what we conceive as quality, which has changed over time and remains in constant evolution (Fontalvo Herrera et al., 2022b). Furthermore, when increasing the efficiency and effectiveness of productive processes or services is a constant objective of productive companies (Rojas-Martínez et al., 2020). Therefore, it becomes necessary to eliminate unexpected defects that generate excessive costs and production losses (Antosz et al., 2022), highlighting that these failures can be reduced by improving production system processes (Sharma et al., 2019a). Now, quality in products and services refers to conformity with established standards and specifications, as well as the ability to consistently and efficiently meet the needs and expectations of customers (Martin et al., 2020, 2021; Banquez Maturana & Fontalvo Herrera, 2023). It involves minimizing defects, process optimization, and continuous improvement to ensure that the delivered product or service meets previously defined requirements (Redman & Hoerl, 2023).

In this line of thought, its importance lies in its direct impact on customer satisfaction, the company's reputation, and its competitiveness in the market (Aguilar et al., 2020; Skalli et al., 2022). That's why the constant pursuit of quality contributes to customer loyalty, reducing operating costs, increasing efficiency, and ultimately, the sustainable success of the organization (Izquierdo Espinoza, 2021; Terán Ayay et al., 2021). In line with this, the relevance of evaluating the performance of a concurrent parallel production system through Six Sigma metrics operation curves and observing its performance in terms of sigma Z level lies in providing criteria and assessments of the maximum and minimum capabilities for producing with quality in the system and its subprocesses. Also, when reviewing the scientific and productive context in terms of statistical control, there is no observation of the application of Six Sigma metrics under variable conditions and the operation curves generated by it to study a concurrent parallel production system. Therefore, this research constitutes a new and innovative contribution to evaluating a productive system in terms of quality, making it possible to determine the Z-quality performance level of the productive system and the processes that compose it, as well as the operation curves (CO) that allow evaluating the production of a good or service under changing conditions.

In light of the aforementioned, the following questions arise for the development of this research: How can we evaluate the performance of a concurrent parallel production system measured by Six Sigma metrics under variable conditions? How can we propose the operation curves for the overall production process and the independent processes using Six Sigma metrics? How can we analyze the quality performance of the production system and processes under variable conditions to determine, for a given quality performance level Z, its effect on performance Y, the defects per million opportunities (DPMO), and the quality defects (n)? To address these research questions, the overall objective of this research is to "evaluate the performance of a concurrent parallel production system through new Six Sigma metric operation curves." This overarching objective leads to the following specific objectives: (i) Evaluate the performance of a concurrent parallel production system measured by Six Sigma metrics under variable conditions. (ii) Propose the operation curves for the overall production process and the independent processes using Six Sigma metrics. (iii) Analyze the quality performance of the production system and processes under variable conditions to determine, for a given quality performance level Z, its effect on performance Y, the defects per million opportunities (DPMO), and the quality defects (n). The development of this research was given from a conception heuristic that allowed to establish the operational assumptions of the productive system, then proceeded to calculate the metrics of six sigma, then through a sensitivity analysis of the level of performance Z continued to propose the new curves of operation of the function of the metrics of six sigma. This allowed to establish the capacities of each process.

2. Theoretical framework

2.1. Evaluation of the quality of a production system

In the present day, quality has evolved into a pivotal factor in satisfying an ever-more demanding customer base. This necessitates the development of frameworks and criteria designed to assess the performance level of this quality within production systems, in this regard, production systems play a fundamental role in manufacturing. As per Fernandes et al. (2023), a system is a set of components that interact to achieve a specific goal, with a focus on minimizing defects for end-users. Therefore, this necessitates the development of a logically ordered and sufficiently coherent set of procedures to govern the functioning of the whole. Thus, it is imperative to employ quality assessment as an essential tool in attaining operational efficiency and, ultimately, performance (Kansara, 2020). In this context, one of the tools employed by companies is the Six Sigma methodology, which arises from the need to enhance product and/or service quality in the face of competitors, reducing defects per million, improving the Sigma Z level, and increasing performance (Fontalvo Herrera et al., 2022b). Consequently, manufacturing and service organizations continually refine their processes for improved operational performance, using Six Sigma (Gupta et al., 2019; Sodhi, 2023). However, it is essential to measure the quality and performance of these production processes, enabling organizations to make improvements through the analysis of defects per million opportunities (DPMO) and their corresponding achievement levels in Sigma Z and performance Y (Fontalvo Herrera et al., 2022a). The focus of this tool is based on ascertaining customer satisfaction by measuring and utilizing equipment that allows for the continuous reduction of the number of errors in millions per measurement—a highly precise technique for quality control. Taking as a fundamental premise the measurement of how many defects or errors occur in a process, to explore different systematic ways of eliminating them.

2.2. Six sigma metrics for evaluating a product system

In line with the previously discussed strategies for achieving optimal quality performance in systems and processes, various methodologies exist for assessing the quality of these production systems. Six Sigma and its metrics serve as a tool that relies heavily on statistical analysis to establish a process's capability to reach a specific level of quality (Fontalvo Herrera & Banquez Maturana, 2023). It consistently allows for the evaluation of criteria such as performance (Y), the quality performance level (Z), defects per million opportunities (DPMO), and defects (n). These authors have pointed out that the quality performance level Z of Sigma measures the improvement capacity of a system, process, or quality dimension. The higher the Z level, the better the achievements of the system or the analyzed quality characteristic (Pacheco, 2014; Sharma et al., 2019b; Kumar et al., 2020). It is worth noting that the Six Sigma methodology is grounded in data analysis and metrics to reduce process variation and enhance its stability, prioritizing processes and variables significant to the company (Simanová et al., 2019; Kumar & Khanduja, 2021). Its primary objective is to increase the Sigma level to achieve a product or service quality that results in no more than 3.4 defects per million opportunities (DPMO), reflecting an excellent performance level of one or 100% (Qayyum et al., 2021; Mishra et al., 2021). Furthermore, Six Sigma serves as a tool to enhance process efficiency and significantly reduce product defects, thus contributing to bolstering the company's competitiveness in the market by increasing customer satisfaction through dependable products or services (Patel & Patel, 2021).

Furthermore, it has a favorable impact on the organization's productivity by effectively reducing defects, thereby enabling a reduction in non-quality costs. This, in turn, translates into a positive effect on the financial standings of the companies that implement it (Lokesh et al., 2020). It is worth noting that representing qualitative results in terms of sigma simplifies the analysis of these outcomes (Fontalvo Herrera et al., 2022a), which proves beneficial for prioritizing and developing improvement strategies. Additionally, it allows for an objective comparison of process performance regardless of the type of operation. Additionally, the incorporation of Six Sigma swiftly identifies processes in need of significant change based on their weaknesses and aids in selecting processes requiring immediate resolution to effect improvements that positively impact quality (Mishra et al., 2021).

2.3. Parallel production system

In order to assess the quality performance using Six Sigma metrics, the features and operational conditions of a parallel production system are analyzed. In this context, Hadipour et al. (2019) emphasize that to establish a reliable production system, parallel systems offer operational benefits by comprising different subsystems. This safeguarding the system against failures in one of its components. Therefore, parallel systems consist of multiple lines situated in such a way as to enhance system efficiency through the use of shared resources (Aguilar et al., 2020). Integrating these parallel work lines is a common and practical approach for addressing bottlenecks and balancing assembly lines. It is worth noting that this manufacturing practice often results in increased production capacity and meeting production deadlines that would otherwise be unattainable (Russell & Taghipour, 2020). Hence, parallel production systems are gaining popularity as subsystems within Industry 4.0, particularly when employing robots due to their enhanced rigidity, load-to-weight ratio, and dynamic properties. It is relevant to mention that the use of series-parallel systems leads to hybrid series-parallel robots, which are more challenging to model and control than series or tree-type systems (Mronga et al., 2022). This technique brings about the benefit of improved control, coordination, and reduced manufacturing times or task completion, as well as a more responsive adaptability when making product changes based on demand fluctuations.

2.4. Six sigma operating curves

In accordance with the measurement of the quality of the concurrent system in parallel, the operating curve is a tool that allows to evaluate the performance of the quality level of the process or system under variable conditions. These curves are statistical analysis and graphical representations that enable an analysis to understand the relationship of metrics and defects generated in a production line for varying conditions of the sigma Z quality performance level. In addition, they significantly facilitate the ability to visualize and understand how quality metrics behave in relation to a wide range of Z performance levels in a given process or system. This set of criteria makes the operating curves a useful tool for analyzing the production line or service provision when the quality Z performance level changes, which is used to manage and improve the quality of products or services in an organization. The operating curves consider the level of quality performance Z of each process, in variable conditions in the range of 0 to 6 and contrast this level Z with the different metrics generated for the process under study, such as defects in parts per million opportunities (DPMO), yield (Y) and defects (n) that are generated within the production process.

Fontalvo Herrera et al. (2022a) and Singh & Mahendru (2021), applied Six Sigma metrics in the evaluation of production systems and were able to demonstrate the impact of changing the quality performance level Z on defects (n), defects in parts per million opportunities (DPMO) and yield (Y). With great clarity, their research shows that as performance level Z increased, defects in parts per million DPMO decreased significantly, while yield Y increased. Likewise, authors Fontalvo Herrera et al. (2022b) observed a similar pattern of behavior when they employed Six Sigma metrics in conjunction with multivariable statistical control tools, such as control chart and multivariable quality capability indicators, as detailed in their paper entitled "Three-phase method for evaluating logistics service using Six Sigma metrics, Hotelling's T-squared control chart and a multivariable capability indicator." In summary, the operation curves of the Six Sigma metrics constitute a valuable tool in the evaluation and improvement of quality in an organization by being able to determine the maximum and minimum performance capacity of a process in terms of the variable Z quality level, and its effect on the defects (n), yield (Y) and defects in part per million (DPMO) of a global system or a process. Thus, these curves make it possible to establish maximum and minimum Z-quality performance capabilities in organizations and their processes and thus to make statistically supported decisions and consequently to effectively and accurately improve production or service delivery conditions to reduce defects.

3. Methodology

The development of this research was developed from a heuristic perspective, with a rational propositional-quantitative analysis, to achieve the results of this study the following method was established i) survey of the quality system for the production system; ii) identification of the criteria to measure the processes independently and globally; iii) calculation of the critical variables of the process, such as defects per process, the input and output units of each process; iv) contextualization of the six sigma metrics to measure the processes and the global system; v) evaluation of the metrics for the system and processes under varying conditions of the Z quality performance level; vi) proposed Z vs Y, Z vs DPMO and Z vs n operating curves; vii) evaluation of the performance of the overall system and processes with six sigma metrics; viii) determination of the maximum capacities of the Z quality performance levels for each component of the system and ix) analysis of the quality performance of the processes and the overall system by means of the proposed operating curves. To carry out the analysis of the performance of the production system in parallel concurrently, the Six Sigma metrics presented in Table 1 were used, which provide a consistent way to measure and compare different processes.

Once the production system was modeled in concurrent parallel, we proceeded to contextualize the application of the metrics described in Table 1. As shown in Figure 1, the system under study consists of four processes, have the same global sigma level (Z) and with these sigma levels defective units were calculated for processes 1, 2, 3 and 4; respectively. In addition, the same initial number of units (U_0) is processed in each process; however, there are differences in the distribution for processing. In the concurrent parallel production system, from the initial quantities that enter the system () enter process 2, U_0 then these are divided into half of the units () passing to processes 1 and 3, and the remaining amount of these processes U_0 and U_1 (U (3)) passes only to process 4.

Taking into account the production system studied, use was made of the six sigma metrics, which establishes a consistent way of measuring and contrasting production processes, by means of the metrics used by Fontalvo Echavez et al. (2021), whose Equations 1, 2 and 3 are presented below:

$$DPMO = \frac{n}{U \ x \ O} x1.000.000 \tag{1}$$

$$Z = \sqrt{2.93 - 2.221 * \ln\left(DPMO\right)} + 0.8406 \tag{2}$$

$$Y = \left(1 - \frac{n}{U \ x \ O}\right) \tag{3}$$

where:

Z = the quality performance level of the process;

Y = process performance;

n = the number of non-conformities in the process;

U = the quantity of quality-critical units reviewed;

O = the opportunity for error per unit, which in our case is set to 1 for all processes.

For the construction of operation curves, a sensitivity analysis was conducted by varying the sigma Z quality performance level and determining O as the response variable (DPMO), Y, and the number of defects (n). This was performed under the operational conditions of the analyzed system, which range from 3.1 to 4.7 according to the established model's operational conditions. In addition, the performance of z was established according to the criteria presented in Table 2.

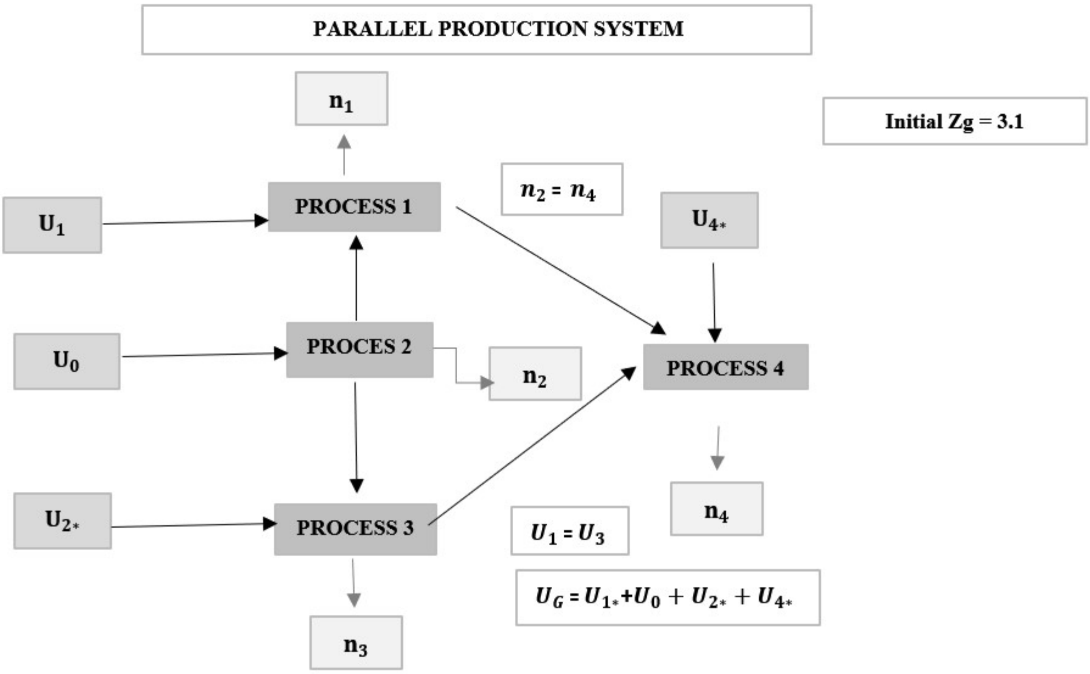

Figure 1. Diagram of the parallel productive system. U*: units entering externally to the process. Where: * is a simple symbology that does not alter the pro cess. **Source:** The authors.

Table 1. Six Sigma metrics used to compare system performance.

Metric	Definition
DPMO	Number of defects per million opportunities
U	Number of critical units reviewed
O	Opportunity for error per unit
Z	Sigma level
n	Number of nonconformities or faults present in the process
And	Process performance

Source: The authors.

Table 2. Performance criteria for serial and parallel systems.

Sigma level (Z)	Performance
< 3.0	Deficient
3.0 ≤ .Z. ≤ Z3.5	Acceptable
3.5 <.Z. ≤ 4.6	Well
Z> 4.6	Excellent

Source: The authors.

4. Resulted

Next, the operating curves of the production system of the processes are presented independently and from form to global obtained from the metrics applied at different sigma levels for the two systems.

Figure 2 shows the diagram of the parallel production system with its initial operating values, which were used in the calculation of the six sigma metrics, taking into account these operating conditions and the quality level Z, an operating range was obtained for the global system that ranged from 3.1 to 4.17.

From Figure 3 and Table 3 it can be seen that as the defects in parts per million (DPMO) decrease, the sigma level begins to increase, the values are not so dispersed thanks to the fact that the increasing figures by DPMO do not have much difference by the quantities of units processed in the analyzed system.

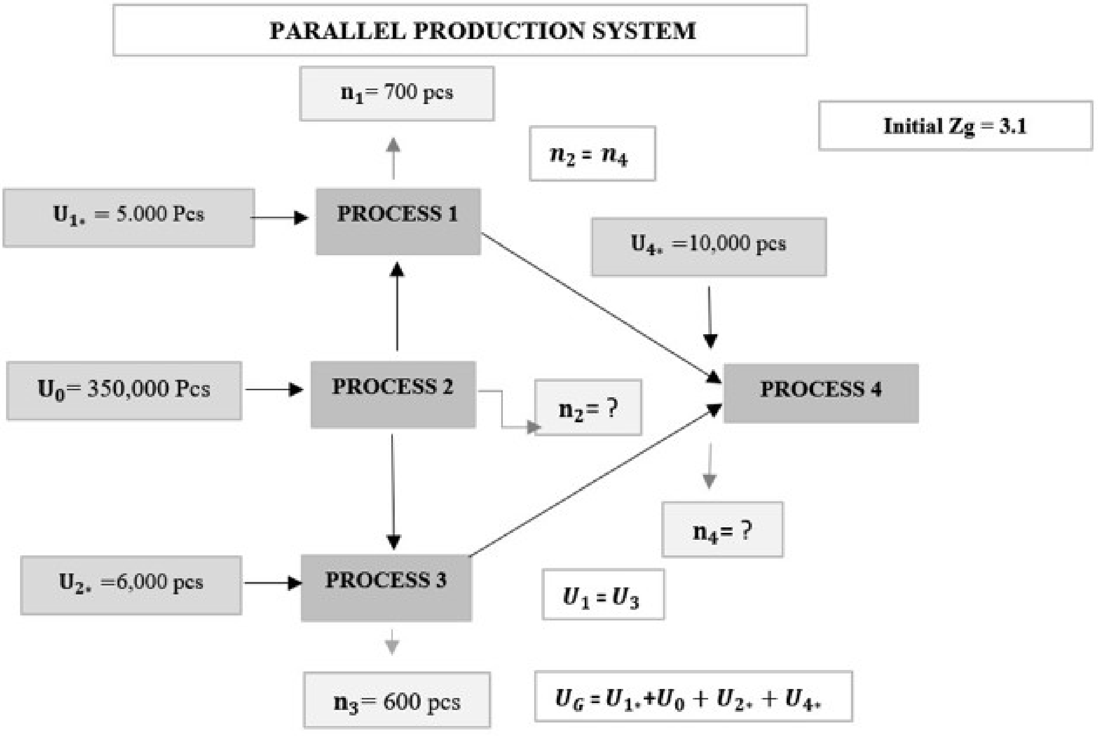

Figure 2. Diagram of the system productive in parallel with values. **Source:** The authors.

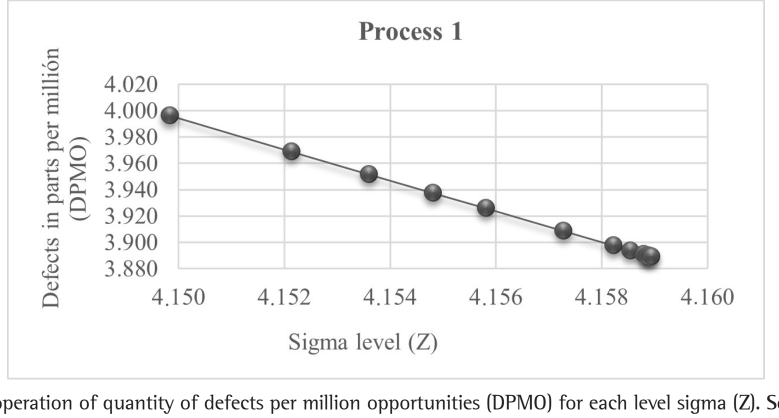

Figure 3. Curve of operation of quantity of defects per million opportunities (DPMO) for each level sigma (Z). **Source:** The authors.

When the Figure 4 is reviewed, it is observed that as the sigma level (Z) increases the performance also does, this is because they are related to increasing the sigma level decreases the defects which causes the performance to be higher.

In Figure 5 it is perceived that the number of defects remains the same, and the level sigma (Z) v an increasing, this is given as a result of DPMO is decreasing, although the defects are the same the number of units received is increasing.

Table 3. Result of the Six Sigma metrics applied to process 1 in the production system in parallel.

Process 1				
U_1	DPMO	n_1	Z_1	Y_1
175,171	3,996	700	4.150	99.60%
176,376	3,969	700	4.152	99.60%
177,146	3,952	700	4.154	99.60%
177,789	3,937	700	4.155	99.61%
178,320	3,926	700	4.156	99.61%
179,105	3,908	700	4.166	99.61%
179,609	3,897	700	4.157	99.61%
179,784	3,894	700	4.158	99.61%
179,920	3,891	700	4.159	99.61%
179,954	3,890	700	4.159	99.61%
179,976	3,889	700	4.159	99.61%
179,996	3,889	700	4.159	99.61%

Source: The authors.

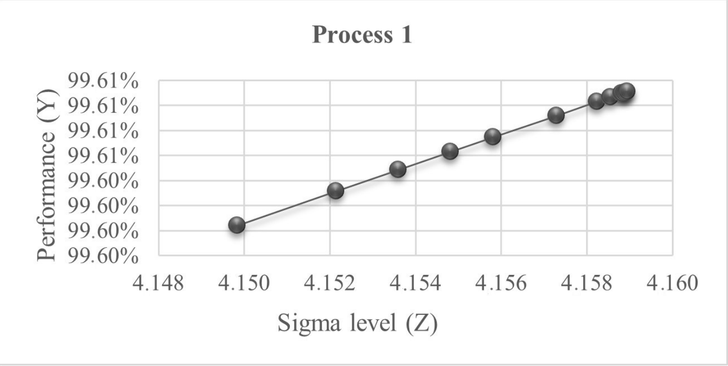

Figure 4. Operating curve percentage of yield (Y) for each sigma level (Z). **Source:** The authors.

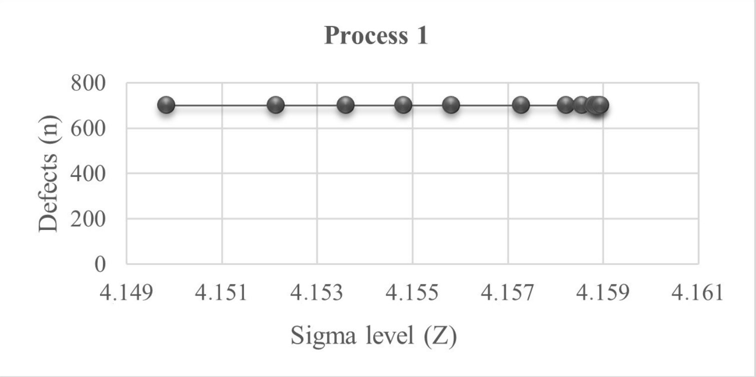

Figure 5. Defect percentage operation curve (n)for each sigma level (Z). **Source:** The authors.

After calculating the CO operation curves of the system in parallel, in the ranges inherent to the operating conditions of the system from 3.1 to 4.17 of the production system and calculating the metrics of Seis Sigma for process 2, it was observed that being constants the number of units received and the defective products have the tendency to decrease in the process, there is a performance at the end of 5.56 3, thus showing excellent performance with yields of 99.999% and low amounts of DPMO compared to the initial units of income.

Based on Figure 6 and Table 4, it can be seen that the sigma level (Z) reaches a maximum value of 5.563 thanks to the fact that the minimum values of defects per million (DPMO) were 24, if (Z) were to increase, the defects per million would become negative values, since this is the maximum quality that the system can provide in this process.

When analyzing the operation curve raised in Figure 7 of process 2 it can be seen that in the conditions of this process for the maximum level signa Z of 5.63 results in a decrease in defects that reaches 8 defective units, which is excellent according to the performance evaluation criteria established in Table 2.

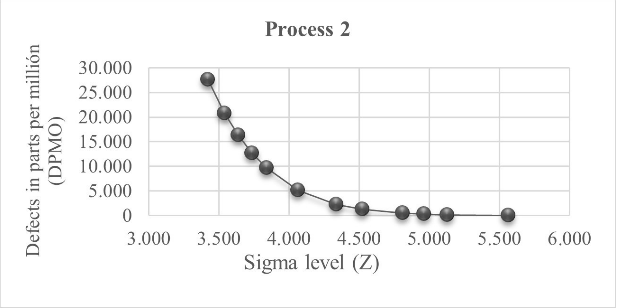

Figure 6. Operating curve of the number of defects per million opportunities (DPMO) for each sigma level (Z). **Source:** The authors.

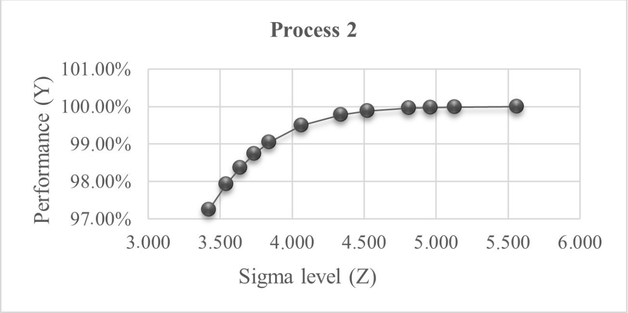

Figure 7. Performance percentage operation curve (Y) for each sigma level (Z). **Source:** The authors.

Table 4. Result of the metrics Seis Sigma applied to process 2 in the production system in parallel.

Process 2				
U_2	DPMO	n_2	Z_2	Y_2
350,000	27,592	9,657	3.421	97.24%
350,000	20,709	7,248	3.542	97.93%
350,000	16,308	5,708	3.638	98.37%
350,000	12,634	4,422	3.738	98.74%
350,000	9,599	3,360	3.841	99.04%
350,000	5,113	1,789	4.066	99.49%
350,000	2,233	782	4.340	99.78%
350,000	1,234	432	4.523	99.88%
350,000	458	160	4.811	99.95%
350,000	262	92	4.964	99.97%
350,000	140	49	5.130	99.99%
350,000	24	8	5.563	99.999%

Source: The authors.

A detailed analysis of Figure 8 shows that a change from z=3.421 to z=5.563, achieves a significant reduction in the defects n of process 2, which range from 9.657 to 8.

Table 5 shows that for process 3, once the metrics were evaluated under variable conditions of the general sigma level within the delimited range of 3.1 to 4.1 7, good performances of sigma levels were presented between 4.203 to 4.21 2 with yields of 99.66% and low levels of DPMO.

From Figure 9, it is observed that the sigma level (Z) did not give much variability having values being its maximum level of process 3 a value 4.212, since the (DPMO) did not have significant differences in its figures. It is important to note that, considering that the number of defects is constant, it does not apply in concept of an operation curve, associated with the analysis of variable conditions that do not apply in this process.

When analyzing Figure 10, they apply the same criteria analyzed in the previous figure, and the maximum yield obtained was 99.67% this is because the number of defects was common and the number of units received did not take such high values.

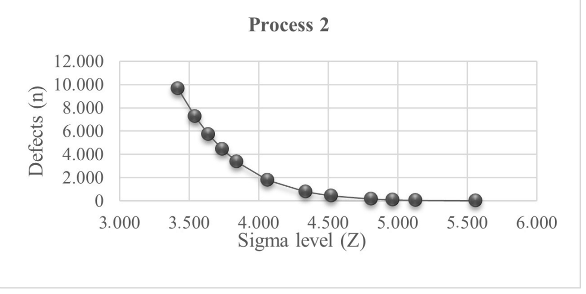

Figure 8. Defect percentage operation curve (n)for each sigma level (Z). **Source:** The authors.

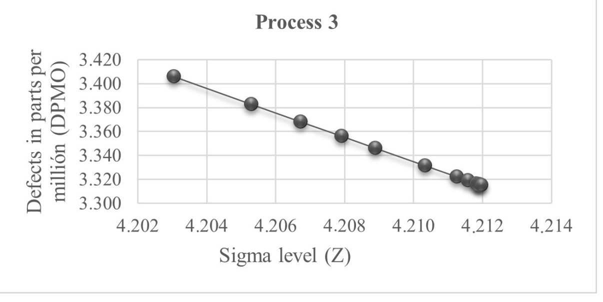

Figure 9. Curve of operation of quantity of defects per million opportunities (DPMO) for each level sigma (Z). **Source:** The authors.

Table 5. Result of the metrics Seis Sigma applied to process 3 in the production system in parallel.

Process 3				
U_3	DPMO	n_3	Z_3	Y_3
176,171	3,406	600	4.203	99.66%
177,376	3,383	600	4.205	99.66%
178,146	3,368	600	4.207	99.66%
178,789	3,356	600	4.208	99.66%
179,320	3,346	600	4.209	99.67%
180,105	3,331	600	4.210	99.67%
180,609	3,322	600	4.211	99.67%
180,784	3,319	600	4.212	99.67%
180,920	3,316	600	4.212	99.67%
180,954	3,316	600	4.212	99.67%
180,976	3,315	600	4.212	99.67%
180,996	3,315	600	4.212	99.67%

Source: The authors.

As the number of defects is constant, only movement can be evidenced in the axis of the sigma level (Z), although (n) is constant (DPMO) is variable which helps to increase the sigma level (see Figure 11).

When the sensitivity analysis is performed to construct the operation curves of process 4 considering the general sigma level Z in the established range of 3.1 to 4.17 of the global system and calculate the operation curve, an excellent performance of 5.576 is evidenced for the last level analyzed, with performance of 100.00% and minimum amounts of DPMO. The above can be verified with the results presented in Table 6.

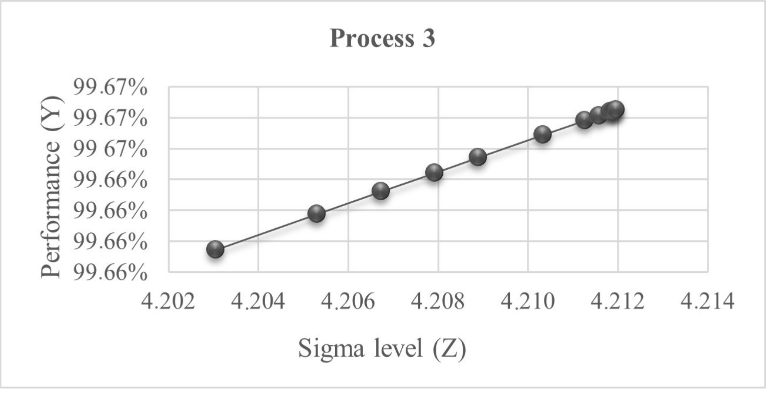

Figure 10. Yield percentage operation curve (Y) for each sigma level (Z). **Source:** The authors.

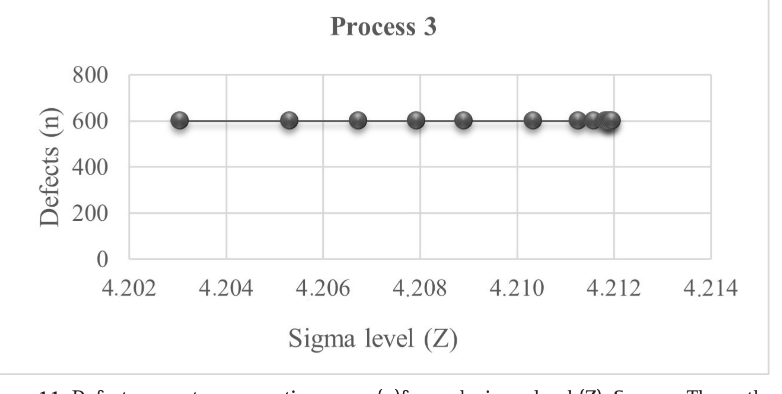

Figure 11. Defect percentage operation curve (n)for each sigma level (Z). **Source:** The authors.

Table 6. Result of the metrics Six Sigma applied to process 4 in the production system in parallel.

Process 4				
U_4	DPMO	$.n_4.$	Z_4	Y_4
360,043	26,823	9,657	3.433	97.32%
362,452	19,997	7,248	3.556	98.00%
363,992	15,681	5,708	3.654	98.43%
365,278	12,105	4,422	3.754	98.79%
366,340	9,171	3,360	3.858	99.08%
367,911	4,864	1,789	4.083	99.51%
368,918	2,119	782	4.356	99.79%
369,268	1,170	432	4.539	99.88%
369,540	434	160	4.826	99.96%
369,608	248	92	4.978	99.98%
369,651	133	49	5.144	99.99%
369,692	23	8	5.576	99.999%

Source: The authors.

Figure 12 shows that the process begins with one of the highest values of defects in parts per million (DPMO), as well as high sigma levels (Z), therefore, it can be said that the defects decreased considerably, generating the maximum sigma level as in process 4.

Figure 13 shows from the proposed operation curve that (Z) reaches a maximum performance of 5.576 with a yield of Y 99.999%.

From the operation curve presented in Figure 14, for process 4 it is observed that for the sigma level of performance 5,576 it is observed that this process generates only 8 defects, which shows the usefulness and relevance to reduce and improve production systems of these characteristics.

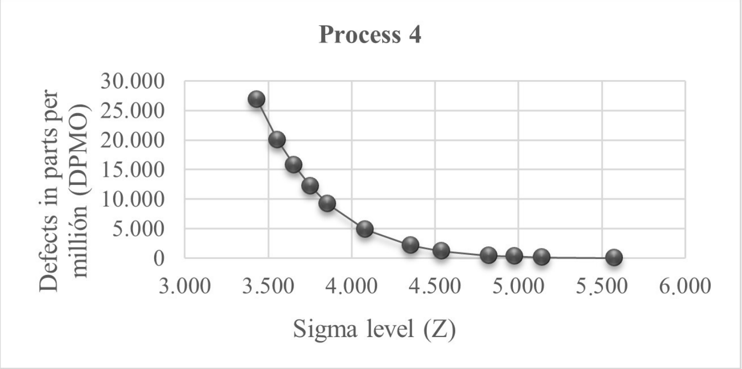

Figure 12. Parts per million defect quantity (DPMO) operating curve for each sigma level (Z). **Source:** The authors.

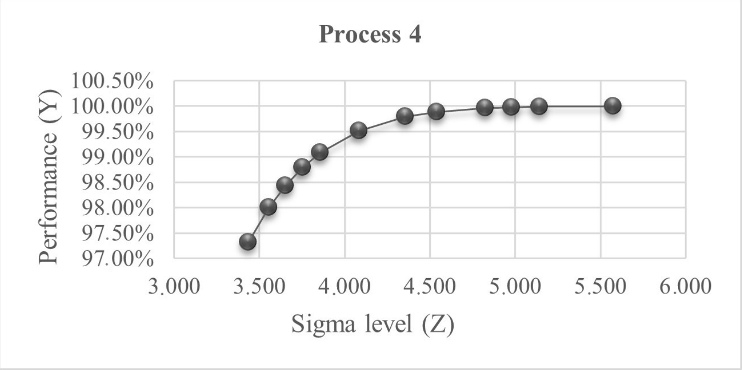

Figure 13. Performance percentage operation curve (Y) for each sigma level (Z). **Source:** The authors.

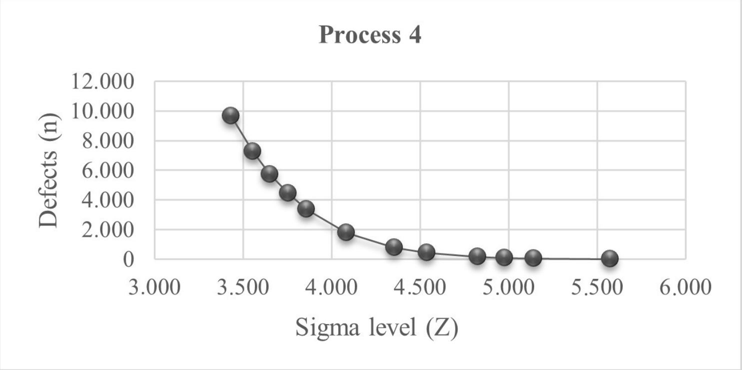

Figure 14. Defect percentage operation curve (n)for each sigma level (Z). **Source:** The authors.

4.1. Findings of the performance evaluation of the concurrent parallel production system

When the operating conditions of the global production system are reviewed, to construct the operation curve in the permitted ranges of 3.1 to 4.17 typical of the operating conditions associated with the production levels and their defects; it was observed that the number of defects per million opportunities decreases, the performance of the system is increased to 99.62%, and the number of units that meet the characteristics of quality is also increased, from 350,185 to 369.683 units (see table 7). In Figure 14 of the global process, it can be evidenced in the respective operation curve the behavior of the sigma level against the number of defects generated (n), that is, the operation curve Z Vs n Global, from where we can affirm that when Z takes values of 4.17 the defects go from 20.657 to 1.317, for this reason it can be said that having values close to 4.2 the process decreases the defects from 20,657 to 1367, which when contrasted with Table 2 allows us to affirm that the operation of the system has a good overall performance.

Figure 15, shows the Z Vs DPMO Operation curve, and shows that for a sigma Z level of 4.17, the overall overall system generates 4239 Defects partly per Million.

For the same sigma level of the overall process of Z 4.17 the effect on the decrease of the defect or defects, shows an equal performance 99.82%, which is excellent for the system studied (see Figure 16).

Finally, from Figure 17, it is observed that under the operating conditions of the system for a value of Z equal to 4.17, the effect on the reduction of defects n is excellent, considering that these are reduced to 1,317 defects, as previously indicated in Table 7.

As a result of this research into the analysis of Six Sigma metric operation curves, it can be affirmed that the process with the highest quality performance level, Z, was Process 4, with a quality performance level Z ranging between 3.433 and 5.576. This resulted in a reduction of defects (n) from 9.657 to 8, and a decrease in defects per million opportunities (DPMO) from 26.823 to 23. Simultaneously, it significantly improved the process performance (Y), increasing it from 97.32% to 99.99% (see Tables 8 and 9).

Table 7. Overall system result.

Overall result				
Z_G	$DPMO_G$	n_G	Y_G	U_S
3.1	55,565	20,657	94.44%	350.185
3.2	45,132	15,796	95.49%	355.204
3.3	36,329	12,715	96.37%	358.285
3.4	28,982	10,144	97.10%	360.856
3.5	22,913	8,019	97.71%	362.981
3.7	13,939	4,879	98.61%	366.121
3.9	8,180	2,863	99.18%	368.137
4	6,183	2,164	99.38%	368.836
4.1	4,631	1,621	99.54%	369.379
4.13	4,239	1,484	99.58%	369.516
4.15	3,994	1,398	99.60%	369.602
4.17	3,762	1,317	99.62%	369.683

Source: The authors.

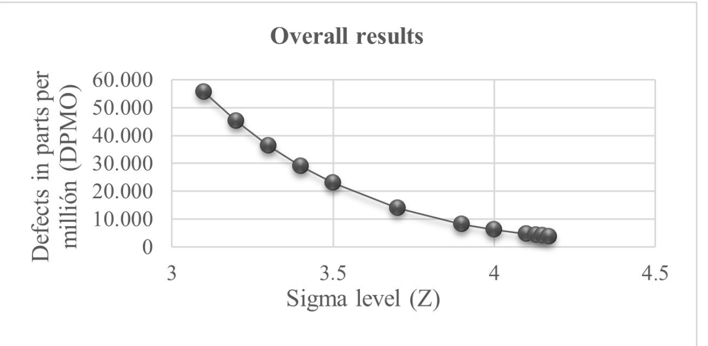

Figure 15. Operating limit of parts per million defects (DPMO) for each sigma level (Z). **Source:** The authors.

Additionally, it is evident that the process with the lowest quality performance level, Z, was Process 2, maintaining a quality performance level Z of 3.421, keeping defects constant at 9.657, and DPMO at 27.592, while performance remained at 97.24% (see Tables 8 and 9).

On the other hand, the overall system analysis reveals that the lower end of the quality performance level, Z, at 3.1, corresponds to a high DPMO of 55,565, with 20,657 defects (n), and a performance of 94.44%. Conversely, a quality performance level Z of 4.17 leads to a significant increase in performance, from 94.44% to 99.62%. Additionally, the DPMO decreases from 55,565 to 3,762, and defects reduce from 20,657 to 1,317. This underscores the relevance of Six Sigma metrics for evaluating process performance under varying conditions (see Table 7).

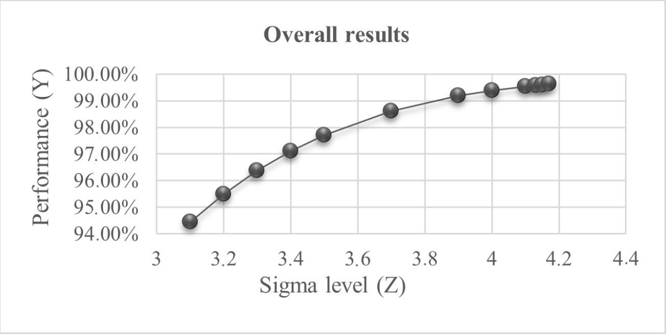

Figure 16. Yield percentage operation curve (Y) for each sigma level (Z). **Source:** The authors.

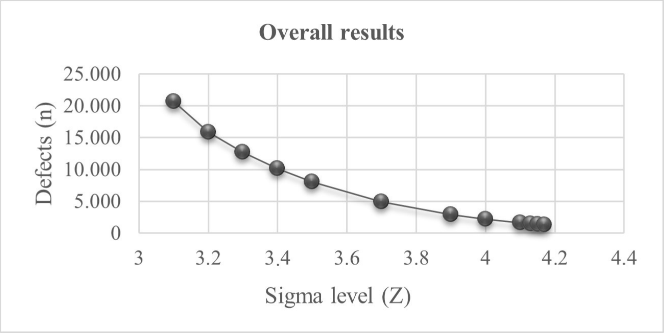

Figure 17. Defect percentage operation curve (n) for each sigma level (Z). **Source:** The authors.

Table 8. Reduced process performance.

Process	U	DPMO	n	Z	Y
1	175,171	3,996	700	4.150	99.60%
2	350,000	27,592	9,657	3.421	97.24%
3	176,171	3,406	600	4.203	99.66%
4	360,043	26.823	9.657	3.433	97.32%

Source: The authors.

Table 9. Improved process performance.

Process	U	DPMO	n	Z	Y
1	179,996	3,889	700	4.159	99.61%
2	350,000	27,592	9,657	3.421	97.24%
3	180,996	3,315	600	4.212	99.67%
4	369,692	23	8	5.576	99.999%

Source: The authors.

5. Discussion

The authors (Fontalvo Herrera et al., 2022b) in their study “Three-phase method to evaluate logistics service using Six Sigma metrics, Hotelling’s T-square control chart and a principal component capability indicator” worked with six-sigma metrics, and have used these in hotelling control charts, and geometric multivariable capability indicators, other studies have used these metrics to look at the performance of telephone companies over time in a longitudinal and timely manner (Fontalvo Echavez et al., 2021), as well as in studies to evaluate the quality of service in a gas company (Fontalvo Herrera et al., 2022a). That is, they have also analyzed the behavior of six sigma metrics under variable conditions over time, despite not using the operation curves proposed in this research.

However, the contribution of this research is that unlike the work carried out where six sigma metrics were used to analyze the behavior of the quality dimensions analyzed over time. In this research, the performance of the processes and subprocesses of a concurrent parallel production system was assessed, to which the operation curves Z vs DPMO, Z vs Y, Z vs n were proposed in an innovative way, with the purpose of evaluating the productive system in variable conditions and in this way contribute to the scientific context innovative criteria that allow identifying how to achieve good performances of the s metric s six sigma to reduce defects in parts per million, defective samples n, as well as improve performance Y.

6. Conclusion

As a theoretical and methodological contribution, this research integrated concepts related to the evaluation of a production system’s quality, Six Sigma metrics, parallel production systems, and operation curves. It established an effective method based on Six Sigma metrics, enabling the evaluation of the performance of a concurrent parallel production system and determining the influence of the quality level (Z) on defects (n), defects per million opportunities (DPMO), and yield (Y).

The most significant contribution of this research lies in the methodological proposal that allows for: (i) Modeling a specific quality measurement system. (ii) Structuring and assessing said quality measurement system using Six Sigma quality metrics. (iii) Monitoring the performance of the analyzed system with the proposed operation curves of Six Sigma metrics. (iv) Establishing maximum and minimum quality performance capacities for each process and for the overall system. (v) Analyzing and making decisions for the improvement of the intervened system. This represents an innovative contribution in the field of statistical control of production and operations.

From a practical perspective, this research proposes the operation curves of the Six Sigma metrics for the global production process and the independent processes of the analyzed system. It also establishes the performance of the Six Sigma metrics for the processes and the system under study. Notably, process 4 exhibited the highest performance in terms of the Z quality level, while process 2 displayed the lowest performance.

For future research, we invite the academic and scientific community to replicate the proposed method in various business contexts, service provision, or production processes. The aim is to determine the maximum and minimum capacities for quality performance, enabling informed decision-making to reduce defects, production costs, and, consequently, enhance overall quality and customer satisfaction.

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