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Research Article

New multivariate capacity indicators with Six Sigma metrics to assess service quality

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Abstract

Paper aims: To compare the relevance of Six Sigma metrics with geometric and multivariate capacity indicators to assess the performance of service quality dimensions.

Originality: A novel method based on Six Sigma metrics with geometric and multivariate capacity indicators is proposed to assess the performance of service quality dimensions.

Research method: A quantitative evaluative and, on a second level, comparative approach is addressed, for which primary information from 12 periods of a tourism service company was used.

Main findings: It is shown that multivariate capacity indicators are more demanding, the geometric capacity indicator being the most demanding with a value of 0.7091, followed by the Mean Capacity Indicator with a result of 0.7094, that is, these are more rigorous than the Six Sigma metrics used worldwide. This allows for a more sensitive assessment of variation and therefore a timely response to it.

Implications for theory and practice: A sensitive method is provided that allows assessing the quality of a service and comparing the relevance of Six Sigma metrics with geometric and multivariate capacity indicators. This is done to make agile improvement decisions according to the variation in the performance of the evaluated dimensions of the service.

Keywords

Service quality. Six Sigma, tourism service. Geometric indicator. Multivariate capacity indicator.

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1. Introduction

As a result of globalization, the information that is handled worldwide about the use of biometrics in the management of institutions, to generate improvements in services, efficiency, traditional procedures by human service not only require a lot of manpower, but also a lot of time and are prone to errors (Fontalvo Herrera et al., 2020). The service sector, especially tourism, is one of the contexts where customers are increasingly demanding, due to its very nature. Taking into account that the customer pays for a service that guarantees comfort, tranquility, well-being, timely and relevant attention (Banquez Maturana & Fontalvo Herrera, 2023). Likewise, globalization and the offer of multiple tourist services make this sector a field that must guarantee conditions of full satisfaction to users. Similarly, the growing need to compete with global standards has forced the service sector to undergo rapid technological and structural changes (Tzeng et al., 2022). Therefore, in this type of service organization, companies strive to propose new criteria, metrics, and indicators that allow the evaluation of service quality dimensions from different perspectives.

Now, several approaches have been proposed to assess service quality, such as the one adopted by the authors Fontalvo Herrera et al. (2022b), who evaluated the quality of customer service centers using Six Sigma metrics. Their methodology included identifying quality dimensions and evaluating them in terms of defects per million opportunities (DPMO), number of defects (n), quality level Z, and performance Y. The results showed high performance, with an average above 97% and all quality dimensions above the critical sigma value, indicating effective service delivery.

Similarly, Fontalvo Herrera et al. (2022a) in their study sought to measure the quality of the distribution service of a parcel company in Colombia using Six Sigma metrics. The results showed satisfactory performance with average values between 3.47 and 4.13 in the Six Sigma metrics. In addition, the multivariate analysis revealed that the process is stable in most periods, and the logistics service had a good overall performance, with an index of 0.669. Likewise, Barreto & Herrera (2022) in their research work, evaluated the quality of production of a pasta company using Six Sigma metrics, achieving an average yield of 96.89% and an average Z quality level of 3.67 in the stages of the process during the 12 study periods. Undoubtedly, these methods offer valuable perspectives for the scientific and business community, if they allow measuring the performance of the quality dimensions of the services offered and the productive processes.

Considering the above, the motivation of this research is focused on the fact that having different metrics provides different perspectives of performance measurement that facilitate the evaluation and improvement of the dimensions of a service with different approaches. Also, by having a more rigorous indicator, there is a more sensitive measurement process that contributes to timely improvement actions, since a small change in the variation of the process will be detected faster by the most rigorous indicator.

Given the above, the following problem questions arise: How can the dimensions of the service be evaluated through Six Sigma metrics? How can the performance of the multidimensional geometric capacity indicator be measured in the dimensions of service quality? How can the performance of the multidimensional mean capacity indicator be evaluated in the dimensions of service quality? Which indicator is more rigorous and stricter between the Six Sigma metric, the multidimensional geometric capacity indicator, and the multidimensional average capacity indicator to allow the improvement of the evaluated service?

All the above leads us to propose the following objectives for this research: As a general objective, to propose a method that allows evaluating and comparing the dimensions of a service through Six Sigma metrics and multivariable capacity indicators. This objective is broken down into the following specific objectives: i) to evaluate the dimensions of the service through Six Sigma metrics; ii) to evaluate the performance of the multidimensional geometric capacity indicator in the dimensions of service quality; iii) to evaluate the performance of the multidimensional mean capacity indicator in the dimensions of service quality; and iv) to carry out a comparative analysis of the performance of the Six Sigma metric, the multidimensional geometric capacity indicator, and the multidimensional average capacity indicator to determine which is the most rigorous and strict, and that allows the improvement of the evaluated service.

2. Theoretical framework

2.1. Six Sigma metrics

Service companies face a number of constant challenges in terms of quality. From customer service to operational efficiency, customer satisfaction and process optimization, continuous improvement is essential to remain competitive in an increasingly demanding market (Barreto & Herrera, 2022; Hou, 2023). One of the methodologies that has proven effective in addressing these problems is the Six Sigma metrics (González-Cebrián et al., 2022; Noskievičová & Moravec, 2022). This is a methodological and management approach that focuses on improving quality by reducing variability in processes and products (Fontalvo Herrera et al., 2022b). It uses a set of statistical tools and techniques to identify and eliminate defects or failures in processes, resulting in greater efficiency, less waste, and ultimately, a better customer experience.

Several studies have demonstrated the positive impact of implementing Six Sigma in different service sectors. For example, Ahmed et al. (2024) and Thakur et al. (2023) examined how Lean and Six Sigma are applied to optimize quality in different service environments. Singh & Ravi (2023) conducted a bibliometric analysis on the application of Lean Six Sigma in services over the past decade, highlighting its growing importance and effectiveness. In addition, Kholil (2023) showed how Lean manufacturing analysis can reduce delays in service delivery. Flores et al. (2022) applied Lean Six Sigma in small and medium-sized enterprises, improving service level performance. Finally, Banquez Maturana & Fontalvo Herrera (2023) performed a global performance evaluation using multivariate statistical control, demonstrating the usefulness of Six Sigma in various service contexts.

Similarly, Banquez Maturana & Fontalvo Herrera (2023) evaluated the performance of a service using Six Sigma, achieving a quality indicator of 0.77804. Another comparative analysis by Banquez Maturana & Fontalvo Herrera (2023) showed better performance in series systems, with a maximum value of 1.07896. Fontalvo Herrera et al. (2024a) proposed an innovative method to control service quality with Six Sigma, improving service accuracy. Also, during the COVID-19 pandemic, they evaluated job search performance, highlighting the usefulness of Six Sigma metrics in complex situations.

Now, the Six Sigma methodology establishes a consistent way to measure and compare the quality dimensions of a service, using the metrics created by Bill Smith (1993), whose Equations (1, 2, and 3) are presented below:

$$DPMO = \frac{n}{U \; x \; O} \; x1{,}000{,}000 \quad (1)$$

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

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

Where,

Z = level of process performance.

Y = process yield.

n = number of nonconformities of the process.

U = number of critical units reviewed for quality.

O = opportunity for error per unit, which in our case will be 1 for all processes.

2.2. Multidimensional capacity indicators

In accordance with the above, another evaluation method frequently used by companies to measure the quality of their services is multidimensional capacity indicators (Cho & Han, 2022). In this line, multiple authors in their research show the importance of using indicators to evaluate performance in an organization (Taleb et al., 2019), showing the relevance of addressing process monitoring in a multidimensional way as a strategy to improve the company (Wang et al., 2020). In this sense, multidimensional indicators are consistent with this type of service improvement strategy.

Regarding these multivariate capacity indicators, there are 5 different approaches to calculating capacity indicators according to the authors:

- Those based on the relationship between the tolerance area and a process area, as suggested by (Li et al., 2021).
- A second group that uses the proportion of non-conforming products, such as those presented by Banquez Maturana & Fontalvo Herrera (2023).
- Another group based on the application of the Principal Component Analysis technique, as proposed by Rehman et al. (2022).
- A fourth group that includes other proposals, such as the one presented by Zhang & Wang (2020).
- Parametric and nonparametric capacity indices that apply FDA functional data (Kusumawati et al., 2021).

It should be noted that multidimensional capacity indicators allow organizations to evaluate not only the quality of their individual processes but also how they interact and integrate within the overall system (De la Ossa De Ávila et al., 2018). These multidimensional approaches are crucial in an increasingly complex business environment, where interdependencies between different processes and services can significantly affect the final quality perceived by customers. In addition, the diversity in calculation methods, such as those based on tolerance areas or principal component analysis, provides companies with the flexibility to choose the approach that best suits their specific needs (Rahmer & Solana Garzón, 2020). This, in turn, facilitates the implementation of continuous improvement strategies that address all the critical dimensions of the service, ensuring a more comprehensive and accurate approach to quality management.

2.3. Multidimensional geometric capacity indicator

Likewise, multidimensional geometric capacity indicators are used to integrate the previous quality measurement methods to evaluate the performance of the services offered by companies. Now, the authors Banquez Maturana & Fontalvo Herrera (2023), propose the multivariate capacity indicator presented to evaluate the characteristics v, which was modified to adjust it to the guidelines required in the Six Sigma methodology. Equation 4 is presented below:

$$MC_p = \frac{1}{3}\varnothing^{-1}\left\{\frac{\left[\prod_{j=1}^{v}(p_J)^{1/V} + 1\right]}{2}\right\} \tag{4}$$

Where,

MC_p is the multidimensional geometric capacity indicator.

$\varnothing^{-1}$ represents the inverse function of the standard normal cumulative distribution.

$\Pi_{j=1}^{v}$ indicates the product of the terms for each dimension j in a total of v dimensions.

p_J is the performance parameter associated with dimension j.

V is the total number of dimensions.

The evaluation of multivariate capability, according to this methodology, is carried out by means of the percentage based on the v dimensions involved.

2.4. Multidimensional mean capacity indicator

Similarly, Fontalvo Herrera et al. (2020), propose a synthesis of multivariate capacity indicators, within which they point out the use of multivariate capacity indicators related to the analysis of proportions, which allows rigorously measuring the performance of the quality dimensions of services and determine the areas that require improvement. From the above, the proposal of this research arises, which is to apply the average performance Y of the Six Sigma methodology (Fontalvo Herrera et al., 2022a).

The calculation is carried out using the following expression (Equation 5):

$$MS_p, = \frac{1}{3}\varnothing^{-1}\left\{\frac{\left[\prod_{j=1}^{v}\left(\frac{P_i + .. + P_v}{k}\right)_j + 1\right]}{2}\right\} \tag{5}$$

In this case, the parameter P_j is defined using the following expression (Equation 6):

$$P_j = \left(1 - \frac{N_j}{U_j x O_j}\right) \text{ with } j = 1, 2, \ldots, k \tag{6}$$

Where,

MC_p is the multidimensional geometric capacity indicator.

$\varnothing^{-1}$ represents the inverse function of the standard normal cumulative distribution.

$\Pi_{j=1}^{v}$ indicates the product of the terms for each dimension j in a total of v dimensions.

p_J is the performance parameter associated with dimension j.

V is the total number of dimensions.

Nj is the number of defective units in dimension j.

Uj is the total number of units in dimension j.

Oj is the number of defect opportunities in dimension j.

In correspondence with the capacity indicators in univariate cases, a process with optimal performance is expected when the values of this indicator are greater than one (Banquez Maturana & Fontalvo Herrera, 2023).

3. Methodology

The research methodology was based on a comprehensive and systematic approach, starting with the collection and debugging of primary information to ensure its relevance and accuracy. Subsequently, the quality dimensions to be evaluated were identified, and the metrics were contextualized in relation to these specific dimensions. Once these bases were established, we proceeded to evaluate the selected metrics and calculate the geometric and mean multidimensional capacity indicators. This research, of a quantitative evaluative nature, followed a logical-positive approach that facilitated the realization of a deep comparative analysis between various Six Sigma metrics, such as defects per million opportunities (DPMO), number of defects (n), quality level Z, and performance Y of the service. In addition, the geometric and mean multidimensional capacity indicators were evaluated, allowing for a comprehensive and detailed comparison of the quality performance in the service, according to the different approaches and metrics used. Likewise, it was possible to contrast the level of rigor of the three evaluation criteria of the performance of the provision of a service. The origin of science was generated as a result of the empirical comparison of the performance evaluation of the service quality dimensions evaluated from the Six Sigma metric and the two multivariate capacity indicators, which allowed showing which criterion of the statistical control tool it is more rigorous. The essence of science is based on the intensive use of statistical control metrics and indicators to evaluate the performance of service quality dimensions. As a truth criterion, the comparative analysis of the performance of the metrics and indicators that were the object of this investigation was taken, valued with the empirical information of the service company related to the quality dimensions taken from the service company. This made it possible to show which of the three statistical control criteria used to evaluate performance is most rigorous and offers the best opportunities for improvement.

To carry out the comparative analysis of the Six Sigma metrics, the multidimensional geometric capacity indicator, and the multidimensional mean capacity indicator, a tourist service was identified in this investigation, its dimensions and their definition in Figure 1 and Table 1.

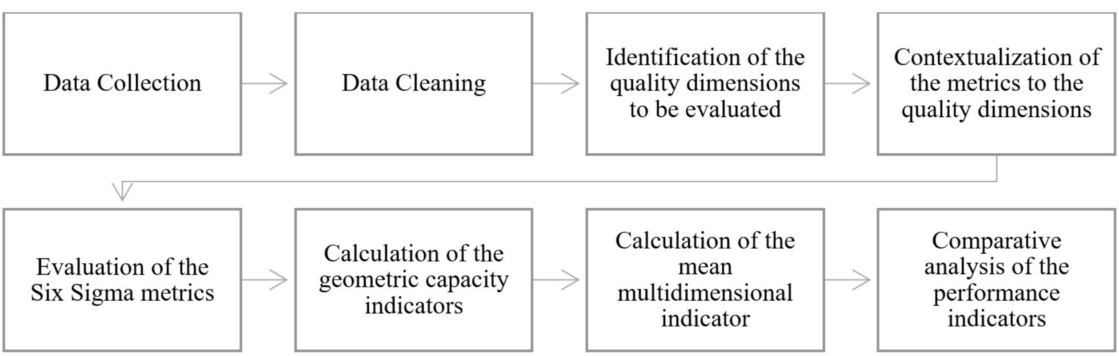

Figure 1. Comparative analysis method of Six Sigma metrics and multivariate capacity indicators.
Source: The authors.

Based on the 2019 tourist service information provided by the tourist service organization, related to the service under investigation, the Six Sigma metrics and the other two multivariate capacity indicators under investigation were evaluated. The dimensions of quality to be evaluated in the hotel establishment, along with their respective indicators, are presented in Table 2, which provides an overview of how each quality dimension is measured.

Table 1. Characterization of the dimensions of the selected service.

Evaluated Service Dimension	Characterization of Service Dimensions
Staff Skills	The competencies of the staff to provide good service are evaluated.
Infrastructure Quality	It is verified that the required comfort conditions for the service were met.
Service Planning and Control	It is evaluated that the service planned to satisfy the customer is executed in a timely manner.
Service Relevance	It is verified that the service meets the needs and expectations of the tourist service.

Source: The authors.

Table 2. Dimensions of quality to be evaluated in the hotel establishment.

		Dimensions of Quality of the Evaluated Service	Indicators for Measuring the Dimensions of Quality of the Evaluated Service
Objective: Customer Satisfaction	Evaluated Service: Tourism	Staff Skills	Six Sigma Metrics
		Infrastructure Quality	Geometric Capacity Indicator
		Service Planning and Control	Mean Multidimensional Capacity Indicator
		Service Relevance	

Source: The authors.

Figure 1 describes in detail the analysis method developed in the research, showing how to develop the comparative analysis between the Six Sigma metrics, the geometric multivariate capacity indicators, and the mean capacity. The method leads us to identify which statistical control criterion is more rigorous and offers better improvement opportunities to the evaluated service.

4. Results

To achieve the objectives of this research, in the first stage, a quantitative evaluation of the Six Sigma metrics of the quality dimensions is carried out. In the second stage, the performance of the quality dimensions is evaluated using the multidimensional geometric capacity indicator, and in the third stage, the multidimensional mean capacity indicator is calculated. With the performance evaluation, it can finally be shown which of the three statistical control criteria is more rigorous to evaluate a service. And, finally, in the fourth stage, all the Six Sigma metrics and the multivariate capacity indicators that are the object of this investigation are compared.

STAGE 1: Evaluation of Six Sigma metrics for quality dimensions

The information related to the quality dimensions of the service to be analyzed has been collected to determine which metric or capacity indicator is more rigorous, these are presented in Table 3.

With the information in Table 3, the quality dimensions were contextualized with the empirical information from the company to the Six Sigma metrics to evaluate the tourism service under investigation.

Evaluation of the quality dimensions of the tourism service, based on the Six Sigma metrics.

U: Number of tourist services provided

O: Probability of error

n: Number of tourist service provisions that are not subject to complaint

Y: Performance of the quality dimension of the tourist service

DPMO: Defects per million opportunities

Now, for the calculation of the Six Sigma metrics, Equations 7, 8 and 9 are taken into account. With these, the values of defects per million opportunities (DPMO), the sigma level (Z) and the yield (Y) are obtained to assess the tourism service under study.

$$DPMO = \frac{n}{t} *1,000,000 = \frac{n}{u \times o} *1,000,000 \tag{7}$$

$$Z = \sqrt{(29.3 - 2.221 * \ln(DPMO))} + 0.8406 \tag{8}$$

Table 3. Dimensions of quality in tourist service

Criterion	Period	Compliant Services	Nonconformities	Total Services
Staff Skills	January	818	42	860
	February	698	32	730
	March	612	16	628
	April	640	24	664
	May	740	30	770
	June	722	34	756
	July	710	46	756
	August	882	54	936
	September	776	36	812
	October	682	22	704
	November	710	34	744
	December	904	42	946
Infrastructure Quality	January	808	52	860
	February	688	42	730
	March	590	38	628
	April	636	28	664
	May	732	38	770
	June	724	32	756
	July	854	36	890
	August	910	26	936
	September	790	22	812
	October	688	16	704
	November	712	32	744
	December	896	50	946
Service Planning and Control	January	42	42	84
	February	692	38	730
	March	596	32	628
	April	636	28	664
	May	738	32	770
	June	726	30	756
	July	850	40	890
	August	902	34	936
	September	782	30	812
	October	682	22	704
	November	718	26	744
	December	898	48	946
Service Relevance	January	830	30	860
	February	716	14	730
	March	610	18	628
	April	642	22	664
	May	754	16	770
	June	728	28	756
	July	866	24	890
	August	920	16	936
	September	794	18	812
	October	690	14	704
	November	728	16	744
	December	926	20	946

Source: The authors.

$$y = 1 - \frac{n}{u^{*}o} \tag{9}$$

On the other hand, the quantitative evaluation of the quality dimensions of the tourism service is presented through the approach of the Six Sigma metrics, as seen in Table 4. Additionally, Table 5 presents the average yields per period, providing an overview of the service performance over time.

Table 4. Valuation of the six sigma metrics of the service

Staff Skills			
Period	**DPMO**	**Z**	**Y**
January	48,837.2093	3.163	95.12%
February	43,835.61644	3.214	95.62%
March	25,477.70701	3.455	97.45%
April	36,144.57831	3.302	96.39%
May	38,961.03896	3.268	96.10%
June	44,973.54497	3.202	95.50%
July	60,846.56085	3.055	93.92%
August	57,692.30769	3.081	94.23%
September	44,334.97537	3.208	95.57%
October	31,250	3.367	96.88%
November	45,698.92473	3.194	95.43%
December	44,397.463	3.208	95.56%
Infrastructure Quality			
Period	**DPMO**	**Z**	**Y**
January	30,232.55814	3.382	96.98%
February	28,767.12329	3.403	97.12%
March	30,254.77707	3.381	96.97%
April	21,084.33735	3.534	97.89%
May	24,675.32468	3.469	97.53%
June	21,164.02116	3.533	97.88%
July	20,224.7191	3.552	97.98%
August	13,888.88889	3.701	98.61%
September	13,546.79803	3.711	98.65%
October	11,363.63636	3.778	98.86%
November	21,505.37634	3.526	97.85%
December	26,427.06131	3.440	97.36%
Service Planning and Control			
Period	**DPMO**	**Z**	**Y**
January	48,837.2093	3.163	95.12%
February	52,054.79452	3.132	94.79%
March	50,955.41401	3.142	94.90%
April	42,168.6747	3.232	95.78%
May	41,558.44156	3.239	95.84%
June	39,682.53968	3.260	96.03%
July	44,943.82022	3.202	95.51%
August	36,324.78632	3.300	96.37%
September	36,945.81281	3.292	96.31%
October	31,250	3.367	96.88%
November	34,946.23656	3.317	96.51%
December	50,739.95772	3.144	94.93%
Service Relevance			
Period	**DPMO**	**Z**	**Y**
January	34,883.72093	3.318	96.51%
February	19,178.08219	3.573	98.08%
March	28,662.42038	3.405	97.13%
April	33,132.53012	3.341	96.69%
May	20,779.22078	3.541	97.92%
June	37,037.03704	3.291	96.30%
July	26,966.29213	3.431	97.30%
August	17,094.01709	3.620	98.29%
September	22,167.48768	3.514	97.78%
October	19,886.36364	3.559	98.01%
November	21,505.37634	3.526	97.85%
December	21,141.64905	3.533	97.89%

Source: The authors.

Table 5. Average yields per period

Average yield per period			
Period	**DPMO Medium**	**Z Medium**	**Y Medium**
January	40,697.67442	3.256	95.93%
February	35,958.90411	3.331	96.40%
March	33,837.57962	3.346	96.62%
April	33,132.53012	3.352	96.69%
May	31,493.50649	3.379	96.85%
June	35,714.28571	3.321	96.43%
July	38,245.34808	3.310	96.18%
August	31,250	3.426	96.88%
September	29,248.76847	3.431	97.08%
October	23,437.5	3.518	97.66%
November	30,913.97849	3.391	96.91%
December	35,676.53277	3.331	96.43%

Source: The authors.

From the results obtained from the evaluation of the quality dimensions through the Six Sigma metrics, it can be affirmed that good performance was evident in most periods, based on the fact that the Y performance percentages are above 95% performance for each period.

In stage 2, the global performance of the geometric multidimensional indicator is calculated when calculated with the 4 dimensions of the service and with the 12 periods. Similarly, in stage 3, the global indicator of mean multidimensional capacity is calculated with the 4 dimensions of the service and with the 12 periods.

> STAGE 2: Evaluation of the performance of the quality dimensions of the service by means of the geometric indicator of multidimensional capacity.

Considering Equation 10, the global performance of the geometric multidimensional capacity indicator of the service was evaluated, which was:

$$MC_p = \frac{1}{3}\varnothing^{-1}\left\{\frac{\left[0.9593\times\ldots\times 0.9643\right]^{1/4}+1}{2}\right\} = 0.7091 \tag{10}$$

This measurement is made for each dimension, in the case of staff competencies, where the multidimensional geometric indicator for the 12 periods evaluated presents the following value (Equation 11):

$$MC_p = \frac{1}{3}\varnothing^{-1}\left\{\frac{\left[0.9512\times\ldots\times 0.9556\right]^{1/12}+1}{2}\right\} = 0.6727 \tag{11}$$

> STAGE 3. Evaluation of the performance of the quality dimensions of the service by means of the mean multidimensional capacity indicator.

Taking into account, Equation 12, the value of the global performance of the multidimensional mean capacity indicator of the service was:

$$MC_p = \frac{1}{3}\varnothing^{-1}\left\{\frac{\left[0.9565+\ldots+0.9748\right]/4+1}{2}\right\} = 0.7094 \tag{12}$$

This measurement is made for each dimension, in the case of the dimension of staff competencies for the 12 evaluated periods it presents the following value (Equation 13):

$$Mc_p = \frac{1}{3}\varnothing^{-1}\left\{\frac{\left[0.9512+\ldots+0.9556\right]/12+1}{2}\right\} = 0.6728 \tag{13}$$

From stages 2 and 3 it is clear that when comparing the service performance results through the global Geometric and Mean capacity indicators, the Geometric indicator is more rigorous when using the 4 dimensions and the 12 periods and therefore the measurement process is more sensitive to changes, which allows for more timely improvement decision-making by the person responsible for quality.

STAGE 4. Comparative performance analysis of Six Sigma metrics, the multidimensional geometric quality capability indicator, and the multidimensional mean capability indicator.

From the different equations proposed in this research, all the metrics and multidimensional capacity indicators were calculated, for each dimension of the service quality object of this research, which are presented in Table 6.

Table 6. Comparative analysis of Six Sigma metrics and multivariate capacity indicators in the evaluation of service quality dimensions.

Criteria	Staff Skills	Infrastructure Quality	Service Planning and Control	Service Relevance
Average DPMO	43537	21928	42534	25202.9
Average Z Level	3.23	3.53	3.23	3.47
Average Y Performance	95.65%	97.81%	95.75%	97.48%
Geometric Multidimensional Capability Index (GMCI)	0.6727	0.7638	0.6760	0.7460
Average Multidimensional Capability Index (AMCI)	0.6728	0.7639	0.6761	0.7461

Source: The authors.

Table 7 and 8 present the performance evaluation criteria associated with the six sigma metrics and the multivariate capacity indicators used in this research.

Table 7. Performance criteria for Six Sigma metrics.

Sigma Z Level	Performance
$Z < 3.0$	Deficient
$3.0 \leq Z \leq 4.0$	Good
$4.0 < Z$	Excellent

Source: The authors.

Table 8. Performance criteria for multidimensional capacity indicators.

Deficient	Geometric Multidimensional Capability Index (ICG)	Average Multidimensional Capability Index (ICM)
Good	$ICG < 0.6$	$ICM < 0.6$
Excellent	$0.6 \leq ICG \leq 0.75$	$0.6 \leq ICM \leq 0.75$
Deficient	$0.75 < ICG$	$0.75 < ICM$

Source: The authors.

From the results found in this research, it follows that the geometric and mean multidimensional capacity indicators, proposed as a tool for service variation, are more rigorous than traditional Six Sigma metrics, such as DPMO, Y, Z, and n, since these multivariate capacity indicators present more conservative values. In addition, as the main finding, it can be observed that the geometric capacity indicator is the most demanding evaluation criterion among those used. Similarly, it is observed that when the Y, DPMO, and Z metrics of Six Sigma are used, the values observed in the table show good performance. As previously indicated, being a more rigorous indicator, the process of measuring the dimensions of a service is more sensitive, so a change in the variation of the process can be detected more quickly, which allows those responsible to take improvement actions faster. Similarly, this research provides a method for measuring the quality dimensions of a service using three types of indicators. These allow evaluating the service in terms of performance, analyzing its evolution over several periods, and carrying out a global analysis using the mean and geometric multidimensional capacity indicators. Findings that are consistent with the intentions and objectives set out in this research.

5. Discussion

This research conducted a comparative analysis between Six Sigma metrics and geometric and mean multidimensional capability indicators. The results showed that the geometric indicator reached a value of 0.91163, while the mean multidimensional indicator obtained a value of 0.9559. These indicators allow a rigorous evaluation of service quality and, therefore, a timelier approach to addressing variation in service delivery dimensions.

Regarding the previous work of Fontalvo Herrera & Banquez Maturana (2023), which carried out a comparative analysis of multivariate capability indicators in two different fields of study, achieving a maximum result of 1.07896 compared to the other of 1.07461, it is observed that, similar to this research, capability indicators are a useful tool for measuring and improving service quality. This approach can be replicated in other areas with innovative approaches, encompassing multiple aspects of high variability. However, these studies did not consider the diversity of evaluation perspectives for decision-making that this research contributes.

Furthermore, Banquez Maturana & Fontalvo Herrera (2023) evaluated the performance of a service through multivariate statistical quality control. They calculated Six Sigma metrics such as DPMO, Z level, and yield, and assessed the overall and multidimensional performance of the service. The results indicated that the quality of the company's service was excellent, with a geometric multidimensional quality capability indicator greater than 0.75, reaching 0.77804. This novelty reflects effective control and the potential for continuous improvement in the company's processes. This aligns with the findings of this research, highlighting the relevance and effectiveness of multivariate capability indicators, particularly the geometric indicator, and its rigor in driving service improvements based on quality dimensions. This allows for a more rigorous and sensitive performance assessment, enabling better identification of variations and, consequently, more agile decision-making.

Similar studies by Fontalvo Herrera et al. (2024a) propose an innovative method for evaluating and controlling service quality using Six Sigma performance metrics, the main quality indicator, and the geometric capability indicator. The results highlight that the geometric indicator, with a value of 0.91163, is the most rigorous, and the integration of these indicators enhances the reliability and precision of the service. This finding is consistent with the results of this research.

Other studies have shown similar results. Fontalvo Herrera et al. (2024b) evaluated job search performance during the COVID-19 pandemic using both Six Sigma metrics and the multivariate geometric indicator. In this context, the geometric indicator showed a value of 0.67, which falls within the range of $0.5 \leq MCp < 0.75$. However, these studies did not address a method that would integrate three indicators to provide different perspectives on the performance of the evaluated service, which is an important contribution of this research.

Collectively, these studies emphasize that while Six Sigma metrics are effective for measuring performance and reducing defects, multidimensional and multivariate indicators provide a more comprehensive and detailed evaluation of service quality and performance. The geometric indicator, in particular, proves to be more rigorous and detailed, offering a complementary and more precise perspective in assessing service quality, thereby facilitating more timely decision-making.

The application of the proposed method, which integrates three indicators to assess the quality dimensions of a service, and its comparison with other approaches that also effectively evaluate services using similar metrics and indicators in different contexts, provides external validation and supports the relevance of the proposed method. Moreover, its practical utility for improving the evaluated service and decision-making within the context of the study object reinforces the internal validity of the method.

6. Conclusion

Regarding the method proposed in the objective, the usefulness of integrating Six Sigma metrics and multivariate indicators is observed. The proposed methodology not only demonstrates the effectiveness of using Six Sigma metrics for a specific and concrete evaluation of service performance but also highlights how multivariate capability indicators offer a holistic and comprehensive view. This combination is advantageous for those responsible for the service improvement process, as it allows for an independent assessment of the different quality dimensions. Likewise, multidimensional indicators allow for a thorough evaluation of quality, identifying the main factors that affect the provision of the service under investigation.

By calculating the service's Six Sigma metrics and the geometric and mean multivariate capability indicators, this research established rigorous criteria for measuring service dimensions. This provides the business sector with the possibility of evaluating these dimensions and, if greater rigor is required, using the proposed multivariate capability indicators, which allows for a precise assessment of service performance. Furthermore, performance can be assessed in terms of its evolution and behavior over time, and thanks to multivariate capability indicators, a holistic and comprehensive perspective is obtained to evaluate all service dimensions.

The comparative analysis and the findings of this research show that the most rigorous indicator is the geometric multidimensional indicator, which allows for a comprehensive evaluation of all service dimensions. However, the proposed method also facilitates the periodic and longitudinal monitoring of key dimensions, which contributes to the continuous construction of quality in the service process.

The implications of this research highlight that although Six Sigma metrics are useful for a specific evaluation of service performance, multivariate capability indicators provide a more complete and accurate assessment by offering a comprehensive view of the various quality dimensions. This holistic perspective is crucial for organizations seeking not only to improve the quality of their service in a timely manner but also to manage and optimize all service areas continuously. Multivariate indicators allow for more precise identification of factors that affect the service and monitoring of its evolution over time, resulting in sustained and more effective improvement compared to the exclusive use of Six Sigma metrics. Therefore, for organizations seeking significant and lasting improvement, adopting a methodology that integrates both types of indicators can be more beneficial and strategic in practice.

One limitation of this research is that only four quality dimensions of the service were evaluated, and the comparative analysis was only between the performance of indicators. Therefore, it is suggested to analyze other services with more quality dimensions and to evaluate and analyze the performance of quality dimensions between different types of services. The scientific and business community is also invited to replicate the proposed method in other services with different dimensions, both nationally and internationally. Likewise, as future research, it is planned to establish a comprehensive measurement framework using a dynamic table to evaluate performance under variable conditions and to explore the method from another perspective.

References

Ahmed, S., Hawarna, S., Alqasmi, I., Mohiuddin, M., Rahman, M. K., & Ashrafi, D. M. (2024). Role of Lean Six Sigma approach for enhancing the patient safety and quality improvement in the hospitals. *International Journal of Healthcare Management*, *17*(1), 52-62. http://doi.org/10.1080/20479700.2022.2149082.

Banquez Maturana, A. G., & Fontalvo Herrera, T. J. (2023). Global performance evaluation based on multivariable statistical control of a public utility company. *Pesquisa Operacional*, *43*, e270103. http://doi.org/10.1590/0101-7438.2023.043.00270103.

Barreto, R., & Herrera, R. (2022). Application of a proposed reliability analysis multivariate capability index on manufacturing processes. *Quality Engineering*, *34*(1), 1-15. http://doi.org/10.1080/08982112.2021.1973035.

Cho, Y., & Han, H. (2022). Linking online review characteristics to perceived service quality and behavioral intentions in the hotel industry: a text mining approach. *International Journal of Hospitality Management*, *98*, 103003.

De la Ossa De Ávila, J. J., Acosta, R. J. H., Alvear, K. H., Gélvez, E. F. (2018). Application of multivariate statistical control to measure the process capability of compression springs in stainless Steel. *Prospectiva*, *16*(2), 49-58. http://doi.org/10.15665/rp.v16i2.1495.

Flores, J. C. Q., Daza-Moran, F., Ramírez-Alva, A., & Collao-Diaz, M. (2022). Improving Service Level performance by implementing Lean Six Sigma in SMEs of the gaming peripherals industry in Peru: a case study. *South African Journal of Industrial Engineering*, *32*(2). http://doi.org/10.7166/33-2-2710.

Fontalvo Herrera, T. J., Acosta, R. H., & Maturana, A. G. B. (2024a). Performance evaluation method of the service quality dimensions using Six Sigma metrics, the main components' quality indicator and the geometric capacity indicator. *Engineering Management in Production and Services*, *16*(1), 65-76. http://doi.org/10.2478/emj-2024-0005.

Fontalvo Herrera, T., Dominguez, E. D., & Fontalvo, O. (2022b). Six Sigma method to assess the quality of the service in a gas utility company. *International Journal of Process Management and Benchmarking*, *12*(2), 220. http://doi.org/10.1504/IJPMB.2022.121628.

Fontalvo Herrera, T., Herrera, R., & Zambrano, J. (2020). Three-phase method to assess the logistics service using Six sigma metrics, Hotelling's T-square control chart and a Principal component capacity indicator. *International Journal of Productivity and Quality Management*, *1*(1), 1. http://doi.org/10.1504/IJPQM.2021.10043566.

Fontalvo Herrera, T., Mejía Zambrano, F., & Banquez Maturana, A. G. (2024b). Personal evaluation in job search considering: vocation, responsibility and self-confidence by means of six sigma and a geometric multivariate capability indicator. *Migration Letters: An International Journal of Migration Studies*, *21*(5), 1428-1441. Retrieved in 2024, May 23, from https://migrationletters.com/index.php/ml/article/view/9857

Fontalvo Herrera, T., Morelos Gomez, J., & Garcia, N. (2022a). Evaluación de la calidad de la producción de pastas comestibles mediante Seis Sigma. *Investigacion e Innovación en Ingenierias*, *10*(1), 160-177. http://doi.org/10.17081/invinno.10.1.5696.

Fontalvo Herrera, T., & Banquez Maturana, A. (2023). Comparative analysis of multivariate capacity indicators for serial and parallel systems. *International Journal of Six Sigma and Competitive Advantage*, *14*(4), 468-489. http://doi.org/10.1504/IJSSCA.2023.134454.

González-Cebrián, A., Hermenegildo, M., Climente, M., & Ferrer, A. (2022). Multivariate Six Sigma: A case study in an outpatient pharmaceutical care unit. *Quality Engineering*, *34*(2), 277-289. http://doi.org/10.1080/08982112.2022.2042018.

Hou, C.-D. (2023). A simple test to determine the contributors of fraction nonconforming shifts in a multivariate binomial process. *Quality Engineering*, *35*(2), 279-289. http://doi.org/10.1080/08982112.2022.2124876.

Kholil, M. (2023). Lean manufacturing analysis to reduce delaysin the inflight entertainment service before departure check-in process. *The International Journal of Scientific and Academic Research*, *03*(02), 13-23. http://doi.org/10.54756/IJSAR.2023.V3.2.3.2.

Kusumawati, A., Jun-Hwa, C., Thanh, M., & Huang, J. (2021). Evaluation of online travel agent service quality using the importance-performance analysis approach: a study in Indonesia. *Journal of Retailing and Consumer Services*, *58*, 102341.

Li, X., Yafei, L., & Shanika, K. (2021). Evaluating the quality of online tourism service using a hybrid approach based on text mining and an improved intuitionistic fuzzy TOPSIS. *Information Processing & Management*, *58*(6), 102604.

Noskievičová, D., & Moravec, L. (2022). Using principles and selected tools of Lean Six Sigma to improve sustainability: A case study. *Quality Engineering*, *34*(2), 264-276. http://doi.org/10.1080/08982112.2021.2024230.

Rahmer, B. D. J., & Solana Garzón, J. (2020). Análisis comparativo de indicadores de capacidad multivariante. El caso del clúster manufacturero cartagenero. *Revista de Métodos Cuantitativos para la Economía y la Empresa*, *29*, 172-189. http://doi.org/10.46661/revmetodoscuanteconempresa.2961.

Rehman, M. A., Sevgin, A., Lei, Y., & Wei, H. (2022). Assessing the e-service quality dimensions and their impacts on customer satisfaction and loyalty: empirical evidence from e-commerce firms. *Journal of Retailing and Consumer Services*, *64*, 102817.

Singh, A., & Ravi, P. (2023). Lean six-sigma (LSS) applications in hospitals: a decade (2011–2020) bibliometric analysis. *International Journal of Productivity and Performance Management*, *72*(8), 2270-2291. http://doi.org/10.1108/IJPPM-07-2021-0432.

Smith, B. (1993). Six-sigma design (quality control). *IEEE Spectrum*, *30*(9), 43-47. http://doi.org/10.1109/6.275174.

Taleb, M., Ramli, R., & Khalid, R. (2019). Measuring the efficiency of community colleges using super efficiency approach for the case of non-discretionary factors in data envelopment analysis with sensitivity analysis. *International Journal of Process Management and Benchmarking*, *9*(2), 149. http://doi.org/10.1504/IJPMB.2019.099326.

Thakur, V., Akerele, O. A., & Randell, E. (2023). Lean and Six Sigma as continuous quality improvement frameworks in the clinical diagnostic laboratory. *Critical Reviews in Clinical Laboratory Sciences*, *60*(1), 63-81. http://doi.org/10.1080/10408363.2022.2106544. PMid:35978530.

Tzeng, G.-H., Shen, K., & Wang, F.(2022). A hybrid model for improving the service quality of public transportation: combining DEMATEL and IPA. *Transportation Research Part E, Logistics and Transportation Review*, *154*, 102333.

Wang, Y., Ye, Z., Zhang, Y., & Huang, Z. (2020). A comprehensive review of satisfaction and loyalty studies for online shopping. *Electronic Commerce Research and Applications*, *39*, 100905.

Zhang, Z., & Wang, X. (2020). A study on the influence of omnichannel service quality on consumer satisfaction in the context of online-to-offline commerce. *Journal of Retailing and Consumer Services*, *54*, 102033.