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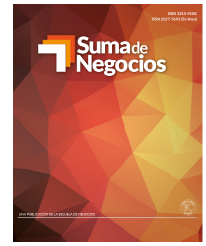

Research paper

Management control for quality in a hospitality business using ARP curves and the multivariate geometric indicator

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ABSTRACT

Introduction / Objective: this study aims to assess the quality of service in a hospitality business with three service lines: premium, standard, and basic, operating under variable conditions. The analysis incorporates operational curves based on Six Sigma metrics and the multivariate geometric capacity indicator. The theoretical framework covers key concepts, including management control, service quality, Six Sigma metrics, average run length performance (ARP) curves, and geometric capacity indicators.

Methodology: the study adopts a rational quantitative approach combined with a sensitivity analysis that adjusts the Sigma performance level (Z) from 3 to 6. It introduces ARP operational curves and the multivariate geometric capacity indicator as tools to evaluate and optimize performance.

Results: the premium and standard service lines achieved the highest Sigma Z levels, consistently exceeding 5. The analysis identified the required production units in each process to transition from an initial performance level (Z_1) to a target level (Z_2). Furthermore, the multivariate geometric indicator classified the overall service as excellent.

Conclusions: the study presents an innovative method grounded in ARP operational curves and multivariate geometric capacity indicators, aligned with Six Sigma metrics. This approach establishes robust control criteria to monitor operational conditions effectively, supporting decision-making processes aimed at enhancing service quality performance.

Control de gestión para la calidad en una empresa hotelera con curvas ARP y el indicador geométrico multivariante

Palabras clave:
Servicio hotelero,
gestión,
curvas de operación,
rendimiento promedio de corrida,
métricas Six Sigma,
indicador geométrico multivariante.

RESUMEN

Introducción / Objetivo: este estudio tiene como objetivo evaluar la calidad del servicio en una empresa hotelera que opera con tres líneas de atención: preferencial, estándar y básica, bajo condiciones cambiantes. Para ello, se implementaron las curvas de operación basadas en métricas Six Sigma y el indicador geométrico de capacidad multivariante. El marco teórico desarrollado incluye conceptos sobre control de gestión, calidad en los servicios, métricas Six Sigma, curvas de operación de rendimiento promedio de corrida (ARP) e indicadores geométricos de capacidad.

Metodología: se utilizó un enfoque cuantitativo racional y un análisis de sensibilidad, ajustando el nivel de desempeño Sigma Z entre 3 y 6. Se propusieron las curvas de operación de rendimiento promedio de corrida (ARP) y el indicador geométrico de capacidad como herramientas principales para el análisis.

Resultados: el análisis demostró que las líneas de servicio preferencial y estándar presentaron los mejores niveles de desempeño, todos superiores a un nivel Sigma Z de 5. Además, se identificó el número de unidades necesarias para progresar de un nivel de desempeño inicial (Z_1) a un nivel objetivo (Z_2). Finalmente, el servicio general fue calificado como excelente mediante la aplicación del indicador geométrico multivariante.

Conclusiones: se desarrolló un método innovador basado en las curvas de operación de rendimiento promedio de corrida (ARP) y los indicadores geométricos de capacidad, fundamentados en métricas Six Sigma. Este método permite establecer criterios de control para monitorear las condiciones operativas del servicio, facilitando la toma de decisiones orientadas a mejorar el desempeño de la calidad.

Introduction

The world is currently grappling with a pressing issue - the rapid and immense population growth. This has led to a stark increase in the inadequacy of people's daily needs, a situation of grave concern (Nayak et al., 2023). In response to this urgent situation, organisations have been compelled to seek a stable source of business. They have adopted a strategic approach based on management control, where researching customer needs and the management capabilities required to meet those needs is a typical sensing activity to achieve quality products or services (Čirjevskis, 2023).

Providing services with desirable quality is a crucial success factor in service industries, especially in the hospitality industry (Saghih & Bidokhti, 2023). Six Sigma continues to be a novel approach to quality management; it is an organisational strategy that seeks to reduce costs and continuously improve all types of processes without losing sight of end-consumer satisfaction (Bagherian et al., 2022; Kenge & Khan, 2021). One of the sectors with the highest demand is the hotel sector; its evolution and growth significantly impact both the customer and the profitability of a country (Na-Nan et al., 2024). Authors such as Yacoub and Harb (2023) determine the importance of the tourism sector for the global economy as crucial.

The analysis of the performance measurement of companies is fundamental and critical for their survival and growth in today's competitive and dynamic business environment (Garg & Agrawal, 2023). Therefore, Six Sigma metrics operating curves, with their ability to represent the relationship between process quality, process variability, and the minimisation of defects in the delivery of products or services to the customer, play a crucial role in facilitating informed decision-making regarding possible adjustments and improvements, providing the confidence to make the right choices (Hu et al., 2024).

Through intangible and customised products, a service meets specific needs. Across management control supported by average run performance operating curves (ARP) of Six Sigma metrics, the number of units needed to improve the performance of a service can be detected, where customer experiences affect loyalty goals and the quality of each experience (positive or negative) directly influences repurchase intention (Bakhshandeh et al., 2023). The multivariate geometric indicator allows measuring multiple characteristics or dimensions of quality; it is widely used in processes to obtain numerical measures of their potential, achieving a comprehensive rating useful for efficient decision-making management, which refers to having more output with less input (Lee et al., 2023). Similarly, other authors have pointed out how the practical applications of Six Sigma for statistical quality control are evolving through the integration of different approaches (Escobar et al., 2024; Fontalvo et al., 2024c).

It is also important to note that, in the business context, different models for quality control and management are currently being implemented (Hariyani et al., 2024). However, these models are not supported by quantitative metrics and indicators that allow for a rigourous and objective analysis of organisational performance. This creates a research gap that this study aims to fill (Delahoz-Domínguez et al., 2024). The proposed Six-Sigma metrics and the multivariate indicator are designed to meet this need, facilitating the evaluation of performance from different perspectives (Silva et al., 2023).

The importance of this research lies in the fact that based on the analysis of multivariate processes, a hotel's service is studied to identify the critical variables indicated for management control, seeking by means of changing characters to simulate the different sigma levels according to the metrics and operating curves to monitor the processes and control the service (Sim et al., 2024). Although the work focuses on hotel service, the proposed method and tools are replicable to any service, which, together with its mathematical and statistical foundations, provides and constitutes a significant contribution to any service organisation (Kim et al., 2024).

Similarly, it is crucial to note that in the current business landscape, various quality control and management models are in use. However, these models lack the support of metrics and quantitative indicators, hindering the quantitative analysis of organisational performance (Kapur et al., 2024). This research aims to bridge this significant research gap by proposing the use of Six Sigma metrics and a multivariate indicator to comprehensively evaluate performance (Bhat et al., 2023).

The following questions are posed for research development: How can a hotel service be assessed using a measurement system? How do we design and run average performance curves of Six Sigma metrics to monitor the number of units when Z changes? How do we establish an indicator to integrate the processes that make up a service in a specific way? How can management control in a hotel service be achieved to improve quality?

To answer these research questions, the following objectives are established: i) To evaluate the performance of the hotel service. ii) To establish ARP curves that allow defining the number of units produced to detect that Z changes from min to max. iii) To comprehensively qualify the hotel service using the multivariate geometric indicator. iv) To define the parameters to control hotel service management.

Theoretical framework

Management control to achieve quality

Management control allows companies to assess their level of compliance, because they are not fully aware of the key tools, metrics and parameters that are crucial and meaningful for effective performance measurement (Garg & Agrawal, 2023). This administrative process takes corrective measures to ensure that activities in an organisation are executed according to the established plans, as it effectively monitors and supervises processes, resources and results, ensuring control over these, significantly impacting the services and/or products offered by a company, thus achieving its development and success (Sonhaji et al., 2024). This type of information must have valid quality metrics and it is necessary to follow the metrics to maintain the high accuracy of the data (Gupta, 2023).

Controlling a company's management is instrumental in achieving organisational competitiveness (Bagherian et al., 2024a). It benefits the operational level by facilitating the coordination of the different areas, leading to results such as customer satisfaction and production efficiency in today's market (Gonzalez Santacruz et al., 2024). This control is about integrating all the components of a product or service to improve its management, ensuring that the company is always at the forefront of the market at every stage of the product/service life cycle (Wings & Harkonen, 2023).

Quality in hotel services

More goods or services are needed for a company to guarantee its permanence in the market. But it must add value to differentiate itself from its competitors and be able to attract more customers. Authors such as Kim (2021) consider the development of new products as a set of activities that integrate customer knowledge. In this sense, quality is the level of acceptability of a process, product, or service that also exceeds customer expectations. Badiru (2022) affirms that integrating quality is the basis for organisational survival and advancement. Where quality exists, business growth will follow.

Maintaining high-quality standards in hotel services directly influences consumer purchase intention and loyalty (Trakulsunti et al., 2024). Reputation is critical in the service industry, where service is an experiential product, whose quality cannot be verified before purchase (Pei et al., 2021).

Customer requirements, such as functionality, quality, and performance specifications, are not a one-time capture but require repeated interactions with customers (Kim, 2021). The advent of new technologies has revolutionised the extraction and analysis of customer feedback, empowering customers to actively participate in the co-creation of value, new service delivery systems, and new technologies (Adel, 2022).

Monitoring and controlling processes have become necessary for companies; quality is in the eye of the beholder and the customer's mind (Badiru, 2022). Metrics are criteria to measure a process in a standardised way; for this reason, Six Sigma focuses on improving quality management methodology that can help companies improve their current processes, products, or services; this technique leads to increased operational efficiency and the optimisation of manufacturing processes, as it monitors poor quality issues by decreasing the significant variation in processes and therefore creates robust products and processes (Madhani, 2022; Qayyum et al., 2021). It will, therefore, be comparable to the Six Sigma standard of 3.4 defects per million opportunities and will serve as a basis on which improvements are suggested and monitored (Shaik et al., 2021).

As Six Sigma metrics are closely related to customer satisfaction, their implementation allows hotel services to identify areas of improvement in the customer experience, optimising the service based on acquisition, stay, and retention, increasing the likelihood of the service being recommend to others, which has a significant impact on the profitability of the business (Bagherian et al., 2024b). If the organisation optimises the use of resources, efficiency translates into economic advantages for the organisation. It will generate a competitive advantage and create new products or services reflected in revenue (Valencia, 2021). The results of the study by Alblooshi et al. (2023) showed that when a citizen feels that the service helps resolve their problems, their satisfaction tends to increase.

Six Sigma metrics ARP operating curves Six Sigma metrics

Operating curves are a novel tool that allows measuring the quality of a process using the number of defects (n), parts per million defects (DPMO), and yield (Y) for a sigma performance level (Z) under varying conditions (Fontalvo et al., 2024a). This set of criteria makes operating curves a valuable tool to analyse the production or service delivery line when the quality performance level Z changes (Fontalvo et al., 2024b), allowing the identification of criteria that offer opportunities for improvement to manage the quality of an organisation's products or services (Fontalvo et al., 2024c). In their research, the authors Fontalvo et al. (in print) and

Fontalvo and Banquez (2023) use the Six Sigma metrics operating curves to compare the performance of two production systems in series and in parallel, determining which is the most efficient. In this way, the Six Sigma metrics ARP operating curves are used to improve the productivity of a system by explicitly detecting the amount of product that needs to be produced to make Z change from Z_1 to Z_2.

Y_i = Process performance for the i state of the product in good condition.

1-Y_i = % of the defective product.

ARP = 1/(1-Y_i) = The total product that must be generated to achieve a yield Y_i

Z_i major = Y_i major = 〖ARP〗_i major = n_i major = units to be produced to achieve a performance Y_i major.

Z_i lower = Y_i lower = 〖ARP〗_(i) lower = n_i lower = units to be produced to achieve a yield Y_i lower.

Z = Six Sigma metrics sigma level.

Y = Process performance according to Six Sigma metrics.

n = Shortcomings of the service delivery system.

ARP (np) = Number of units to be produced to detect that Z changes from Z_1 to Z_2

When performing the sensitivity analysis of Z when it is between 3 and the highest sigma level, it immediately generates Y values that allow different ARP values to be calculated, as shown in Figure 1.

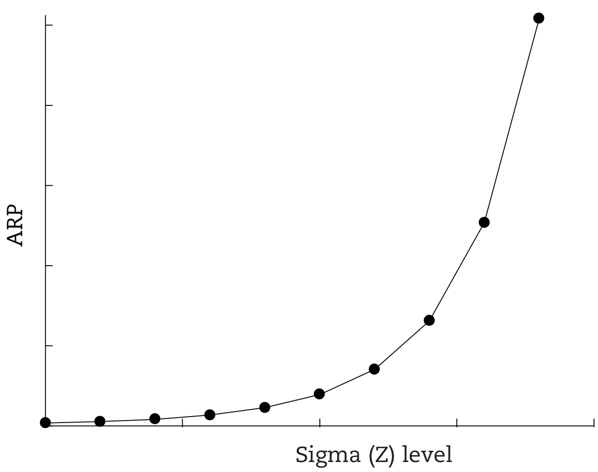

Figure 1. Operating curve of (ARP) for each sigma (Z) level

Source: Own elaboration.

Multivariate geometric indicator of capacity

Currently, there is a more efficient way to monitor processes, including more than one variable and looking at how they correlate with each other (Herrera et al., 2018). Multivariate geometric capability indicators act as a number-based statistical measure capable of assessing the performance of a system or process, particularly in the context of multiple variables, as they focus on outcomes. Monitoring processes with different multivariate statistical control tools, such as multivariate capability indicators and multivariate control charts, facilitates the process of the constant improvement of a company. The robust research of Zacharia and Ravichandran (2022) showed that Six Sigma-based control charts work best, instilling confidence in the proposed methods.

Authors such as Cheng et al. (2012) propose monitoring v characteristics, assuming normality and independence, using the multivariate capability index, MCT, using the following formulation:

$\boldsymbol{MC_K^T} = \frac{1}{3}\,\emptyset^{-1}\left\{\frac{\left[\prod_{j=1}^{v} P_j\right]^{\frac{1}{k}}+1}{2}\right\}$ = the geometric average of compliant units present in the $\boldsymbol{v}$ dimensions involved in quality monitoring.

$\boldsymbol{P_j}$ es $\sum_{i=1}^{k}\frac{pk}{k}$ es j = 1, 2,..., v = P_j is the average percentage of non-conformities in the jth dimension and P_k, that is:

$\boldsymbol{P_k} = \left(1 - \frac{N_i}{U_i \times O_i}\right)$ = with **i** = **1**, **2**,..., **k**, they assume an optimal process performance when the values exceed unity.

Methodology

Data

This work was undertaken in the field of basic research. It is an experimental study implemented to acquire new knowledge concerning the underlying basis of the phenomena as well as the observable facts of the object of study (Marchiori & Minelli, 2023). It consists of a mathematical model that allows the variables and operating conditions of the overall statistical control system and its processes to be considered and contextualised by means of Six Sigma metrics to the service system (Hariyani et al., 2024). Thus, according to the operating conditions of the statistical control system (Sabani et al., 2024), a simulation and sensitivity analysis was performed to generate the system data under varying conditions by modifying the performance level of Z from 3.0 to the maximum capacity of the system and processes. The data and information from the research were generated as response variables for the simulation and sensitivity analysis. The system was evaluated with the above, and the response variables were obtained according to the established quality tools under variable conditions (Wittenberger & Teplická, 2024). Consequently, it was possible to establish the n (defects), the DPMOs, and the Y performance, which was used in the proposed method for a given sigma Z level of the overall system and the service processes under study.

Type, scope, and design

The study employed deductive reasoning supported by mathematics, statistics, multivariate statistical control, Six Sigma metrics ARP curves, and multivariate quality capability indicators. In this line, a simulation and a sensitivity analysis were developed based on the Z performance level of the operating conditions of the service system. With the proposed mathematical model, the performance of the service processes under study was calculated using the sensitivity analysis and the simulation response variables. With the above, n (defects) and DPMO, were generated and used in the proposed method, which consisted of i) determining the overall DPMO; ii) calculating the overall and sub-process defects for each Z level; iii) calculating the Y performance, as well as the defects in parts per million DPMO; iv) proposing the ARP operation curves to control the system;

v) calculating the multivariate indicator of capacity to evaluate the system; and vi) analysing the conclusions and results of the proposed method.

Procedure

Through simulation, primary information was generated associated with the operating conditions of the system under variable conditions related to the Six Sigma metrics quantity of defects in parts per million opportunities (DPMO) and performance (Y) through a sensitivity analysis modifying the sigma Z performance level from 3 to 6 and analysing its effect on the DPMO and Y metrics of the hotel service provision processes. The evaluation model was contextualised in the operating conditions of the hotel's three service lines.

The following metrics are defined for the service evaluation process and its levels; see Table 1.

Table 1. Six Sigma metrics

Metrics	Definition
DPMO	Represents the number of defects that could occur per million opportunities
Z	Sigma Level
Y	Process performance
U	Number of incoming units
O	Opportunity for error
T	Total defects (UxO)
n	Number of non-conformities
S	Unit output (U-n)
ARP	Average run performance (Y)

Source: Own elaboration.

The following diagram represents the functioning of hotel service and its three lines of attention, to which the metrics above will be applied; see Figure 2.

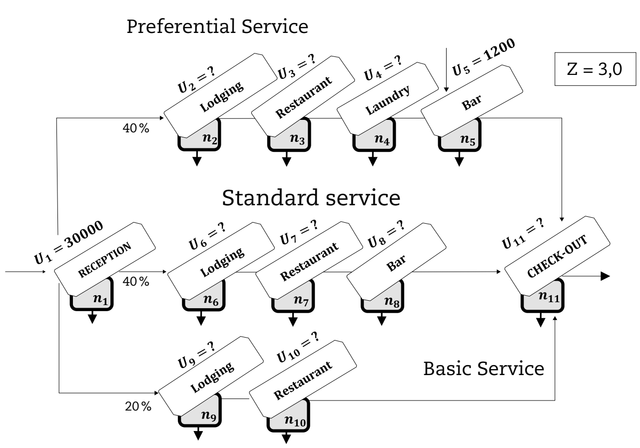

Figure 2. Hotel service system

Source: Own elaboration.

Data analysis

A diagram was designed to evaluate the hotel service's functioning (Figure 2), showing its operation. Service is made up of three different lines of attention. The hotel, with its remarkable capacity, receives 30 000 clients at reception, demonstrating its efficiency and ability to handle a large volume of guests. These clients are accommodated according to their interests. The first line is that of preferential services, which consists of accommodations, a restaurant, laundry, and a bar; the latter is also open to the public, where it receives 12 000 external clients per month. The second service line is the standard: accommodation, restaurant, and bar; it was also evaluated considering 12 000 customers per month. Finally, the third basic service line expects to receive 6000 services per month, for a total of 30 000 services for the system under analysis.

Next, the total number of defective services that the system produces was calculated (n_g), by applying the following formula

$$n_g = \frac{DPMO * U * O}{1.000\ .000} \quad (1)$$

Where DPMO is calculated as a function of the overall sigma level. (Zg), as follows

$$DPMO = e\left[\frac{29{,}3 - (z - 0{,}8406)^2}{2{,}221}\right]$$

$$DPMO = e\left[\frac{29{,}3 - (3{,}0 - 0{,}8406)^2}{2{,}221}\right] = 65.693 \quad (2)$$

We replace it in the equation (1]:

$$n_g = \frac{65\ .693\ * 31\ .200\ * 1}{1.000\ .000} = 2.050$$

Having obtained n_g, the following equations are equated to n_1 to find their value.

$$n_g = n_1 + 2\,n_2 + 3\,n_3 + 4\,n_4 + 5\,n_5 + 2\,n_6 + 3\,n_7 + 5\,n_8 + 2\,n_9 + 3\,n_{10} + 5\,n_{11}$$

$$2.050 = n_1 + \frac{1}{2}n_1 + \frac{1}{3}n_1 + \frac{1}{4}n_1 + \frac{1}{5}n_1 + \frac{1}{2}n_1 + \frac{1}{3}n_1 + \frac{1}{5}n_1 + \frac{1}{2}n_1 + \frac{1}{3}n_1 + \frac{1}{5}n_1$$

$$n_1 = \frac{2050}{4.35} = 471 \quad (3)$$

$U_1 = 30.000$	(4)	$U_7 = (U_6 - n_6)$	(10)
$U = (U_1 - n_1) * 40\%$	(5)	$U_8 = (U_7 - n_7)$	(11)
$U_3 = (U_2 - n_2)$	(6)	$U_9 = (U_1 - n_1) * 20\%$	(12)
$U_4 = (U_3 - n3)$	(7)	$U_{10} = (U_9 - n_9)$	(13)
$U_5 = (U_4 - n_4) + 1200$	(8)	$U_{11} = (U_5 - n_5) + (U_8 - n_8) + (U_{10} - n_{10})$	(14)
$U_6 = (U_1 - n_1) * 40\%$	(9)	$U_g = U_1 + U_5$	(15)

The equations that help determine the number of units (U) entering each process are now defined.

Once n and U are known for each process, the number of defects in parts per million is calculated. (DPMO) [16], followed by, the corresponding sigma (Z) level [17].

Finally, the performance (Y) [18] and the run-average performance curve are calculated:

$$DPMO = \frac{n}{U*O} * 1.000.000$$

$$Z = \sqrt{29{,}3 - 2.221 * \ln\ (DPMO)} + 0{,}8406 \quad (16)$$

$$Y = 1 - \left(\frac{n}{UxO}\right) \quad (17)$$

$$RPC = \frac{1}{(1-Y)} \quad (18)$$

Each hotel service according to the determined conditions will be evaluated according to a defined sigma level, applying the following Table of ranges as a reference.

Table 2. Performance criteria for Six Sigma metrics

Sigma (Z) Level	Performance
Z < 3,0	Deficient
3,0 ≤ Z ≤ 3,5	Acceptable
3,5 < Z ≤ 4,6	Outstanding
Z > 4,6	Excellent

Source: Own elaboration.

On the other hand, the geometric multivariate capacity indicator is applied CM_K^T this proposes the monitoring of v characteristics using the following formula:

$$CM_K^T = \frac{1}{3}\,\varnothing^{-1}\left\{\frac{[\prod_{j=1}^{v} P_j]^{\frac{1}{k}}+1}{2}\right\} \quad (19)$$

This methodology calculates the geometric average of units that comply with the standards in v dimensions related to quality control. In addition, it enables the evaluation of the average percentage of non-conforming units (n) with the standards in the jth dimensions using Six Sigma metrics.

$$\sum_{i=1}^{k} \frac{pk}{k} \quad j=1, 2\ldots, v \quad (20)$$

Pj represents the average number of nonconformities (n) in dimension j, and pk is the probability measure for each of the categories or modalities of the evaluated dimension, that is

$$pk = 1 - n_i \quad \text{where } i = 1,2,\ldots,k \quad (21)$$

The results achieved will be scored against the performance criteria established by the indicator using the following Table.

Table 3. Performance criteria for the geometric capacity indicator

Geometric capacity indicator (SM_K^T)	Performance
$CM_K^T < 0{,}5$	Deficient
$0{,}5 \le CM_K^T \le 0.75$	Good
$CM_K^T > 0{,}75$	Excellent

Source: Own elaboration.

Ethical considerations

By the stated scope of the basic research, this study was conducted by structuring a mathematical model of the system under study, which was thoroughly analysed through simulation and sensitivity analysis. Therefore, this research did not require the participation of people to obtain information. Consequently, aspects such as obtaining informed consent are not addressed.

Results

With the model proposed in the method, the performance of hotel service is evaluated by applying Six Sigma metrics. A sensitivity analysis was carried out by varying the level of sigma Z quality performance, and the following results were obtained.

The sigma levels of the overall service show a significant variation, with data ranging from 3, the minimum value, to 4,8, the maximum value. This range reassures stakeholders that the hotel's service performance consistently operates between acceptable and excellent levels. Notably, both reception and check-out processes demonstrate this, starting with sigma levels of 3,64 and 4,21 (outstanding) and culminating with figures of 5,18 and 5,59 (excellent), respectively.

Table 4. Minimum and maximum values for each process according to Six Sigma metrics

	Minimum and maximum values for each process							
	Minimums				Maximums			
Processes	Z	Y	ARP	Performance	Z	Y	ARP	Performance
Global service	3	92,991%	14	Acceptable	4,8	99,951%	2.032	Excellent
Reception	3,64	98,429%	64	Outstanding	5,18	99,989%	9.070	Excellent
Pref. Lodging	3,54	98,005%	50	Outstanding	5,13	99,986%	7.255	Excellent
Pref. Restaurant	3,70	98,643%	74	Outstanding	5,23	99,991%	10.881	Excellent
Pref. Laundry	3,80	98,968%	97	Outstanding	5,30	99,993%	14.506	Excellent
Pref. Bar	3,92	99,246%	133	Outstanding	5,38	99,995%	19.946	Excellent
Stand. Lodging	3,54	98,005%	50	Outstanding	5,13	99,986%	7.255	Excellent
Stand. Restaurant	3,70	98,643%	74	Outstanding	5,23	99,991%	10.881	Excellent
Stand. Bar	3,89	99,175%	121	Outstanding	5,36	99,994%	18.133	Excellent
Bas. Lodging.	3,24	96,011%	25	Acceptable	4,94	99,972%	3.627	Excellent
Bas. Restaurant	3,41	97,230%	36	Acceptable	5,05	99,982%	5.440	Excellent
Check-out	4,21	99,678%	310	Outstanding	5,59	99,998%	47.141	Excellent

Source: Own elaboration.

Preferred service, which includes lodging, restaurant, laundry and bar, operates between an outstanding criterion, with values above 3,5 for each process, and an excellent criterion, with values above 4.6 for each process; similar results are obtained for the standard service, which includes lodging, restaurant and bar.

Basic service, comprising accommodation and a restaurant, demonstrated lower performance than the other services, operating between acceptable and excellent performance.

Analysis - Average Run Performance (ARP) operating curves for each Sigma (Z) level

Through operation curves, the different processes in hotel service were analysed concerning the Six Sigma metrics (Z) and their average run performance (ARP), calculating the number of services that must be provided to go from a Z_1 to a Z_2 level.

For the overall service of the quality control system, it is observed that the sigma level goes from $Z_1=3$ (acceptable) to $Z_2=4,8$ (excellent), which requires 2018 services to be provided, a result obtained from the difference between ARP max and ARP min, for the case of reception its sigma level changes from $Z_1=3,64$ (outstanding) to $Z_2=5,18$ (excellent) which requires nine services to be provided. Finally, hotel check-out shows an improvement in its sigma level from $Z_1=4,21$ (outstanding) to $Z_2=5,59$ (excellent), requiring 46 831 services. (Figures 2, 3 and 4).

The quality control system for preferential service detected a change in its lodging in its sigma level from $Z_1=3,54$ (outstanding) to $Z_2=5,13$ (excellent), which requires 7205 services to be offered; on the other hand, the restaurant showed a change in its sigma level from $Z_1=3,70$ (outstanding) to $Z_2=5,23$ (excellent), requiring 10 807 services to be offered; regarding the laundry, its sigma levels increased from $Z_1=3.80$ (outstanding) to $Z_2=5,30$ (excellent), which requires 10 205 services to be offered. Eight hundred seven services, for the laundry, its sigma levels increased from $Z_1=3,80$ (outstanding) to $Z_2=5,30$ (excellent), requiring 14 409 services to be produced; finally, the bar's sigma level went from $Z_1=3,92$ (outstanding) to $Z_2=5,38$ (excellent) requiring 19 813 services to be provided. (Figures 5, 6, 7 and 8).

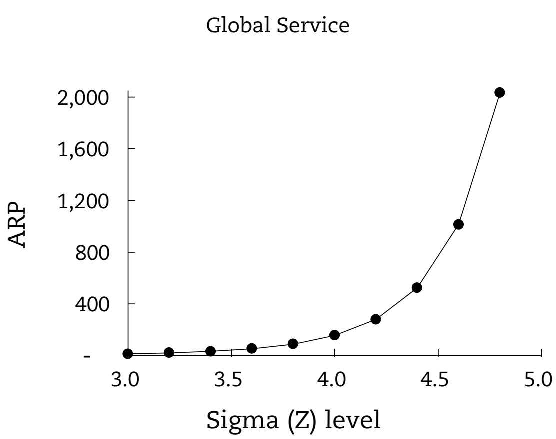

Figure 2. Operating curve (ARP) for each sigma (Z) level
Source: Own elaboration.

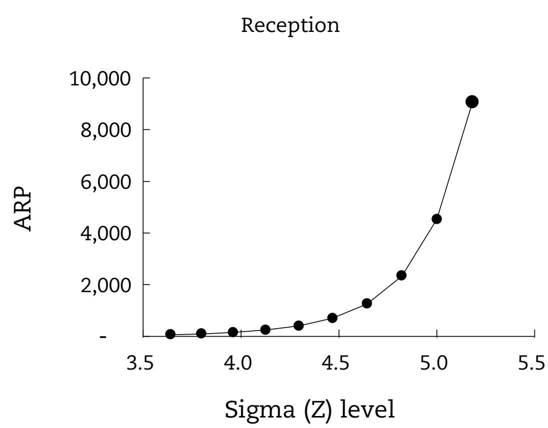

Figure 3. Operating curve (ARP) for each sigma (Z) level
Source: Own elaboration.

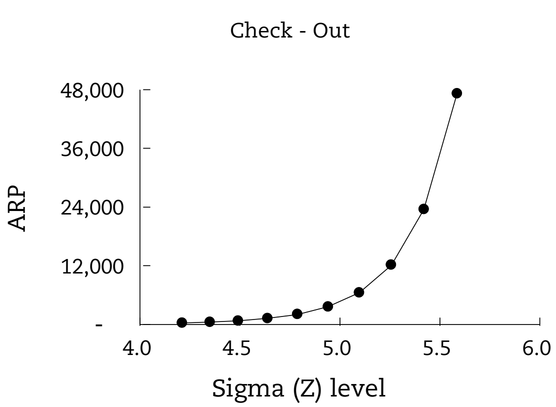

Figure 4. Operating curve (ARP) for each sigma (Z) level
Source: Own elaboration.

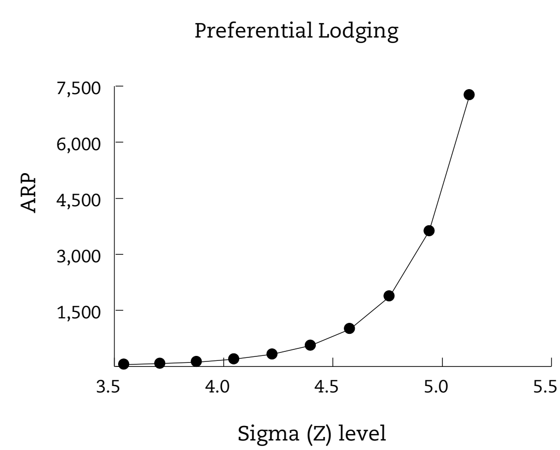

Figure 5. Operating curve (ARP) for each sigma (Z) level
Source: Own elaboration.

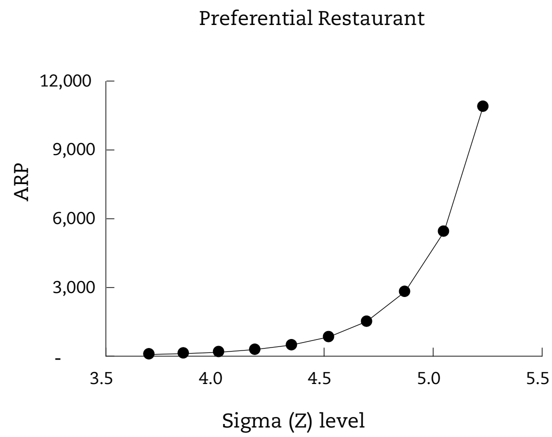

Figure 6. Operating curve (ARP) for each sigma (Z) level

Source: Own elaboration.

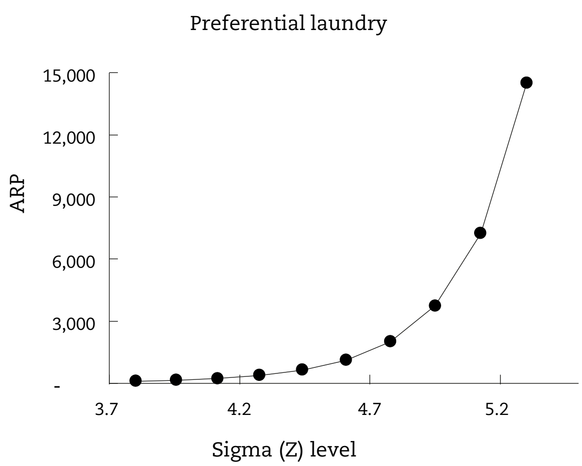

Figure 7. Operating curve (ARP) for each sigma (Z) level

Source: Own elaboration.

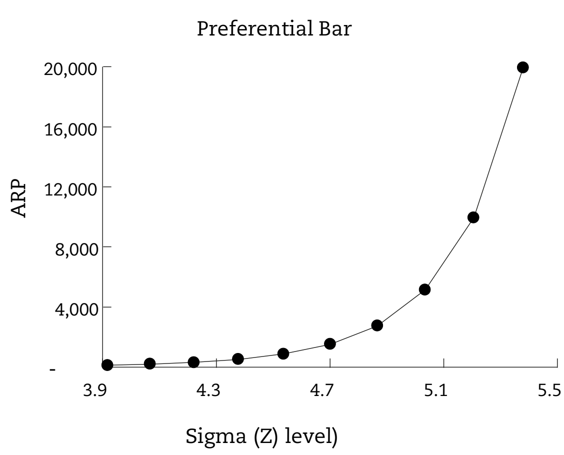

Figure 8. Operating curve (ARP) for each sigma (Z) level.

Source: Own elaboration.

For the standard service of the quality control system, regarding lodging, there is a change in the sigma level from Z_1=3,54 (outstanding) to Z_2=5,13 (excellent), which requires 7205 services, in the case of the restaurant, it is observed that the sigma level changes from Z_1=3.70 (outstanding) to Z_2=5,23 (excellent) requiring 10 807 services to be offered and finally, the bar presented a change in its sigma level from Z_1=3,89 (outstanding) to Z_2=5,36 (excellent) which requires 18 012 services to be produced (Figures 9, 10, and 11).

The quality control system corresponding to hotel basic service observed regarding its accommodations that the sigma level went from Z_1=3.24 (acceptable) to Z_2=4,94 (excellent), which requires 3602 services to be provided; for the restaurant sigma level changes from Z_1=3,41 (acceptable) to Z_2=5,05 (excellent) needing to offer 5404 services. (Figures 12 and 13).

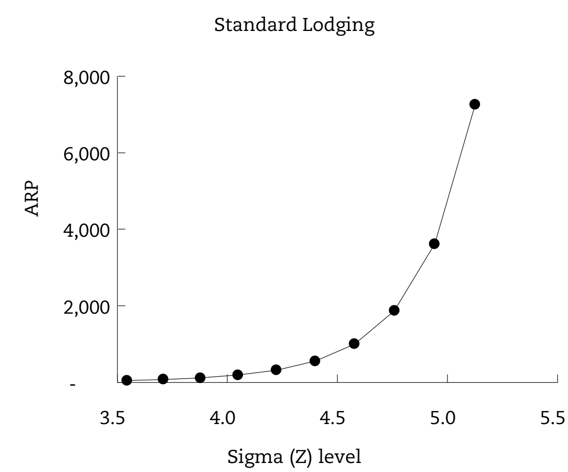

Figure 9. Operating curve (ARP) for each sigma (Z) level

Source: Own elaboration.

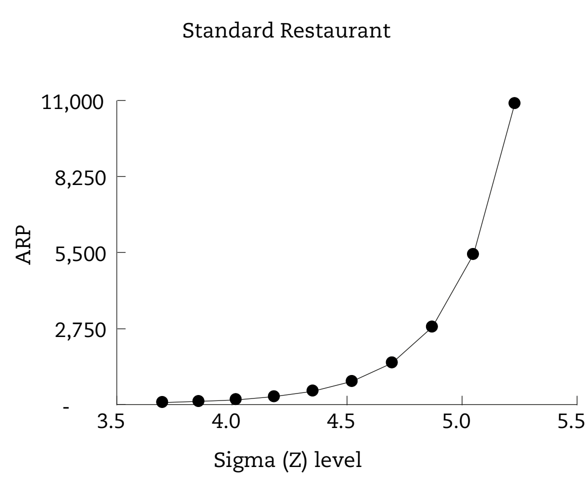

Figure 10. Operating curve (ARP) for each sigma (Z) level

Source: Own elaboration.

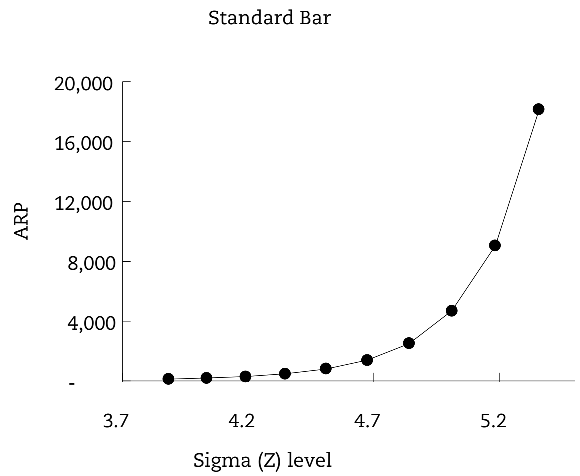

Figure 11. Operating curve (ARP) for each sigma (Z) level
Source: Own elaboration.

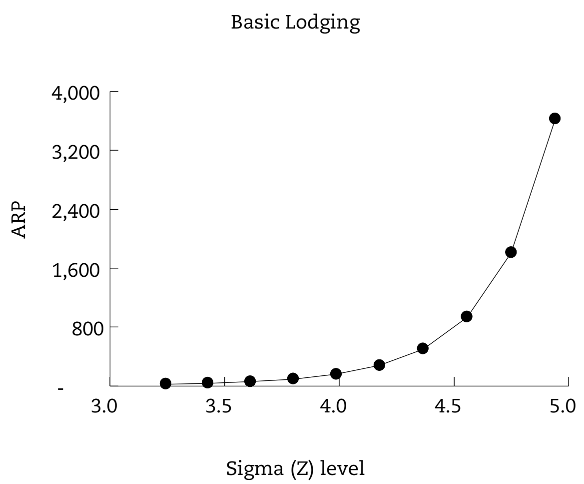

Figure 12. Operating curve (ARP) for each sigma (Z) level
Source: Own elaboration.

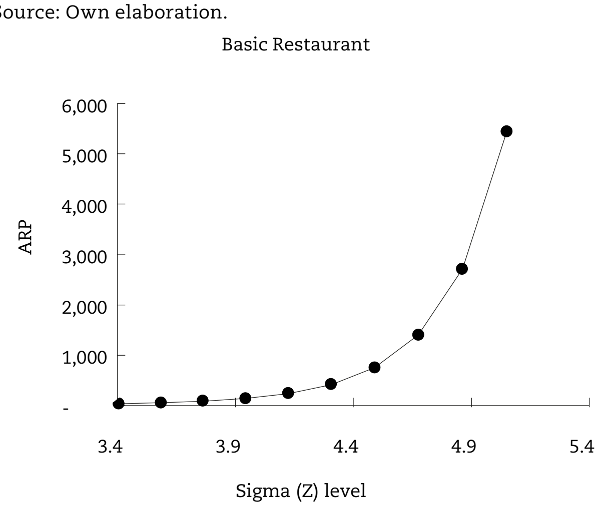

Figure 13. Operating curve (ARP) for each sigma (Z) level
Source: Own elaboration.

Multivariate geometric indicator of capacity

The geometric multivariate capability indicator in the Six Sigma methodology is applied in the following way. First, the performance averages (Y) are found for each process; then, they are multiplied. It is raised to 1/11 where 11 represents the number of total processes in the service; one is added and divided by 2, obtaining a result to which the inverse standard normal distribution divided by three is applied, as shown in the equation [20], presenting the following result (Table 5).

Table 5. Average of the processes for calculating the geometric indicator of capacity

Geometric capacity indicator		
Processes	**(y) Average**	**D.N.E.I.**
1	0,996	
2	0,995	
3	0,996	
4	0,997	
5	0,998	
6	0,995	0,95
7	0,996	
8	0,998	
9	0,989	
10	0,993	
11	0,999	

Source: Own elaboration.

$$CM_K^T = \frac{1}{3}\,\emptyset^{-1}\left\{\frac{[(98,429\% \dots 99,989\%) * \dots * (99,678\% \dots 99,998\%)]^{\frac{1}{11}} + 1}{2}\right\}$$

$$CM_K^T = \frac{1}{3}\,\emptyset^{-1}\left\{\frac{\left[\prod_{j=1}^{v}[0,996]+1\right]}{2}\right\} \quad (22)$$

$$CM_K^T = \frac{1}{3}\,\emptyset^{-1} = 0,998$$

$$CM_K^T = 0,95$$

Performance criteria (see Table 3):

If $CM_K^T < 0,5$ the service performance is deficient.

If $0,5 \leq CM_K^T \leq 0,75$ the service performance is good.

If $CM_K^T > 0,75$ the service performance is excellent

The results achieved indicate that the geometric indicator globally evaluates the performance of the hotel service by integrating variables related to the performance of each process. Once the process capability indices have been obtained, they are used to obtain numerical measures of the service potential. It is reassuring to note that the general and specific quality of hotel service is excellent, as the multidimensional geometric quality capability indicator is higher than CMT ≥ 0,75, underscoring the high standard of service quality.

As a finding, the improvement of the service area throughout its operation is demonstrated, with sigma levels ranging between 3 and 4,8 in overall service, receiving a performance between acceptable and excellent. Something notable in the analysis was the relationship between reception and check-out. However, they received equal incoming units, and an improvement in check-out was evident, with a higher sigma level of 5,59, a positive characteristic in hotel service. Of the three different lines of attention offered by the hotel, preferential service and standard service demonstrated why they are the most requested by clients; both services presented sigma (Z) levels greater than 5, being catalogued as excellent, in addition, their yields (Y) reached percentages more significant than 99.98%, obtaining through the ARP operation curves the most significant difference, which indicates an increase in the growth of the sigma level from Z_1 to Z_2. Hotel basic service presented the lowest results, initially with acceptable sigma levels, then moving on to excellent. Finally, the multivariate geometric capability indicator CM_K^T was used to evaluate hotel service integrally, obtaining a result of 0,95. Thus, hotel service is catalogued as excellent (≥ 0,75) in general and of a specific quality, with which it can be asserted that the performance of the process complies with the defined objectives of the client.

Discussion

The contribution of this research is the evaluation of hotel service composed of 3 different service lines through the development of the operation curves of Six Sigma metrics to evaluate the performance of the system under changing conditions, implementing ARP operation curves as novel tools which are helpful in detecting the necessary services that need to be produced to move from Z_1 to Z_2 level and the geometric indicator of capacity as a potential gauge of the performance of a process to comply with the guidelines pre-established by the client. In this way, we contribute to the scientific environment with innovative criteria that allow us to identify how to use the ARP operation curves of Six Sigma metrics and the geometric indicator of capacity to qualify and measure the performance of a service (Pacagnella Junior et al., 2024).

Other authors have analysed the interaction of different factors, multivariate quality capability indicators, Six Sigma metrics, and tools for the implementation of statistical control systems in organisations to improve quality (Einhorn et al.,2024; Fontalvo et al., 2024c). In line with this study, Fontalvo et al. (2024a), in their research "Performance of a concurrent parallel production system through new Six Sigma metrics operating curves," propose a novel method that provides criteria to monitor the performance of a production system under changing conditions. This method, involving the construction of Six Sigma metrics operating curves, is not just a theoretical concept, but a practical tool that allows for the monitoring of quality performance under changing conditions and the analysis of how these changes affect the reduction of defects in any production system (Fontalvo et al., 2024b). The research also includes a comparative analysis of multivariate capability indicators for serial and parallel production systems, supported by Six Sigma metrics (Fontalvo & Banquez, 2023). Unlike previous articles, this primary research develops new operating curves based on the Six Sigma metrics' Average Running Performance and geometric indicators, specifically applied in the context of the hotel service sector. It, therefore, provides new perspectives for assessing the performance of the evaluated service system.

Furthermore, a variety of strategies has been explored to enhance customer service in the hotel industry. The research has shown that top management support and customer relationship management are the most effective strategies, significantly influencing service requirements (Saghih & Bidokhti, 2023). Moreover, the implementation of an innovative analysis method for technological management in the era of Industry 4.0 has shown promising results, reducing production costs and improving internal management efficiency (Zhang et al., 2023). In contrast to main research, a sensitivity analysis was conducted using novel tools tailored for managing hotel services, determining the optimal number of services to be produced for improving Z. These strategies hold the potential to significantly improve the future of the hotel industry.

It's important to underscore that the mathematical model of the integrated statistical quality control system, Six Sigma metrics, the Six Sigma metrics operation curves, and the multivariable capacity indicator transcend the boundaries of the hotel service sector. The global defect balance and the calculations of the levels following Z, DPMO, and performance Y are part of a universally applicable method that can be implemented in any service context at a global level, connecting us to a larger community of quality control professionals (Gupta et al., 2024).

Conclusions

As a methodological and theoretical contribution, this research articulates the concepts of hotel service quality, Six Sigma metrics, Six Sigma metrics operation curves, ARP operation curves, and capability indicators. A practical and applicable method was established based on the ARP operation curves of the Six-Sigma metrics and capacity indicators, which allows a hotel service's performance to be evaluated comprehensively and globally with a multi-process approach.

The value of the methodological proposal of this research allows: (a) To model a measurement system for a specific service. (b) To evaluate this measurement system by implementing Six Sigma metrics. (c) To monitor its performance through a sensitivity analysis with the Six Sigma metrics operation curves. (d) To determine maximum and minimum capacities to know the services that must be produced for Z to change from Z_1 to Z_2 through the ARP operation curves. (e) To qualify the service in a general way, integrating multiple variables. (f) To assess according to the criteria of Six Sigma metrics and the capability indicators. (g) To analyse and make decisions to improve and control the intervened service. This represents an innovative contribution to the evaluation of any hotel service in an international context.

From a practical approach, this research has allowed us to evaluate the performance of Six Sigma metrics for the processes and the service in question. More importantly, it has established robust control criteria to monitor the service operating conditions, enabling us to determine the optimal number of services to be provided. This allows us to detect when the dispersion measure changes from Z_1 to Z_2, facilitating decision-making for better-quality performance management. We have used Six Sigma metrics ARP operating curves and capability indicators for an overall or independent service, underscoring the methodological rigour of our study.

Furthermore, regarding future research and practical challenges associated with the findings and results of this research, the scientific community and the business and service sector are invited to replicate the proposed method in other business contexts. Their role in this replication is crucial, as it will enable the establishment of timely, longitudinal, and holistic performance standards, and the analysis of performance from different perspectives, leading to actions that contribute to quality improvement. This should be accompanied by training processes associated with the model's tools, such as statistical quality control, Six-Sigma metrics, Six-Sigma metrics operation curves, and the geometric quality capability indicator of Six-Sigma metrics. These are essential for those who play a vital role in the quality improvement processes of the organisation, where the proposed method developed in this basic research is replicated. Organisations must also guarantee the resources associated with the time required for training and the establishment of measurement and data collection points, as well as the technological support to systematise the assessment criteria set out in the measurement methodology that will enable performance standards to be established, a control system to be set up and decisions to be taken to improve the service evaluated.

As in all research, this research has limitations. One of them is to be able to establish a good system for collecting primary data in order to calculate the metrics and the appropriate multivariate quality capability indicator for the respective organisational context. Similarly, the knowledge and understanding of the tools and techniques on the part of the human talent that will implement the method, a task that can be outsourced. Likewise, the availability of technological resources that allow the integral measurement and control system to be systematised for a good analysis and decision making of the performance indicators to guarantee quality in the service or industrial context to be evaluated and managed. It is also a limitation that this basic research, supported by mathematics and statistical control analyses, validates this study's proposed methodology with metrics that may vary and be specific to other business contexts. For example, Fontalvo et al. (in print) and Fontalvo et al. (2024c) propose other multivariate capability indicators, tools, and perspectives of Six Sigma that allow articulating other different comprehensive statistical quality control systems, with which good measurement and control systems were established, for analysis and decision making (Pratik & Yashoda, 2024; Qin et al.,2024).

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Conflict of interest

The authors declare that they have no conflicts of interest.

Authors' contribution

Tomás José Fontalvo Herrera: conceptualisation, formal analysis, research, methodology, writing (original draft), writing (refereeing and editing corrections); Juan José Tous Ferrigno: conceptualisation, formal analysis, research, methodology, writing (original draft), writing (refereeing); Fabio Mejía Zambrano: conceptualisation, formal analysis, research, methodology, writing (original draft), Translation.

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