Analyzing the Short-term and Long-term Sigma Level Relation in a Metal Fabrication Process

Omar Celis-Gracia[1]; Jorge Luis García-Alcaraz[2]; Maribel Mendoza-Solis[3]
[1,2]Universidad Autonoma de Ciudad Juarez, Mexico, *al232735@alumnos.uacj.mx, jorge.Garcia@uacj.mx*
[3]Universidad Tecnologica de Ciudad Juarez, Mexico, *maribel.mendoza@uacj.mx*

Abstract*– This study analyzes the relationship between short- and long-term sigma levels in a metal bottle manufacturing process using an approach based on Six Sigma methodology. Although in the 1990s, Mikel Harry established an average difference of 1.5 sigma between these two metrics, the present work questions the validity of this value, considering technological advances and the evolution of industrial processes. A six-stage methodological design was employed, including identifying a critical response variable, collecting 800 data points by controlled sampling, and performing statistical analysis to determine short- and long-term sigma levels. The results show that for this process, the short-term sigma level is 1.455, whereas the long-term level is 0.423, generating a ratio of 1.023. This suggests that the gap established by Harry does not apply to all cases. The results conclude that updating the metrics used in Six Sigma projects is necessary to improve decision-making accuracy, opening new opportunities to investigate this relationship in other industrial sectors. However, because the analysis was based on a single case study, the proposed methodological sequence should be replicated across different processes and operating conditions before generalizing the observed sigma gap.

Keywords—MSA, Six Sigma, Lean Sigma, Sigma Level, Continuous Improvement.

I. INTRODUCTION

Peter et al. [1] stated that quality management is a primary concern for companies across all sectors, as it directly impacts customer satisfaction, brand reputation, and business success. Similarly, Pozzi et al. [2] stated that consistently maintaining high-quality products and services is a significant challenge for companies in today's dynamic and competitive business environments. This challenge arises from several factors, such as globalization, rapid technological advancements, changing customer expectations, and increasing regulatory requirements [3].

First, globalization has increased the complexity of supply networks and production processes. Many global suppliers provide companies with materials, components, and services to manufacture their products. It is difficult to maintain consistency, reliability, and quality across the supply chain. Supplier performance, regulatory restrictions, and cultural differences can complicate quality management [4]. Second, rapid technical improvements have changed product design, manufacturing, and supply chain processes. While technology improves productivity and innovation, it complicates quality management. Companies must adapt to new technologies, procedures, and tools while maintaining quality throughout the product life cycle [5]. Automation, robotics, and AI increase product reliability, cybersecurity, and data integrity. Third, organizations must adapt to changing client expectations and preferences to maintain high quality. The networked world provides customers with access to information, opinions, and evaluations that shape their expectations regarding product quality, reliability, and performance. To keep customers happy and loyal, companies must monitor feedback, anticipate trends, and handle difficulties [6].

For these reasons, companies must constantly improve their quality. In Mexico, companies known as maquiladoras have been established, which are branches of companies based in other countries that take advantage of the cheap and skilled labor available in the region [7]. Currently, there are 5,138 maquiladora companies in Mexico, of which 498 are in Chihuahua State, and 326 are in Ciudad Juárez. This is the primary sector in the last region. The social importance of this sector is evident in the fact that these companies generate 2,689,209 direct jobs nationwide, 477,480 in Chihuahua, and 316,619 in Ciudad Juárez. However, the economic role of the maquiladora industry is also important because, from January to September 2020, it exported 188.645 billion dollars nationwide; however, companies in Chihuahua imported 22.637 billion dollars, and those in Ciudad Juárez imported 16.978 billion dollars [8].

A. *Six Sigma*

The history of SS dates back to the 1980s, when Motorola, under the direction of engineer Bill Smith, faced intense competition in the telecommunications sector [9]. Smith acknowledged the need for a systematic approach to quality management to address defects and improve industry competitiveness. Drawing inspiration from existing quality management methodologies, such as Total Quality Management (TQM), Statistical Process Control (SPC), and Deming's Plan-Do-Check-Act cycle, Smith developed the SS methodology [10].

SS has gained greater relevance owing to its successful implementation in companies such as AlliedSignal (now Honeywell), IBM and Ford Motor Company [11]. These organizations have significantly improved quality, productivity, and profitability, leading to widespread adoption in manufacturing, healthcare, finance, and services [12].

SS has evolved over the years, with various variants, such as Lean Six Sigma, which integrates lean principles with the SS methodology to improve speed and quality. Organizations continue to refine and adapt SS to meet their needs and challenges, demonstrating its enduring relevance as a powerful tool for continuous improvement and business excellence [13].

B) Short-Term and Long-Term Definition

Short-term sigma is usually evaluated using immediate data to assess the current state of a process [14]. This indicator is particularly useful for identifying rapid solutions and immediate improvements. For example, in laboratory environments, short-term sigma can be used to monitor the performance of assays or tests, allowing for quick adjustments to maintain quality control [15]. Focusing on short-term sigma can help organizations respond quickly to operational issues, ensuring that processes remain within acceptable limits [16].

In contrast, long-term sigma provides a broader perspective by incorporating data over a longer period, which helps in understanding the stability and capability of processes over time. This metric is essential for identifying trends and changes that may not be evident in short-term evaluations. The cumulative effects of process variations influence long-term sigma values and are fundamental for predicting the reliability of the results in various applications, including medical laboratories [17]. For example, studies have shown that strict quality control measures can significantly reduce long-term defect rates, thereby improving patient safety and the reliability of the test results [18].

Moreover, the distinction between short- and long-term sigma is not merely academic but has practical implications for quality-management strategies. Organizations focusing solely on short-term sigma may overlook the underlying issues that could lead to long-term failure. Therefore, a balanced approach that integrates short- and long-term sigma metrics is necessary for comprehensive quality management [19]. This dual approach allows organizations to address immediate concerns and develop strategies to ensure sustained performance improvement over time [20].

In summary, whereas short-term sigma provides valuable information about a process's immediate performance, long-term sigma is crucial for understanding the overall stability and reliability of the process. Both metrics are essential for effective quality management, especially in environments where precision and accuracy are paramount, such as healthcare and laboratories.

C) Gap between Short-term and long-term sigma levels

Harry [21] introduced SS to bring manufacturing processes to a six-sigma level, that is, 3.4 defective parts per million, focusing on reducing process variation using statistical methods. Over time, Mikel realizes that although the processes achieve a significant increase in the sigma level in the short term, this is affected in the long term, as shown in Figure 1. Mikel estimated that the long-term sigma level of the process was affected by 1.5 sigma's compared to that observed in the short term. Although Mikel quantified a negative effect at the sigma level, he could not find its cause and attributed it to inexplicable reasons. It is important to highlight that the long-term sigma level is affected by 1.5 sigma, which implies an additional 40% of non-conforming products compared to the short-term level.

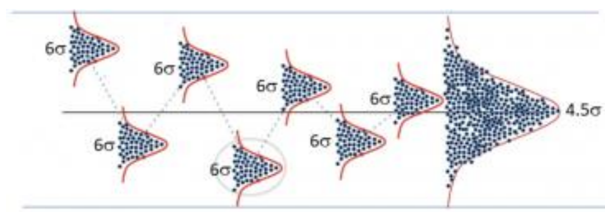

Fig. 1 Short-term and Long-term representation.

Once the sigma level was introduced in the short and long terms, and after seeing that the processes did not reach Six Sigma levels, Mikel decided to give the Six Sigma approach a new twist and determined that the purpose of this philosophy would not be to achieve a six sigma process as originally intended, but rather that the focus would now be based on continuous improvement projects, taking annualized savings for the company as the primary variable.

Therefore, Mikel established since the 1990s that the gap between the sigma levels in the short and long terms is, on average, 1.5. For the past 35 years, this value has been used to estimate the long-term quality level without considering that processes have evolved over time owing to technological advancements and without considering the diversity of existing processes and the various factors that affect long-term variation to different extents.

This study aims to analyze whether the variation in current manufacturing processes differs from the 1.5 sigma established by Mikel Harry, a value calculated decades ago, and compare it with the current quality levels reported in the literature. To demonstrate this, a case study was conducted in a company dedicated to manufacturing metal bottles, where the actual short- and long-term were calculated.

The novelty and scientific contribution of this case study is that it highlights a field of study regarding short-term variation and that the value of 1.5 that has been used for 30 years has changed owing to the evolution of production processes and better measurement systems. Knowing the real value of processes today will allow companies to make better decisions and achieve better results in Six Sigma projects because currently, Six Sigma projects are measured with the short-term sigma value, as the long-term value is lower. Knowing the current value of the gap between the two sigma values will allow companies to conclude their projects based on the long-term sigma level, which represents a greater reality of what happens in the processes, resulting in more significant improvements for the company in terms of savings and profitability, achieving the primary objective of Six Sigma, which is to take the processes to quality levels of 3.4 ppm defects.

The remainder of this document is organized as follows: after a brief introduction, section two presents the methodology employed to demonstrate the purpose of this research. Section three analyses the results. Section four reports the conclusions. Section five presents the limitations and future research directions.

II. Methodology

The methodology used in this study consists of six steps, as described below. To improve the reproducibility and methodological clarity of the study, the evaluation was conducted under normal production conditions using a defined sampling plan, controlled measurement criteria, and documented record quality. The response variable, sampling frequency, measurement instrument, specification limits, personnel involved, and statistical analysis method were established prior to data collection. Measurements were performed by Quality Department personnel using the same measuring method applied for product release, ensuring that the collected data represented the actual behavior of the manufacturing process rather than laboratory-isolated conditions.

To improve the clarity and reproducibility of the proposed approach, Table I provides a structured summary of the methodological sequence used in this study..

TABLE I
METHODOLOGICAL SEQUENCE

1. Select critical response variable
2. Define sampling plan and measurement conditions
3. Verify measurement instrument and records
4. Collect 40 measurements per day for 20 days
5. Perform a normality test
6. Calculate short and long-term sigma level
7. Determine short/long-term sigma gap
8. Interpret limitations and process stability

This sequence provides a structured path from the selection of the response variable to the calculation and interpretation of the short- and long-term sigma relationship.

A. *Step 1. Identify the response variable*

As part of the first step of the methodology, the response variable was identified, and the short- and long-term relationships were determined. As a recommendation, it could be a product parameter that shows lower stability; monitoring the control charts or, if applicable, the quality reports is recommended. According to Pozzi et al. [22], the following aspects should be considered when selecting a variable for problem solving or continuous improvement:

1. High scrap rate
2. Affecting on time deliveries
3. Affecting the quality level (yield) of the product.

On the other hand, Hamid et al. [23] indicated that a critical process characteristic must be selected based on safety and scrap, and once the response variable is selected, the quality personnel who take the measurements and the instruments to be used are identified, as they are considered possible sources of variation during the investigation.

B. *Step 2. Data collection*

Fitriadi et al. [24] stated that there must be at least 30 data points per sample to have a statistically representative sample, and to analyze trends, at least 20 samples must be analyzed to be statistically representative; therefore, data collection for the selected response variable was performed. For this, a sample of size 40 is taken during the manufacturing shift to represent the production for the day. This was performed over 20 days, resulting in 800 data points for the response variable. The Quality Department personnel obtain the measurements and release the product using measuring instruments to monitor the processes.

The sampling plan consisted of 40 measurements per day over 20 production days, resulting in a total of 800 observations. The measurements were taken from parts manufactured under routine operating conditions without intentionally adjusting the machine parameters during the study. The same response variables, specification limits, measurement techniques, and inspection personnel were maintained throughout the data collection period. This approach was selected to evaluate the natural short- and long-term variations in the process during normal production.

It is important to note that this study did not compare different operating conditions, such as cutting speed, feed rate, tooling condition, lubrication/coolant condition, material type, or machine settings. Therefore, the results should be interpreted as a case study under the observed production conditions, rather than as a full factorial experimental design.

C. Step 3. Normality test on sample

Avram et al. [25] mention that it is important to ensure the normality of the sample data before conducting a process capability study because depending on the data distribution is the way to calculate the CPK. On the other hand, Wheeler-Webb et al. [26] state that the Anderson-Darling test is the most accurate for samples = 50, while the Kolmogorov test is better for samples >50.

Therefore, for each sample obtained with a size of 40, an Anderson-Darling normality test was performed to determine whether the data had normal distribution. If the data fit well, Cpk calculations can be performed using a normal distribution curve. If the data have a non-normal distribution, they must be identified, and Cpk is calculated using the distribution that best represents the sample data.

D. Step 4. Calculate the short-term variation

This step aims to calculate the short-term sigma level and daily variation in the process. For this, with the sampling over 20 days of size 40 of the critical parameter of the manufacturing process, the sample mean, standard deviation, Cpk (Process Capability), and sigma level are calculated using the following equations:

$$Mean = \frac{\sum_{i=1}^{n} x_i}{n} \tag{1}$$

$$Standard\ Dev. = \sum \frac{(x - mean)^2}{n-1} \tag{2}$$

$$Cpk = \min\left(\frac{LSE - mean}{std\ dev}, \frac{mean - LIE}{std\ dev}\right) \tag{3}$$

$$Sigma\ Level = Cpk * 3 \tag{4}$$

Where:
n=Sample size
i=Sample element
Cpk=Process capability index
LSE=Upper specification limit
LIE=Lower specification limit

Once the 20 samples with 40 measurements were completed, a run chart was created to analyze the behavior of the short-term sigma level and determine its trend and average.

E. Step 5. Calculate the long-term variation

Using the data collected during the data gathering and equations 1-4, the global average, global standard deviation, global Cpk, and long-term sigma level were calculated.

F. Step 6. Determine the short-term and long-term variation

Equation (5) calculates the relationship between the short-term and long-term sigma levels, expressed as the absolute value of the difference between the Long Term and Short Term.

$$Relationship = |\text{Long Term} - \text{Short Term}| \tag{5}$$

III. Discussions and Results

A. Step 1. Identify the response variable

Following the proposed methodology, the response variable was identified by reviewing the control chart records, and it was found that the external mouth diameter measured variable showed the most significant instability over the past 12 weeks (Figure 2). Subsequently, it was identified that two quality inspectors performed the measurements and fed the control charts using a digital diameter gauge. Although the control chart for the response variable was out of statistical control, instability was observed in the mean chart, which was the main reason for selecting this parameter for the final model.

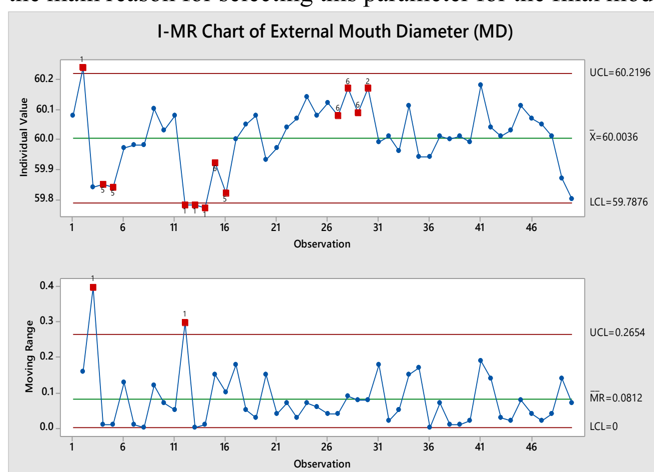

Fig. 2 Response variable behavior

It is important to note that other important factors considered in selecting this response variable are the high scrap levels generated by this feature. The data indicate that approximately 30,000 dollars per month are wasted owing to the instability of this feature, representing 14% of scrap. Similar research indicates that scrap in manufacturing companies in the metal-mechanical sector ranges from 15 to 20% [27]. The company where this research was conducted is very similar to those reported in previous studies.

B. Step 2. Data collection

Next, information was collected from 40 data points per shift for 20 days, resulting in 800 measurements for the response variable, as shown in Table II. The full data is provided in the supplementary material.

TABLE II
DATA COLLECTED FOR THE RESPONSE VARIABLE

Day/ Sample	1	2	3	…	40
1	60.05	60.15	60.22		60.05
2	60.08	60.16	60.21		59.97
3	59.96	59.97	60.13		59.98
…					
20	60.01	59.96	60.27		59.88

Before data collection, the measurement instrument was verified to be within its valid calibration period, according to the company's calibration control system. The instrument identification, calibration status, and traceability records were reviewed prior to use. In addition, the instrument conditions were visually checked to confirm that they were suitable for the measurement activity. The most recent Measurement System Analysis available for this characteristic was reviewed to confirm that the measurement system was acceptable for process monitoring purposes.

It is important to highlight that the data were obtained under normal processing conditions and with experienced personnel. It is important to highlight that the data were obtained under normal processing conditions and with experienced personnel. Therefore, the results reflect the actual behavior of the process during this study period.. Upon observing Table 1, it can be observed that at first glance, there is variation between measurements inside and outside each sample as shown in Figure 3, which confirms the instability observed during step 1 of the methodology.

Figure 3 shows that the process was not fully under statistical control during the initial evaluation because several observations exceeded the control limits. This behavior suggests the presence of assignable causes affecting the process mean and confirms that the selected response variable was appropriate for analyzing the difference between the short- and long-term sigma levels. Therefore, the out-of-control condition was not removed from the analysis; instead, it was considered as part of the real long-term process behavior. However, this condition represents a limitation of the study because the estimated long-term sigma level may be affected by special causes that were not isolated or experimentally controlled.

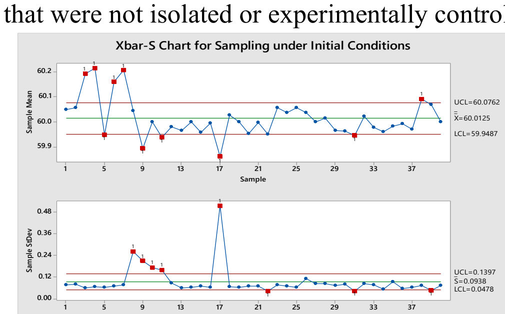

Fig. 3 Control chart for sampling under initial conditions

One implication to be considered during data collection is to ensure that the measuring instruments are calibrated properly. Sometimes, the instruments have a calibration label, but they provide erroneous readings; it is recommended that during data collection, the instruments be validated with standards to ensure proper operation. However, it is essential to ensure that personnel are properly trained and validated. Sometimes, they use different methods, leading to variations and erroneous data during the data collection. Finally, it is essential to consult the last Measurement Systems Analysis (MSA) performed and ensure that it is within the Automotive Industry Action Group (AIAG) acceptable values, which are less than 10% for critical products and less than 20% for non-critical products [28].

C. *Step 3. Normality test on sample*

Next, the previously collected data were subjected to an Anderson-Darling normality test using Minitab 18 software, testing the following hypotheses considering as a criterion that if the p-value is greater than 0.05, the null hypothesis is not rejected:

H_0: The data fit a normal distribution.
H_1: The data does not fit a normal distribution

Table III presents the p-values of the 20 samples analyzed using Minitab 18 software.

TABLE III
NORMALITY TEST RESULTS

Sample	P-Value
1	0.052
2	0.135
3	0.421
4	0.691
5	0.640
6	0.555
7	0.538
8	0.320
9	0.341
10	0.167
…	
20	0.113

Table III shows that the p-values for each of the 20 samples are greater than 0.05; therefore, the null hypothesis should not be rejected. In this case, the data in each sample were normal, which means that the Cpk and sigma levels could be calculated using the mean and deviation as parameters for normal distribution.

D. Step 4. Calculate the short-term variation

Equations 1-4 were used to calculate the mean, standard deviation, Cpk, and sigma levels of each sample. The data are presented in Table IV.

TABLE IV
SHORT-TERM SIGMA CALCULATION

Sample	Mean	Standard Deviation	LIE	LSE	Cpk	Short-Term Sigma
1	60.037	0.079	59.850	60.280	0.788	2.363
2	59.987	0.146	59.850	60.280	0.313	0.938
3	59.984	0.103	59.850	60.280	0.434	1.303
4	59.985	0.109	59.850	60.280	0.410	1.229
5	60.059	0.187	59.850	60.280	0.374	1.121
6	60.013	0.121	59.850	60.280	0.451	1.353
7	60.029	0.116	59.850	60.280	0.513	1.540
8	60.017	0.099	59.850	60.280	0.560	1.681
9	60.032	0.126	59.850	60.280	0.483	1.448
10	59.951	0.380	59.850	60.280	0.089	0.266
11	60.032	0.126	59.850	60.280	0.482	1.446
12	60.020	0.105	59.850	60.280	0.537	1.611
13	60.018	0.110	59.850	60.280	0.508	1.523
14	60.002	0.126	59.850	60.280	0.401	1.204
15	60.002	0.091	59.850	60.280	0.556	1.669
16	59.998	0.097	59.850	60.280	0.507	1.521
17	60.008	0.107	59.850	60.280	0.492	1.476
18	60.025	0.103	59.850	60.280	0.564	1.693
19	60.031	0.112	59.850	60.280	0.538	1.613
20	60.022	0.109	59.850	60.280	0.528	1.585

LSE=Upper specification limit
LIE=Lower specification limit

Subsequently, a run chart was created to visualize the short-term sigma-level behavior of the 20 collected samples. Figure 4 presents the run chart, which shows that 17 out of 20 samples showed stability close to the mean of 1.429. Thus, it can be concluded that the short-term sigma level in this process for the response variable was 1.429.

The mean changes significantly from day to day; therefore, special causes lead to this movement in the process's mean. However, the sigma level of the process underwent significant changes, as listed in Table IV. This parameter ranged from 0.269 to 2.403.

The results found up to this point can be contrasted with other research; on the one hand, BROOKS [29] mentions that the initial sigma level before implementing a Six Sigma project is, on average, 3.1 for companies in the manufacturing sector in Indonesia. Elumalai et al. [30] indicate that the short-term average sigma level in the metal-mechanical sector companies in South America is 3.5. With the results obtained in this step, we found that the average sigma level of this process was 1.429, which differs from the values reported in other investigations. These differences may be explained by the specific process conditions, response variables, measurement systems, production environments, and stability levels of each case study. Therefore, direct comparison with previous studies should be made cautiously, since sigma levels are highly dependent on the process context and data collection conditions.

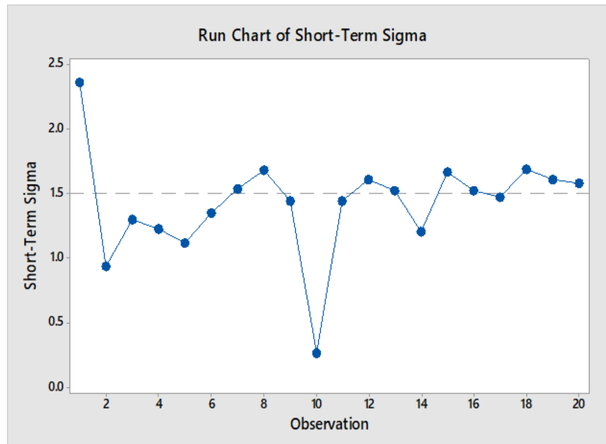

Fig. 4 Run chart for short-term sigma

E. Step 5. Calculate long-term variation

Using the data in Table 3, the global average and standard deviation were calculated, followed by the global Cpk and long-term sigma levels, with the data presented in Table V.

TABLE V
LONG-TERM SIGMA CALCULATION

Global Average	Standar Deviation	Global CPK	Long term variation
60.014	0.375	0.146	0.437

F. Step 6. Determine the short- and long-term relationship

Equation 5 calculates the gap between the short-term and long-term sigma values, which are listed in Table VI.

TABLE VI
CALCULATION OF THE SHORT- AND LONG-TERM RELATIONSHIP

Long term sigma level	Short term sigma level	Relation
0.437	1.46	1.023

IV. CONCLUSIONS

In the last decades, the relationship between short- and long-term sigma has been considered as a universal value of 1.5 sigmas, since it was introduced by Mikel Harry in the 1990s in the Six Sigma Vision, where he stated that this relationship is related to non-explicable causes; therefore, companies have adopted this value as universal to different kinds of processes and different countries. However, technological advancements in different processes and countries have led to the determination of whether this value is actually a universal value that is still the same or should be recalculated. For these reasons, this study analyzes the Short- and Long-term relations in a metal manufacturing process in northern Mexico to evaluate and contrast the 1.5 sigma value introduced by Mikel H.

Evidence shows that the process follows a normal distribution concerning the analyzed response variable, as shown by the initial information regarding the process. The data suggest that the process has a short-term sigma level of 1.46, extending from 0.269–2.403. This suggests that the process caused fluctuations, as the run chart displays at least three points significantly different from the average value. The short- and long-term relationships of this process were 1.023 after applying this approach. This is because the long-term sigma level is 0.437, which can be detected after the methodology is applied.

In conclusion, the case study showed a short-term and long-term sigma gap of 1.023, which differs from the traditional 1.5 sigma shift proposed by Harry. Although the result does not invalidate the traditional value, it suggests that the gap should not be assumed to be universal for all processes, sectors, or operating conditions. Instead, the sigma shift should be empirically estimated when sufficient process data are available to do so.

For roughly 30 years, the link between the short- and long-term rates has been around one and a half. This research is noteworthy for this reason. As a result of this research, the actual value of this gap is close to 1.5, but not exactly. This opens the door for additional analyses, allowing us to use the actual number rather than an approximation. This will enable a proper understanding of long-term variations and guarantee that the focus is on lowering this relationship to retain the short term and the advances that have been made utilizing continuous improvement methodologies over time.

Some of the implications of companies continuing to use this value of 1.5 sigma are the following: on the one hand, most Six Sigma projects conclude based on the short-term sigma values with which savings are calculated, and the reason for using the short term is because it is known that if the long term is used the savings are lower due to the fact that 1.5 sigma implies more than 30% error in improvement, 1.5 sigma's implies more than a 30% error in the improvement, therefore not really knowing the relationship between the short and long term metrics does not allow to correctly estimate the savings and can lead to erroneous decisions to the companies and continue wasting resources. However, continuing to use this theoretical and universal value will not make it possible to reach the six-sigma level, which is the main objective of this approach.

From a practical perspective, the proposed approach can be transferred to other manufacturing processes where a critical-to-quality characteristic is routinely measured and historical or prospective production data are available for the process. However, the numerical values of the short- and long-term sigma gaps should not be directly transferred without considering process stability, measurement system reliability, material variation, machine conditions, and operating parameters. Therefore, the main transferable contribution of this study is the methodological sequence rather than the specific gap value obtained in the analysis.

V. LIMITATIONS AND FUTURE RESEARCH

This study had several methodological limitations that should be considered when interpreting the results. First, although 800 observations were analyzed, they corresponded to one response variable in a single metal manufacturing process; therefore, the findings should not be generalized to all manufacturing processes. Second, the study was conducted under normal production conditions and did not experimentally evaluate the effects of different operating parameters, such as the tool condition, cutting speed, feed rate, lubrication/coolant condition, material batch, or machine settings. Third, the process showed evidence of special-cause variation during the initial control chart analysis, which may have influenced the estimated long-term sigma level. Finally, although the measurement instrument was controlled through the company's calibration system, future studies should include a formal Measurement System Analysis to quantify repeatability and reproducibility before data collection.

The current investigation was conducted within the context of a production process for metal bottles, with the outer diameter of the bottle mouth serving as a response variable. The results of this study represent this and other similar manufacturing processes. Further studies should be conducted on short- and long-term relationships in various commercial, medical, and automotive processes to estimate the relationships that may apply to modern processes. This will help to have a bigger sample and contrast with other research to estimate the real short- and long-term values of sigma.

Future research should expand the number of processes, machines, materials, response variables, and operating conditions. In addition, future studies should incorporate designed experiments or stratified sampling to determine which process factors have the greatest influence on short- and long-term sigma gaps. This would allow researchers to better distinguish between common-cause, special-cause, and measurement system variations.

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