

PROCEDURE FOR APPLYING AND MONITORING CTQ WITH QFD

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Abstract-- Currently, the oil industry remains an essential pillar of the Mexican economy, contributing millions of pesos to the GDP every year. As a result, there is a need to further prioritize customer needs as a core activity in order to maintain this growth, as it is a fundamental economic lifeline for the country.

The objective of this research is to propose the methodological integration of Quality Function Deployment (QFD) and Critical to Quality (CTQ) in this sector, unlike other contexts and industries where these tools have proven to be fundamental in translating the Voice of the Customer (VoC) and improving process quality.

Given this absence, this research, using a quantitative and cross-sectional approach, analyzes the recurring problems that generate costs, mainly through statistical analysis, to evaluate behavior and reduce these failures. The study confirms that the application of these two tools allows for a more accurate and easier understanding of their root causes.

In conclusion, the proposed methodology is effective in reducing variability, strengthening continuous improvement, and can be applied in similar industrial contexts, especially those developing future projects that aim to improve processes through quality tools or ensure consistency of results, such as the aforementioned continuous improvement.

Keywords-- QFD, CTQs, methodology, continuous improvement.

Abstract-- Currently, the oil industry has remained an essential pillar of the Mexican economy, contributing millions of pesos to the GDP year after year. As a result, there arises a need to prioritize customer needs even more as a main activity in order to maintain that growth, since it is a fundamental economic support in the country.

The purpose of this research is to propose a methodological integration of Quality Function Deployment (QFD) and Critical to Quality (CTQs) in this sector, unlike other contexts and industries where these tools have proven to be essential for translating the Voice of the Customer (VoC) and improving the quality of processes.

In response to this absence, this research, using a quantitative and cross-sectional approach, analyzes the recurring problems that primarily generate costs through statistical analysis, in order to evaluate behavior and reduce these failures. The study confirms that applying these two tools allows for a more precise and easier understanding of their underlying causes.

In conclusion, the proposed methodology is effective in reducing variability, strengthening continuous improvement, and can be applied in similar industrial contexts, especially in those developing future projects aimed at improving processes through quality tools or ensuring the consistency of results, as previously mentioned in continuous improvement.

Keywords-- QFD, CTQ's, methodology, continuous improvement.

INTRODUCTION

Historically, the oil industry has been a sector of great importance to Mexico's economy. According to data from INEGI (2025), the sector generated \$872.03 billion pesos in Gross Domestic Product (GDP) in the second quarter of 2024, an annual increase of 4.93%. This vitality is key, as the industry remains a bastion of the economy, with growth projections and a fundamental role in national development (AMEXHI, 2024).

In this regard, a review of previous analyses reveals a research gap, since although there are studies that apply Quality Function Deployment (QFD) in various energy sectors, such as renewable energy, there is insufficient evidence of its integrated methodological application within the oil industry. There is a noticeable lack of integration of the Voice of the Customer (VoC) and Critical to Quality (CTQ) factors, even though both tools are considered fundamental to process design and improvement.

Despite this shortcoming, the value of these tools for competitiveness is indisputable. Recent literature confirms that quality management is fundamental to "continuous product improvement" (Pedroso de Sales et al., 2022). Similarly, QFD is a powerful tool that facilitates "approximation analysis for customer satisfaction" by converting needs into technical specifications, representing the added value of this research.

Likewise, 25 national and international articles on the application of CTQ tools with QFD in different industrial contexts were reviewed. The contributions of Cruz-Rivero et al. (2023) and García et al. (2023) show us that these tools are essential indicators for increasing customer satisfaction and reducing variability in processes, which are fundamental for capturing and structuring the Voice of the Customer, as Guerrero & Cruz (2025) similarly mention. However, the methodological integration of these techniques in the oil industry remains limited, which restricts the ability to identify recurring failures and thus reduces the potential for continuous improvement. Therefore, the overall objective is to develop a methodological proposal that integrates CTQs and QFD. This integration is essential, as QFD has proven to be crucial for service performance management and meeting customer requirements. Likewise, the aim is to apply principles for the optimization and control of operational performance, such as those of Lean Six Sigma, to identify customer requirements and translate them into measurable technical characteristics that improve service quality within the oil industry.

METHOD

The methodology developed in this study is structured in a series of phases that integrate quality tools aimed at identifying, studying, and controlling Critical Quality Parameters (CTQs) through Quality Function Deployment (QFD). It is important to note that this methodology does not correspond to a model previously established in the literature, but rather constitutes an original and innovative proposal developed by the authors based on the strategic integration of both tools. Each of its phases allows for systematic progress from the definition of the project to the verification of results, ensuring that customer needs are correctly translated into technical specifications and improvement actions.

The stages that make up this methodology are detailed below, allowing for a clear and structured visualization of the information obtained during the process and an understanding of the logic behind its design.

Phase 0: Project Definition and Preparation

At this stage, the foundation of the project is established by defining the scope, objectives, and initial criteria of the process to be analyzed. Before presenting the corresponding data, the following table summarizes the key elements that contextualize the preliminary activities that initiate the study and define the framework for the application of quality tools (Zhou et al., 2020).

Table 1. *Description of Stage 0.*

Stage	Key Activity	Purpose
0.1	Scope Definition (Charter)	Establish the business case and work plan. Define the product, service, or process to be designed or improved.

Note: Own creation (2025). Retrieved from: Zhou, J., Zhai, L., & Pantelous, A. A. (2020).

Phase I: Capturing and Prioritizing the Voice of the Customer (VoC and CRs)

The objective of this phase is to listen to, analyze, and translate user opinions into measurable technical requirements.

Stage I.1 is a crucial step in obtaining customer requirements and needs, where questionnaires and interviews are the most commonly used methodologies for collecting Voice of the Customer (VoC) data. This is the necessary starting point for product development. On the other hand, stage I.2 delves deeper into the work of listening, analyzing, and translating customer opinions and points of view into technical terms (Cruz et al., 2023). These customer requirements (CRs), or "What," represent the key requirements that must be identified (Jiménez et al., 2020).

In the same vein, stage I.3 determines the relative importance of customer needs or ideas (Frizziero et al., 2017). The Analytic Hierarchy Process (AHP) (Orozco et al., 2023) or Multi-Criteria Decision Making (MCDM) techniques (Guo Xu et al., 2022) can be used to obtain the importance weights, using fundamental scales such as the 1-9 scale (Orozco et al., 2023). Finally, to complete Phase I, stage I.4 is carried out to evaluate the company's customer satisfaction compared to its competitors in terms of CRs (Santos et al., 2022). It allows objectives to be defined for new designs by differentiating the current state (*Baseline*) from the state of importance (*Importance*).

Table 2. *Description of Stage I.*

Stage	Key Activity	Purpose
I.1	Voice of the Customer (VoC) collection	Use qualitative and quantitative techniques: surveys, interviews (focus groups), analysis of complaints or failures (reactive VoC collection), or technology watch. This information forms the basis of QFD.
I.2	Definition of Customer Requirements (CRs/WHATs)	Translate customer opinions into technical terms. We recommend creating Affinity Diagrams (on three levels, if complex) to group and logically structure the requirements.
I.3	Weighting of CRs (Importance)	Assign a degree of importance to each CR (e.g., Likert scale from 1 to 5 or 1 to 10). This value can be a combined weighting from different sources (e.g., complaints, expert surveys, wholesalers).
I.4	Competitiveness Analysis (Benchmarking)	Evaluate the performance of the company and its competitors in satisfying each CR. This helps to establish goals and priorities for improvement.

Note. Own creation. (2025). Retrieved from: Cruz-Rivero, L., Meráz-Rivera, J., & Lince-Olguín, E. (2023). *The deployment of quality function deployment and theory of inventive problem solving: An analysis of approaches to satisfying customer requirements. Industrial Engineering*, (45), 91–108.; Design for Six Sigma in the Product Development Process Under a Sustainability Point of View A Real-Life Case Study. (2024). *Sustainability*, 16, 10387.; Jiménez Rodríguez, R., Macías Socarrás, I., & Núñez, P. (2020). *Application of QFD to products from a cannery. Espacios*, 41, 225-239.; Frizziero, L., Francia, D., Donnici, G., Liverani, A., & Caligiana, G. (2017). *Sustainable design of open molds with QFD and TRIZ combination. Journal of Industrial and Production Engineering*, 35(1), 21-31.; García-Orozco, S., Vargas-Gutiérrez, G., Ordóñez-Sánchez, S., & Silva, R. (2023). *Using Multi-Criteria Decision Making in Quality Function Deployment for Offshore Renewable Energies. Energies*, 16(18), 6533.; Xu, X.-G., Zhang, L., Mao, L.-X., & Li, K. (2022). *New Approach for Quality Function Deployment Using an Extended CoCoSo Method with Spherical Fuzzy Sets. Systems*, 10(6), 253.; Santos, G., et al. (2022). *QUALITY MANAGEMENT IN THE CONTOURS OF CONTINUOUS PRODUCT IMPROVEMENT. International Journal for Quality Research*, 16(3), 689-702.

Phase II: Quality Function Deployment (QFD)

This phase focuses on building the House of Quality (HoQ), the main module of QFD, delving into the relationship between customer needs and the engineering qualities required to satisfy them, allowing for the prioritization of those technical parameters that directly impact the quality of the welding process. This phase integrates the preliminary analysis with the construction of the House of Quality.

Thus, in stage II.1, the technical requirements (Guerrero et al., 2025), also called functional requirements or "Hows," are established. These are measurable and controllable and represent the organization's response to meet customer requirements (Cruz et al., 2023). Next, in stage II.2, a relationship matrix is constructed that evaluates the influence of key requirements ("What") on the collection of technical requirements ("How"). A weighted relationship scale is used, commonly with values of 9 (strong), 3 (moderate), and 1 (weak or low), and 0 if there is no relationship.

Likewise, in stage II.3, another matrix known as the "Ceiling" of the House of Quality is used to assess the influence that the different "Whats" have on the different "Hows" (Guerrero et al., 2025). Symbols such as "+" (positive correlation) or "-" (negative correlation) are used to indicate the correlation between strategies or activities (Cruz et al., 2023).

To complete phase II, in stage II.4, the Absolute Score of the How is calculated by multiplying the weight of each "What" by the correlation coefficient. This score, after being reordered, indicates the degree of priority for implementing the "Hows" (Guerrero et al., 2025). The appropriate procedure for quality management is to first identify the Critical to Quality (CTQs) in order to focus efforts (Gutiérrez, 2019).

Table 3. *Description of Stage II.*

Stage	Key Activity	Purpose and Reference Citations
II.1	Definition of Engineering Characteristics (ECs/HOWs)	The design team defines the technical, operational, or functional requirements (Hows) necessary to satisfy the CRs. These must be measurable and controllable parameters.
II.2	Construction of the Relationship Matrix (CR-EC)	Identify the impact of each EC on the satisfaction of each CR. Use a standardized correlation scale (e.g., 9 strong, 3 medium, 1 weak, 0 none). To handle uncertain or vague assessments, advanced approaches based on linguistic distributions or spherical fuzzy sets (SFSS) can be used.
II.3	Correlation Analysis between ECs (Ceiling)	Evaluate the interrelationships between CEs (positive: ++/+, negative: --/-) to identify technical conflicts or synergies. This analysis is crucial for resource management and sound decision-making.

II.4	Initial Importance Calculation and CTQs	Calculate the Relationship Score (Absolute and Relative Importance of the ECs) by weighting each CR by the CR-EC correlation coefficient. The ECs with the highest scores become the Critical to Quality (CTQs).
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Note. Own creation (2025). Retrieved from: Guerrero González, M. L., Cruz Rivero, L., Mendo Ostos, L., & Vázquez Estrada, O. W. (2025). VoC and QFD as Integration Tools for the Design of a Concrete Structure Monitoring Prototype. *Science and Reflection*, 4(3), 1495–1516.; Cruz-Rivero, L., Meráz-Rivera, J., & Lince-Olguín, E. (2023). The deployment of the quality function and theory for inventive problem solving: An analysis of approaches to satisfying customer requirements. *Industrial Engineering*, (45), 91–108.; Gutiérrez-García, A. (2019). Quality management through scientific methods. *Journal of Technical Education*, 3(7), 19–26.

Phase III: Prioritization of Critical Characteristics (CTQ/EC)

This phase refines the selection of CTQs to concentrate design and improvement resources.

The main CTQ is selected and a detailed statistical analysis is performed to quantify the performance of the process. At this stage, the sample record, specification limits, and fundamental statistical values are presented. This information allows for analysis of the stability, variability, and degree of compliance of the process with the established parameters.

To begin phase III, stage III.1 consists of using Multi-Criteria Decision Making (MCDM) methods such as AHP, TOPSIS, DEMATEL, or ORESTE to determine the priorities and ranking of engineering characteristics (ECs) (Orozco et al., 2023). In the next phase of Technical Bottleneck Identification, although the specific term "bottlenecks" is not explicitly stated as a stage, the phase is intended to select the ECs with the highest scores (Guerrero et al., 2025), since quality management requires focusing efforts on critical quality attributes (CTQs) (Gutiérrez, 2019).

Finally, in stage III.3, the critical quality factor (CTQ) obtained from QFD is translated into a technical design parameter (for example, one of the thirty-nine TRIZ parameters) (Cruz et al., 2023). This translation is considered a transfer point that maximizes the potential for innovation by applying both methodologies together (Orozco et al., 2023).

Table 4. Description of Stage III.

Stage	Key Activity	Purpose
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III.1	Advanced Prioritization of ECs/CTQs (MCDM)	Apply Multi-Criteria Decision Making (MCDM) methods to overcome the biases of the simple scoring method (ISM) and obtain a more reliable ranking. Recommended methods include AHP, TOPSIS, DEMATEL (for correlation), CRITIC, ORESTE, or CoCoSo.
III.2	Identification of Technical Bottlenecks	Analyze CTQs/ECs in relation to their level of importance and difficulty of implementation (or cost). Critical bottlenecks are those of high importance and high difficulty, which require greater concentration of efforts and possibly redesign strategies.
III.3	Translation into Improvement Parameters (Optional: TRIZ)	In the event of technical conflicts or the need for innovation, the priority CTQ (e.g., "non-toxic") can be translated into one of the 39 design parameters of TRIZ (Theory of Inventive Problem Solving), marking the transfer stage for the resolution of contradictions.

Note. Own creation (2025). Retrieved from: García-Orozco, S., Vargas-Gutiérrez, G., Ordóñez-Sánchez, S., & Silva, R. (2023). Using Multi-Criteria Decision Making in Quality Function Deployment for Offshore Renewable Energies. *Energies*, 16(18), 6533.; Guerrero González, M. L., Cruz Rivero, L., Mendo Ostos, L., & Vázquez Estrada, O. W. (2025). VoC and QFD as Integration Tools for the Design of a Concrete Structure Monitoring Prototype. *Science and Reflection*, 4(3), 1495–1516.; Gutiérrez-García, A. (2019). Quality management through scientific methods. *Journal of Technical Education*, 3(7), 19–26.; Cruz-Rivero, L., Meráz-Rivera, J., & Lince-Olguín, E. (2023). The deployment of quality function deployment and theory of inventive problem solving: An analysis of approaches to satisfying customer requirements. *Industrial Engineering*, (45), 91–108.

Phase IV: Execution, Improvement, and Integration of Solutions

This phase addresses the implementation of the actions necessary to ensure that the design complies with the prioritized CTQs.

With regard to stage IV.1, the target value (*HOW-MUCHs*) that each design requirement must meet to satisfy the customer is quantified (Burgos et al., 2020). The *Suggested Target* is calculated using the Opportunity parameter based on the Importance of the VoC and the Baseline of the competition (Arcidiacono et al., 2024).

Consequently, in stage IV.2, possible solutions and specific action plans are developed, considering the critical inputs previously identified in the analysis (Rodríguez et al., 2023). The structure for the design of methodological guidelines to incorporate good practices is established (Herrera & Narváez, 2017).

To close phase IV, stage IV.3 is the design implementation phase (Arcidiacono et al., 2024). For prototyping and action design, modeling software tools and technical drawings, such as Catia V5, can be used to verify possible interference in the assembly (Santos et al., 2022).

Table 5. *Explanation of Stage IV.*

Stage	Key Activity	Purpose
IV.1	Establishment of Design Goals (HOW-MUCHs)	Determine the specific and quantifiable target value for each prioritized CTQ. Define the direction of improvement (Higher is Better: ↑, Lower is Better: ↓, Same is Better: °).
IV.2	Design of Improvement Actions	Develop strategies, activities, and operational processes necessary to achieve design goals. This includes preventive or corrective actions (e.g., staff training, process standardization, adoption of Lean tools such as FIFO, or acquisition of tools).
IV.3	Implementation and Prototyping	Execute the design or redesign of the product/process. Generate virtual models or prototypes to verify possible interference in the assembly or process (virtual reality).

Note. Own creation (2025). Retrieved from: Arcidiacono, G., Risaliti, E., & Del Pero, F. (2024b). *Design for Six Sigma in the Product Development Process... Sustainability*, 16(23), 10387.; A; Rodríguez-Mera, M. A., Guerrero-Moreno, D., García-Jimenez, J. C., & Peña-Montoya, C. C. (2023). *Application of Lean Six Sigma to improve the thesis process in a higher education institution. [N/A].; Herrera De la Barrera, J., & Narváz Zúñiga, C. (2017). Methodology for understanding the voice of the customer in dynamic environments using quality function deployment (QFD). Teknos Scientific Journal*, 17(2), 63–72.; Arcidiacono, G., Risaliti, E., & Del Pero, F. (2024b). *Design for Six Sigma in the Product Development Process... Sustainability*, 16(23), 10387.; Santos, G., et al. (2022). *QUALITY MANAGEMENT IN THE CONTOURS OF CONTINUOUS PRODUCT IMPROVEMENT. International Journal for Quality Research*, 16(3), 689-702.

Phase V: Continuous Control and Monitoring

QFD is part of a continuous improvement process. This phase ensures that improvements are maintained and remain effective in the long term.

This phase begins with stage V.1, which is the process of ensuring that the product meets the identified key requirements (Guerrero et al., 2025) and that the design specifications meet expectations. Validation is a stage of the DFSS (Design for Six Sigma) model. Subsequently, in stage V.2, key performance indicators (KPIs) are established to control and evaluate the behavior of the process over time (Rodríguez et al., 2023). To do this,

tools such as statistical process control (SPC) are used, which is one of the most widely used tools for quality assurance (Herrera & Narváez, 2017).

The process concludes with stage V.3, which seeks to ensure continuous follow-up and monitoring of the results of the solutions applied. The QFD philosophy is developed in conjunction with other methodologies to be an important enabler, such as the Lean Six Sigma approach, which contemplates continuous and synergistic improvement (Rodríguez et al., 2023).

Table 6. Description of Stage V.

Stage	Key Activity	Purpose
V.1	Validation and Testing	Test and validate the performance of the prototype/process, ensuring that it meets the new quality criteria and project objectives.
V.2	Key Performance Indicators (KPIs)	Establish key performance indicators (KPIs) to monitor the continuous performance of CTQs over time and ensure system stability.
V.3	Review and Continuous Improvement	Evaluate and follow up on the results of the solutions applied using DMAIC or BSC/Balanced ScoreCard methodologies, ensuring that the process is iterative and allows for adaptation to changes in the environment and customer requirements.

Note. Own creation (2025). Retrieved from: Guerrero González, M. L., Cruz Rivero, L., Mendo Ostos, L., & Vázquez Estrada, O. W. (2025). VoC and QFD as Integration Tools for the Design of a Concrete Structure Monitoring Prototype. *Science and Reflection*, 4(3), 1495–1516.; Arcidiacono, G., Risaliti, E., & Del Pero, F. (2024b). Design for Six Sigma in the Product Development Process... *Sustainability*, 16(23), 10387.; Rodríguez-Mera, M. A., Guerrero-Moreno, D., García-Jimenez, J. C., & Peña-Montoya, C. C. (2023). Application of Lean Six Sigma for the improvement of the thesis process in a Higher Education Institution. [N/A].; Herrera De la Barrera, J., & Narváez Zúñiga, C. (2017). Methodology for understanding the voice of the customer in dynamic environments using quality function deployment (QFD). *Teknos Scientific Journal*, 17(2), 63–72.; Rodriguez Mera, M. A., Garcia Jimenez, J. C., Peña Montoya, C. C., & Guerrero Moreno, D. (2023). Application of Lean Six Sigma for the improvement... *Scientia et Technica*, 28(02), 73-85.

DEVELOPMENT

Therefore, energy demand has shown steady growth, driven mainly by the expansion of different markets and the arrival of foreign industries in the country through the phenomenon of companies moving their production to nearby countries and their main market (nearshoring). In this context, Mexico recorded a 23% increase in its energy demand, reaching a historic high of 54 GW (gigawatts) in 2024. Without



However, this increase in demand has put greater pressure on the country's energy infrastructure, highlighting various problems and limitations in some industrial processes. In particular, recurring errors have been identified in the manufacture of underground pipes, which generate additional costs, delivery delays, and even affect the quality of service. Among the most common are defects in welding techniques, lack of coating, and bevel alignment problems.

These errors have a direct impact on the company's operations, as they are present in all types of industries. Therefore, organizational improvement strategies are required to minimize them, since these are errors that, if not controlled, can affect production and jeopardize its stability (Salas et al., 2018). Given this situation, it is essential to analyze the causes of these problems and implement a structural methodology that allows for the technical identification of the critical attributes that determine process quality (CTQs) and how these can be improved through the application of QFD.

Phase 0

This research is quantitative and cross-sectional in nature, using tools that aid continuous improvement, i.e., CTQs integrated with QFD, as the main focus of the study. These tools are developed based on the evaluation of user demand (Izar Landeta & Ynzunza Cortés, 2014), with the aim of establishing a systematic methodology applicable to future projects with similar characteristics.

Likewise, a quantitative study is proposed for this research, aimed at analyzing the behavior of the manufacturing process in the oil industry, specifically in the production of underground piping. This study is based on statistical analysis of the results and descriptive statistics to identify variations and/or recurring behaviors and thus reduce process variability by integrating traditional methodologies and continuous improvement approaches.

Phase I: Capturing and Prioritizing the Voice of the Customer (VoC and CRs)

To address this issue, a detailed diagnosis was carried out to identify the main causes or failures in the process and their impact on the company's operations. In order to

identify the most common errors within the installation process, a verification sheet was also used to summarize the occurrence of each error in the projects.

Table 7. Errors identified.

Error identified	Frequency (per unit)	Estimated cost (\$MXN)
Critical excavation	2	\$ 2,000
Raw material does not comply (PMI test)	1	\$ 48,300.00
Lack of anchoring and poor coating (paint)	5	\$ 2,000
Alignment (cleaning and beveling)	2	\$ 2,000.00
Welding technique defects	10	\$ 5,000.00
Unevenness due to lack of compaction	1	\$ 27,000.00
Lack of training (assembler and operator)	1	\$ 2,700.00
Failure to check maximum working pressure	1	\$ 27,000.00

Source: Own elaboration (2025).

To measure the magnitude of the problems within the organization, a Pareto chart (80/20) is used, which is a graphical tool that organizes various data classifications in descending order, from left to right, using simple bars. This analysis is performed after gathering and classifying the information, with the aim of identifying the main causes of the problem. This allows an order of priority to be assigned (Rincón & Vásquez, n.d.) and enables the most frequent and costly errors in the process to be visualized and prioritized.

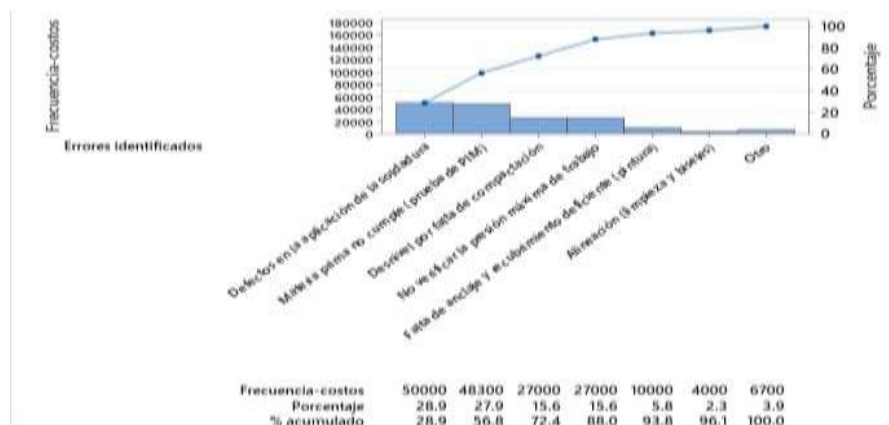


Figure 1. Pareto diagram of identified errors.

Source: Own elaboration (2025).

Analysis of the diagram shows that most of the errors and costs during the installation stage are concentrated in four main causes: defects in the welding process, failure to comply with

raw material specifications (PMI test), failure to verify the maximum working pressure limit, and occasional unevenness due to lack of compaction. These factors represent the greatest negative impact on the operation and are in line with the Pareto principle (80/20), which states that a small number of problems are responsible for most of the effects or consequences on the pipeline.

Phase II: Deployment of the Quality Function (DFQ)

Now, it is necessary to determine which characteristics of the welding process should not be considered errors (the CTQs). It is extremely important to mention that poor welding can compromise the structural integrity of the piping system, causing serious risks such as gas leaks, operational failures, or highly dangerous accidents. Therefore, it is essential to strictly monitor key quality aspects in the welding application.

Table 8. *Essential characteristics for customer satisfaction.*

No.	CTQ	Description
1	Final inspection	Visual inspection of the welded joint finish.
2	Bevel alignment	Correct positioning of the ends using an aligner.
3	Spot welding with E-7018 electrode	Correct application of initial weld spots.
4	Hot pass	Reverse current (with heat) to melt impurities and find the root.

Source: *Own work (2025).*

Subsequently, in order to determine which of these aspects has the highest incidence of errors, a classification is made using defect frequency analysis and a Pareto chart, which shows that the final inspection is the most critical CTQ, making it the main focus of the process.

Table 9. *Frequency of essential characteristics for customer satisfaction.*

No.	CTQ	Frequency (1 in 3.7 km)	Times in 308 joints
1	Final inspection	1 in 5 joints	$308 / 5 = 61.6 \approx 62$

2	Bevel alignment	1 in 10 joints	$308 / 10 = 30.8 \approx 31$
3	Spot welding with E-7018 electrode	1 in 15 joints	$308 / 15 = 20.5 \approx 21$
4	Hot step	1 in 20 joints	$308 / 20 = 15.4 \approx 15$

Source: *Own elaboration* (2025).

Phase III: Prioritization and Statistical Analysis of the Main CTQ

In order to continuously evaluate the performance of the welding process, especially in the final cladding stage, our critical quality parameter, it was decided to perform an analysis based on previous records of measurements taken on welded joints. This evaluation focuses on the critical quality parameter (CTQ) related to the surfacing result, which is decisive in ensuring the structural integrity of the joint and compliance with regulatory standards.

Table 10. Sample record.

Batch data			
Pipe section length	4.6km	4,600	m
Length per pipe	0.012km	12	m
No. of welded joints (N)	383.3333	384	joints

STUDY VARIABLE: Final appearance – weld protrusion						
Responsible:		Batch: 384 welded joints			Sample size: 130	
Date:		Target value: 3.175 mm (1/8")			Unit: millimeters	
		Tolerance: ± 0.25 mm				
FINAL INSPECTION SAMPLES						
3.0941	3.0963	3.3000	3.0336	3.1691	3.0565	3.1892
3.1437	3.1401	3.2238	3.2303	3.1769	3.1772	3.1013
3.0600	3.2727	3.2738	3.1820	3.1368	3.1196	3.1092
3.0707	3.1326	3.0487	3.1051	3.1997	3.2243	3.0445
3.3055	3.1701	3.1508	3.1940	3.1744	3.2095	3.0291
3.1651	3.0445	3.2598	3.2119	3.3383	3.1308	3.0808
3.1468	3.1823	2.9881	3.1549	3.1505	3.1394	3.2656
3.1447	3.1808	3.1520	3.1512	3.2561	3.3239	3.2731
3.1933	3.0557	3.2486	3.2046	3.1646	3.2536	3.2575
3.3953	3.0657	3.2375	3.2054	3.1698	3.0825	3.2141
3.1531	3.2542	3.1808	3.1187	3.0530	3.0726	2.9961

3.2210	3.2070	3.1642	3.0797	3.0391	3.1234	3.1415
3.2165	3.1572	3.1641	3.2218	3.2755	3.1491	2.9226
3.1667	3.0833	3.1241	3.1885	3.0677	3.1501	3.1601
3.1472	3.1017	3.2398	3.1659	3.2100	3.1725	3.1241
3.1481	3.2910	3.1133	3.2435	3.0271	3.2528	3.3192
3.1539	3.0430	3.2155	3.1410	3.1737	3.3209	3.3219
3.1451	2.9991	3.1283	3.2032	3.1510	3.0959	3.2694
3.1245	3.1421	3.1238	3.1035			

Source: Own elaboration (2025).

However, parameters such as the mean of the process, the standard deviation (see Fig. 2), and whether the data distribution is normal or not (see Fig. 3) must be known. It should be noted that MINITAB software is used to calculate the aforementioned parameters in order to obtain more accurate results.

Variable	N	N*	Media	Error estándar de la media	Desv.Est.	Minimo	Q1	Mediana
Sobresaliente de soldadura	130	0	3.1623	0.00718	0.0819	2.9226	3.1123	3.1560

Variable	Q3	Máximo
Sobresaliente de soldadura	3.2144	3.3953

Figure 2. Descriptive statistics.

Source: Prepared by the author based on MINITAB 21.

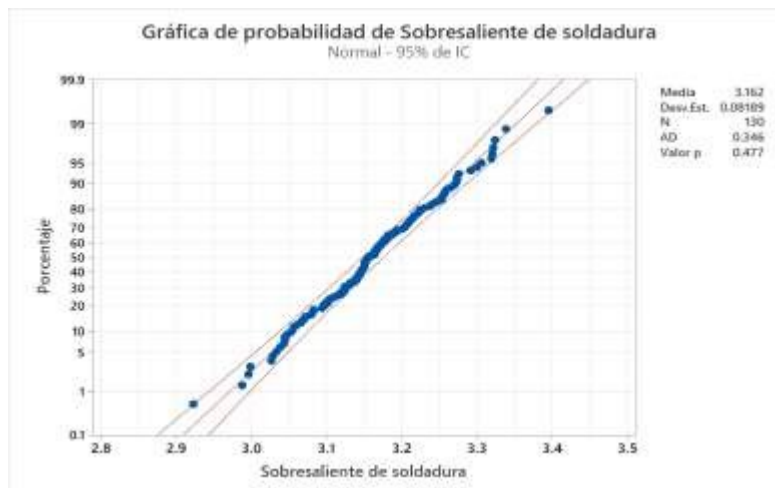


Figure 3. Graph of probability of weld excellence.

Source: Prepared internally based on MINITAB 21.

Therefore, it is concluded that the data belonging to the variable "Weld protrusion (final inspection)" follows a normal distribution, which allows us to continue with the statistical analysis that assumes this condition. Based on the above, the limit of the customer's specifications must be determined. This limit is the protrusion value that all pipe joints should have.

Table 11. *Limits for final finish.*

CTQ: Final finish		
Specifications	Value	Unit
Target value	3.175	mm
Upper limit	3,395	mm
Lower thickness limit	2,922	mm

Source: *Own elaboration (2025).*

Phase IV: Implementation, Improvement, and Integration of Solutions

It is essential to apply quality tools that enable us to identify areas for improvement. On this occasion, the 5 Whys method was used, which revealed that the main cause was the absence of periodic internal reviews or formal diagnoses highlighting the need to establish and formalize the final verification process. Through objective evidence and process analysis, it was concluded that the final inspection presents significant variations in its execution, such as unclear criteria, inconsistent records, and visual results that do not meet the requirements established by the customer. This lack of uniformity prevents a reliable quality standard from being guaranteed and makes it difficult to evaluate progress between previous and current installations. As a corrective measure, a structured plan of internal audits aimed at quality assurance was implemented, specifically to implement a standardized checklist for final inspection, whose purpose is to ensure a detailed visual inspection that is documented and aligned with customer needs. This tool allows for a general evaluation of cleanliness, alignment, coating, visual finish, among other key elements of the pipe installation.

After the improvement was implemented, the pipe manufacturing process was run again, obtaining the following data:

Table 12. *Records from the second sample.*

STUDY VARIABLE: Final inspection – weld protrusion		
Responsible:	Batch: 308 welded joints	Sample size: 120

Date:	Target value: 3.175 mm (1/8")			Unit: millimeters
	Tolerance: ± 0.25 mm			
FINAL INSPECTION SAMPLES				
3,166	3,170	3,173	3,170	3,166
3,169	3,173	3,167	3,169	3,168
3,170	3,173	3,170	3,170	3,170
3,171	3,169	3,171	3,170	3,169
3,167	3,172	3,170	3,175	3,166
3,168	3,171	3,168	3,172	3,168
3,175	3,175	3,166	3,172	3,175
3,167	3,169	3,166	3,172	3,172
3,174	3,175	3,174	3,169	3,174
3,172	3,172	3,175	3,171	3,174
3,167	3,172	3,170	3,168	3,171
3,174	3,170	3,172	3,166	3,165
3,172	3,175	3,170	3,170	3,172
3,166	3,169	3,172	3,168	3,169
3,173	3,172	3,175	3,170	3,169
3,168	3,172	3,172	3,168	3,175
3,166	3,171	3,172	3,174	3,175
3,167	3,169	3,173	3,169	3,173
3,168	3,175	3,172	3,175	3,165
3,166	3,171	3,172	3,170	3,174
3,169	3,173	3,169	3,175	3,171
3,172	3,170	3,171	3,173	3,172
3,167	3,170	3,165	3,168	3,170
3,171	3,169	3,175	3,168	3,171

Source: *Own elaboration (2025).*

Based on the information obtained, a *Sixpack* analysis was performed using MINITAB software to demonstrate the improvement in the process following the proper application of the final inspection checklist.

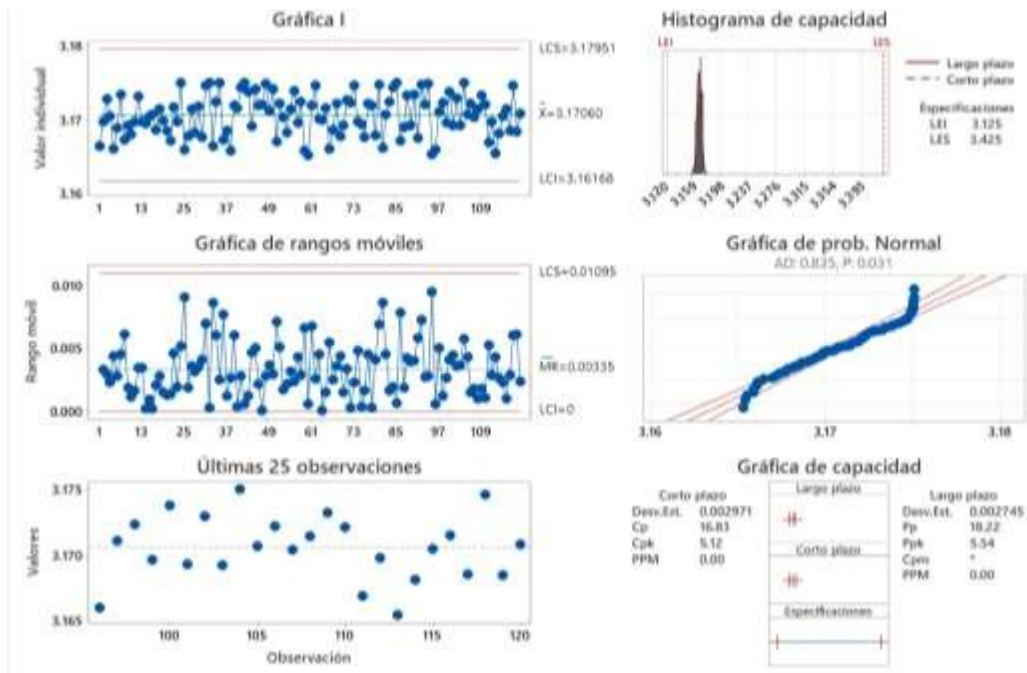


Figure 4. Sixpack Capability Report for the SS process.

Source: Prepared by the author based on MINITAB 21.

The *Capability Sixpack* analysis for the welding process shows that the process is highly stable and under statistical control. No points outside the control limits were detected in the individual values graph or in the moving ranges graph, confirming the stability of the process. Considering the high number of data points and their overall behavior, the fit is sufficiently acceptable to perform the capability analysis. The capability results indicate that the process is highly capable. In the short term, a Cp of 16.83 and a Cpk of 5.12 were obtained. These values are extremely high, reflecting minimal variability and a process that is very well centered within the specification ranges. In addition, the PPM (parts per million out of specification) is practically zero, which means that there are almost no defective products in this process.

Phase V: Continuous Control and Monitoring (RESULT)

In order to evaluate the evolution of quality standards in welding processes, this section presents a comparison between the results obtained (previous and current), emphasizing the performance observed during the final inspection (final visual inspection). The

main statistical parameters of the process capacity to identify improvements achieved, trends observed, and possible areas of opportunity.

Table 13. Comparison of quality parameters.

Previous		Current	
Short Term		Short Term	
Std. Dev.	0.07618	Standard Deviation	0.002971
Cp	1.03	Cp	16.83
Cpk	1.01	Cpk	5.12
PPM	1956.58	PPM	0

Source: Own elaboration (2025).

The progress shown in the results not only represents a technical improvement, but also generates a positive economic impact by reducing the costs associated with reprocessing, waste, and downtime, thereby increasing the overall efficiency and productivity of the process. The data obtained corroborates that the continuous improvement strategy implemented has been effective, allowing us not only to achieve, but even exceed, the quality levels established for the welding process.

CONCLUSIONS

Once the first production run was completed to determine the variability of the weld protrusion (final finish), and the second run was completed after implementation progress, an analysis of variance was applied.

Table 14. ANOVA of weld protrusion.

SUMMARY

Groups	Count	Sum	Average	Variance
PREVIOUS	100	315.9339915	3.159339915	0.006631469
CURRENT	100	317.0603662	3.170603662	7.9093E-06

ANALYSIS OF VARIANCE

Source of variations	Sum of squares	Degrees of freedom	Mean squares	F	Probability	Value critical for F
Between groups	0.006343599	1	0.006343599	1.910901546	0.168420454	3.888852933
Within groups	0.657298465	198	0.003319689			

Source: Prepared internally based on Excel 2025.

The analysis performed using the ANOVA test provides valuable information about the two groups compared. Progress is shown in the "Current" group, with an average of 3.1706, which is slightly higher than the 3.1593 of the "Previous" group. Although the difference is small, the trend is positive, indicating that the actions implemented in the current group contribute to better performance. In addition, there is a considerable decrease in the variance of the current group (from 0.006631 to 7.9093E-06), suggesting that the results are becoming more consistent and stable. Consistency is a key factor in evaluating the positive impact of the strategies applied.

This study demonstrated that the application of an effective methodology for the combined use of world-class tools such as Quality Function Deployment (QFD) and *Critical to Quality* (CTQ) parameters reduces variability and raises process standards. Through an initial diagnosis, it was possible to establish and translate the essential characteristics of customers, which allowed us to understand the origin of the most significant failures within the process.

On the other hand, the statistical results, which were in turn supported by the *Capability Sixpack* and ANOVA analyses, show a considerable decrease in variability, starting with an average of 3.1706 in the "current" group, higher than the 3.1593 in the "previous" group, reflecting an improvement with the implementation of the methodology. These findings confirm that the creative integration of tools such as these brings both quality and economic benefits.

Finally, the findings confirm what was stated by Salas et al. (2018), that the lack of control and standardization in critical processes increases operational risks and affects production stability. The research shows that the methodology model for applying joint tools can be used in different industrial contexts, as long as continuous improvement techniques or projects with similar characteristics are required, thus leading companies to higher levels of productivity, thanks to continuous monitoring that guarantees the permanence of results.

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