Chapter 14
The E-Strategy for Lean-Sigma Solutions, Latin American Case Study in a New Product Validation Process

Francisco J. Estrada-Orantes, Abimael H. García-Pérez and Noé G. Alba-Baena

Abstract The international competition has challenged managers in Latin America to implement state-of-the-art methodologies for problem-solving and continuous improvement, and specifically, the production process validation has become an issue when it has to be completed in a short time span. Typically, the validation activities for critical equipment are performed at least a week prior to the official production launch. If, for any reason, the equipment gets into the plant late, any time taken by the validation process may impact the startup of the line. On the other hand, if production is started without validating the equipment, and performance is not as expected, then, the plant must start a cycle of process improvement activities to get the performance to the expected levels. In general, the continuous improvement activities are organized around two major methodologies: Lean Manufacturing and Six Sigma. While the Lean approach tends to be of a quick-fix type, it gets shorthanded when the causes are not so obvious, and deeper statistical analyses are required. On the other hand, Six Sigma works better when there is plenty of time to conduct all types of tests and analyses to achieve a good cost-effective solution. This chapter explores a combination of the Lean Manufacturing speed with the Six Sigma power of analysis, arranged as a set of sequential steps, for solving industrial problems and giving cost-effective solutions in a short time span. This is achieved by following a strategy identified by these authors as the E-Strategy, which is divided into two phases, the diagnostic and the solution phase. It uses a hierarchical approach of analysis for identifying the root cause of the problem. From the most frequent causes, the problems are eliminated adapting and using the most efficient set of tools. In the E-Strategy, as the complexity of the problem increases, the tools used get more specialized and elaborated. In this chapter, a case study is included as an example of the use of this methodology. The case study shows that the use of the Lean-Sigma approach is effective when following the E-Strategy sequence, and leads to improvements in overall

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performance. The description focuses on the efforts for increasing the conforming outcomes from a crimping process. A pull test is used for performance evaluation of the outcomes. Initial data shows an overall performance of a sigma level of 1.1. However, after following the E-Strategy, running a Taguchi experiment, and performing a series of adjustments a final process evaluation shows an increment to a sigma level of 5.5 for the performance, and a three times reduction in the variation of the process, achieving this solution in a short period of time of 3 days.

Keywords Lean-Six Sigma · E-Strategy · Taguchi · Process validation

14.1 Introduction

The main characteristics of the first decades of the twenty-first-century industrial production and market products is that product lifetimes are short and are likely to become shorter, also the fast delivery, low cost, and higher expectations are the reality and represent current challenges. This means that actual factories need to be able to frequently reconfigure and validate their processes to modify procedures or replace operations.

Also, there is the need for reducing the time for factory workers and managers to learn about the changes, adaptations, and additions to production requirements and processes reconfigurations. Consequently, managers face more possibilities to test the robustness of their operations, and to highlight the weaknesses and failures of their systems. At the same time, they need to keep enhancing the competitiveness and value of their products. Manufacturing systems have to be designed to be flexible or reconfigurable while the operation can resize as the market requires. Moreover, in today's manufacturing the product diversity, shorter delivery, and stretching in pricing are key factors for keeping a successful operation (Gershwin 2017).

Particularly, the validating step of an equipment design algorithm, typically is used to provide a rapid, and smooth confirmation that such equipment performs to customer expectations. The validating step covers the installation of the equipment and the manufacture and evaluation of a significant amount of pieces done under regular production conditions. All unanticipated installation and validation concerns, as well as their corrective actions are implemented prior to the launch of mass production, which is also used to confirm the equipment design process (Yang and El-Haik 2003).

If the results of the validation are not as expected, and problems arise, a structured root cause investigation process is required to create a solution that may solve the problems in a short time so as to minimize the delay for mass production. The way the steps are structured for properly investigating an incident is critical for achieving the expected results (Heuvel et al. 2008).

In short, the main challenges experienced by industrial manufacturing companies, concentrate in keeping the production process running within the expected

lead-times, with a predictable quality, a reliable delivery, and cost-effective initiatives that allow their products stay competitive in the market. In general, manufacturing companies face conditions that involve the identification and correction of problems, and have a tendency to look into the continuous improvement paths. In general, improvement programs are not in the daily agenda, but, when the burden of a company becomes higher than expected, or when the production launching of a new product is at risk, the continuous improvement initiatives arise as the most important programs in the organizations.

The mentioned challenges are generally addressed by using several engineering methodologies such as Six Sigma, Lean Manufacturing, Design for Six Sigma (DFSS), and Re-Engineering approaches. In the case of Latin America, the use of such applications and solution processes are boosted by the strong competition among Latin American enterprises, the established international corporations and the competition with other commercial regions such as the Asian and European zones. Making use of the mentioned methodologies and decision processes, the key for survival and success of the local industrial companies.

14.1.1 Latin American Scenario

When facing the described challenges, managers and industrial owners prefer a simple and fast solution with the minimum investment and fast return. For finding such solutions, researchers in Latin America have been struggling for efficient and clear strategies that fit the needs and requirements of the local industries, but also to overcome the restrictions of the Latin America scenarios. A way of doing this is by adapting tools and approaches known and successfully used in other regions and different economic platforms. In this way, Latin American researchers have been challenged to find solutions and working philosophies that can be adopted and adapted to organizational structures and behavior requirements (Contreras et al. 2006) from other regions as has been occurring at the USA–Mexico border zone for the past six decades (Wilson 2010).

In such experience, researchers have learned that there are conditions and scenarios where the adopted strategy may require additional modifications to adapt it to specific regional needs. That includes incorporating some tools and methods developed locally or importing them from other strategies. Especially, in the USA–Mexico border region, where a high percentage of the manufacturing plants are the USA owned, and most of the equipment come from outside the region, the equipment validation process takes a significant role during the production ramp up of new products. Very often, the equipment validation process has to be conducted in parallel, or very close to the mass production ramp up. Additionally, in some instances, some complexity is added when the results of the validation are not as expected, and a Root Cause Analysis, and a Problem-Solving Technique needs to be used. In such cases, the selection, combination, and adaptation of the tools, to suit the specific needs of a company, will enhance the resulting methodology to

respond to the economic and process restrictions, or, in other instances, to the time constraints and subjective conditions set by some environmental aspects of the territory, as previously reported by these authors and others, who have verified the results during the development of different applications in this region. Reports have also shown that these integrations are more successful when the process is led by experienced engineers, who are flexible to adapt to the complex conditions and restrictions of this economic region.

14.1.2 Approaches Used in Latin America

Considering the described scenario, some engineering approaches have proven to be effective for solving this type of problems, and understanding the characteristics of such procedures, adapted guidelines may be developed for making decisions under the mentioned conditions. For instance, in solving short-term problems the Lean manufacturing approach, the PDCA cycle, and the 8Ds methodology have proven their value. For process improvement, Six Sigma is the most concurred choice, and for optimization projects, Lean-Six Sigma has been the most favored for the efficient results, and moreover for solving short term but complex problems, Lean-Sigma has been used more often because it is efficient and reliable.

14.1.2.1 The "Just-in-Time" or Lean Manufacturing Path

Many companies in the US and Mexico solve critical situations using either, the "quality path", or the "Just-in-Time" (JIT) production path (Schonberger 1986). The JIT ideas were first introduced by Taiichi Ohno in 1978 and are based on the foundations of the Toyota Production System (TPS). This path gains more attention after 1990 when James Womack introduces some ideas and tools for increasing the efficiency of this path (Womack et al. 1990). By redefining the objective focusing in achieving a rapid and continuous series of improvements in the production systems, Womack renames the JIT path to "Lean Manufacturing path". The new Lean Manufacturing path was keeping its identity by using the "just do it" and "keep it simple" strategy. On the other hand, the "Quality" path based on Deming's statistical approach to quality, integrates the tools that use data generated by the process (through an effective in-depth statistical analysis) in order to identify and eliminate the root cause of problems (Deming 2000). Later, the quality path takes a more relevant importance with the development of the Six Sigma approach, which will be addressed in a later paragraph.

However, when the solutions require a flexible approach, or the focus is on keeping the system working as it is, a methodology, such as Lean Manufacturing is preferred. The lean methodology focuses on identifying all immediate threats to the flow of the production process. These threats are identified as waste, and classified as muda, mura, and muri, for their names in Japanese. Muda are all aspects of waste related to the

operation of the production process. Mura is related to fluctuations in the production schedule, and muri has to do with all aspects of the workstation structure and design. Lean manufacturing focuses on reducing the Lead-Time using any available tool to minimize the waste that impacts the production process performance.

According to Womack and Jones (1996) the Lean Manufacturing methodology is based on five principles: (I) **Specify** the Value added of the product. Provide exactly what the customer wants, at the right time, and at the right price. (II) **Identify** the main Value Stream. From the customer's perspective, identify all the activities in the production process that add value to the product. (III) **Develop Flow**. Make sure the process flows without interruptions, delays, or accumulations. (IV) **Use Pull Production** scheduling. The Production should be customer driven, or oriented to fulfill the customer demands. (V) **Strive for Perfection**. Continue looking for perfection by eliminating the different types of waste.

In the Lean manufacturing approach, there are 8 types of waste classified as "Muda". They are described as follows:

1. *Defects*: Parts or products that do not meet the customer's requirements and or specifications.
2. *Over production*: Producing more than what the customer requires, or producing before the customer needs it, or producing faster than the customer's consumption.
3. *Over processing*: Adding processing activities to a production process that are not necessary, and the customer is not willing to pay for. For instance, having someone remove excess material on a molded part, when it was supposed to be perfect going out of the molding machine.
4. *Transportation*: Moving materials or products around unnecessarily.
5. *Motion*: People moving around during the production process unnecessarily.
6. *Inventory*: Keeping more inventory than strictly necessary to keep the process flowing continuously.
7. *Waiting time*: Time that an operation stops production flow waiting for an input (material, machine, people, and order)
8. *Talent*: Waste for not using people's talent to improve the process.

The waste classified as Mura by Lean Manufacturing is described as follows:

1. *Changes*. Waste generated by sudden changes in the production schedule.
2. *Fluctuations*. Flow interruptions and waste generated due to fluctuations in the production schedule.
3. *Inconsistencies*. Waste caused by inconsistencies between the production schedule and the availability of materials.

Additionally, the waste classified as muri include the following descriptions:

1. *Layout*. Waste caused by a poor layout of the workstation.
2. *Tooling*. Waste generated by inadequate tooling.
3. *Work Instructions*. Waste generated by confused work instructions.

Further developments and enhancements to the Lean manufacturing path have incorporated some techniques in an effort to identify and correct problems directly on the production line, whenever they arise. The Toyota Kata approach delineates a structured strategy for identifying causes of problems and improving processes. The Kata approach uses the following steps:

1. Understand the current condition
2. Establish the next target condition
3. Conduct PDCA cycles toward the target condition

Rother (2010) describes in his work the details, and mechanics of the strategy. The procedure is oriented to solve problems on the shop floor, rather than in a meeting room.

In the case of Latin America, several reports have proven that it is possible to successfully adapt the Lean manufacturing approach to production systems in this region.

14.1.2.2 The Six Sigma or Quality Path

In the USA–Mexico border region, continuous improvement methodologies like Six Sigma have proven to be effective when a process improvement requires a deep statistical analysis of the potential causes of a condition in a production system. Six Sigma is defined as a continuous improvement methodology that focuses primarily on the identification and reduction of the process variation. As a structured methodology, Six Sigma was first introduced and implemented in Motorola during the 1990s (Pande et al. 2000).

The power of the statistical analysis makes this methodology ideal for complex improvement challenges where the root cause is hidden deeply in the process parameters or there is an intricate relationship among the variables of such process. The tools proposed for each phase in the Six Sigma methodology have been proven and adapted in many applications. Figure 14.1 shows a relationship between the phases of the Six Sigma improvement process using the DMAIC cycle (Define–Measure–Analyze–Improve and Control), the objectives of each phase and the tools most frequently used for each phase. Six Sigma aims to identify and reduce variation and looks to achieve a performance level of 3.4 defective parts per million (Rath & Strong 2000).

Moreover, the table shown in Fig. 14.1 serves also as a general guidance during the analysis for the improvement teams. Reports provide evidence that in the USA–Mexico region, the use of Six Sigma has been successful for production processes improvement (Camacho et al. 2016; Coy et al. 2016) and for product design cases as reported by Lopez et al. (2016) and Romo et al. (2016).

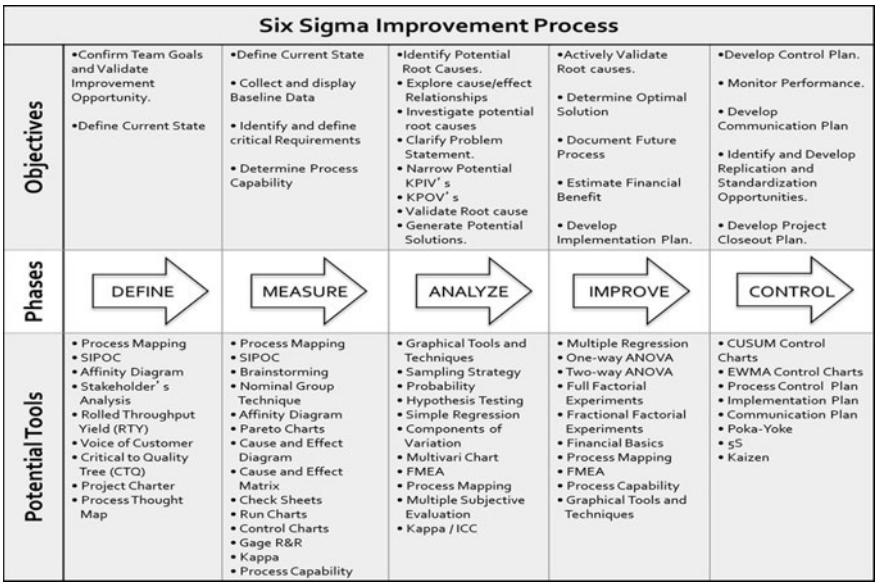

Fig. 14.1 Image of a roadmap of DMAIC phases and the potential tools for each phase

14.1.2.3 Merging Lean Manufacturing and Six Sigma

The need for combining elements used by Lean Manufacturing and those used by Six Sigma was originally identified and proposed by George (2002) and George & George (2003). For some projects addressing primarily organizational wastes affecting the production lead-time, the solutions are more related to the use of the Lean Manufacturing approach, while for long-term projects addressing quality, cost, or delivery issues that required a deep analysis, the Six Sigma approach is preferred as the solving method. However, in many production processes, the reality is that a specific scenario may involve both types of challenges, that is, the lead-time needs to be improved, but it requires a deep statistical analysis to identify and eliminate the hidden root cause of a complex problem.

For such conditions, several combinations of tools coming from Lean manufacturing and Six Sigma have been developed for different scenarios and specific needs. The original combination is known as Lean-Six Sigma (George 2002; George et al. 2005), and its evolution has taken this initiative to a methodology known as Lean-Sigma. While Lean-Six Sigma is seen as a methodology that takes advantage of the structured DMAIC roadmap, and integrates additional tools from Lean manufacturing to each phase, and is primarily used as a long-term process improvement methodology, Lean-Sigma is seen as a short-term problem-solving methodology. Solving a problem using Lean-Sigma will not always bring a process' performance to a six sigma level, but instead, the Lean-Sigma methodology

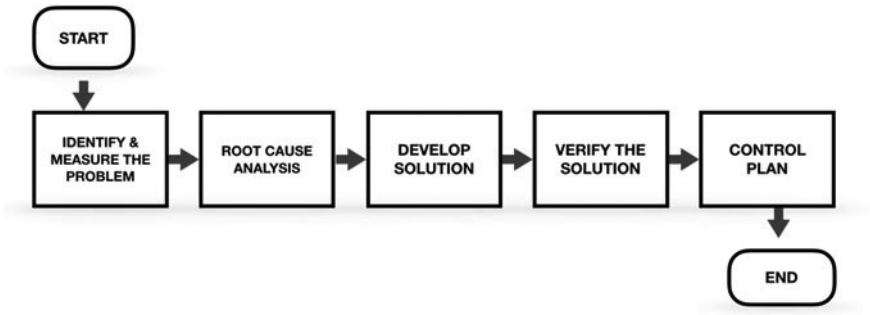

Fig. 14.2 Simplified diagram of the Lean-Sigma methodology steps

uses the incremental approach to take the process quality to the desired level through a series of sequential kaizen, or improvement events (Estrada and Alba-Baena 2014).

Lean-Sigma methodology is based on five rapid improvement steps shown in Fig. 14.2 and stated as follows (Estrada-Orantes and Alba-Baena 2014):

1. *Identify* and measure the problem. How big is it?
2. *Root cause analysis:* What is the root cause of the problem?
3. *Develop a solution:* Identify the alternative solution that best solves the problem.
4. *Verify* the solution: Make sure that the problem is eliminated by the proposed solution.
5. *Control Plan:* Make a quick and effective plan so that the previous situation does not come back.

The synergy between these different approaches was discussed by Estrada and Alba-Baena (2014) and several researchers have reported the use of Lean-Sigma for solving industrial problems in the Latin American environment, among them Gracia et al. (2016) and De la Cruz et al. (2016). Also, Alba-Baena et al. (2016) reported the use of Lean-Sigma during a product Ramp-Up event. However, the use of Lean-Sigma has shown that there are opportunities for defining new strategies in order to make more efficient the use of Lean-Sigma in industrial settings. Recently Alba-Baena et al. (2016) show that the Lean-Sigma strategy of "do it at the speed of Lean with the depth of Sigma", can be structured for solving situations in the restrictive environment of Latin America and give solutions in a short-term span.

14.1.3 The E-Strategy

The Lean-Sigma approach has been proven to be efficient all over the globe; however, at the managerial level more efficient strategies have to be developed in

order to take advantage of the experiences in the use and implementation of Lean-Sigma in the context of the Latin America environment. This chapter releases and describes the E-strategy as a strategy for efficiently solving industrial problems. This strategy is the result of the analysis of the practical application of the Lean-Sigma approach in companies at the USA–Mexico border region. The "E-strategy" is a strategy that follows a series of hierarchical and logical steps in the decision process for solving a problem.

The E-Strategy is based on the Lean-Sigma methodology previously tested by the authors. In the context of the Lean-Sigma methodology, the E-Strategy concentrates on developing specific steps to conduct the Root Cause Analysis, as well as the development of the solution. The E-Strategy uses Diagnostic Phase to the steps used to identify the root cause of the problem, and the Solution Phase to the steps used to create and test the solution. In order to minimize the elapsed time from the manifestation of the problem, through the creation and test of the solution, the E-Strategy quickly evaluates six potential causes in the Diagnostic Phase, and five additional steps to develop and validate the solution.

14.1.3.1 The E-Strategy, Diagnostic Phase

Figure 14.3 depicts the E-Strategy Diagnostic Phase with six potential and basic causes that may be responsible for the problem. The Diagnostic phase may be seen as the quick identification and elimination of common obstacles that interrupt the normal flow of the production process. This phase starts immediately after the problem manifestation. Each cause is analyzed, one at a time, following the order in the diagram. Each potential cause is addressed as a question in order to filter the complexity of the problem. Each question is followed by an action (*make corrections)* and a decision (*Is the problem solved?)* up to the end of the six consecutive steps, and are as follows:

1. *Are prints and drawings correct?* Check and compare the actual prints and drawings used on the floor for all components, sub-assemblies, final products, and equipment involved in the problem, to determine if they are up to date to the most recent revision, and are used correctly.
2. *Are the tools and operating conditions correct?* Review the actual operating tools used on the floor, the working conditions of assembly and fabrication stations, and the parameter values of the equipment, to be in accordance to the official work instructions.
3. *Is raw material correct and to specifications?* Check for compliance to specifications of the raw materials being used.
4. *Is the measuring system correct?* Review the calibration status of testing equipment, and conduct a new analysis for the complete measuring system.
5. *Is process variation in statistical control?* Take additional samples to verify the statistical stability and predictability of the process.

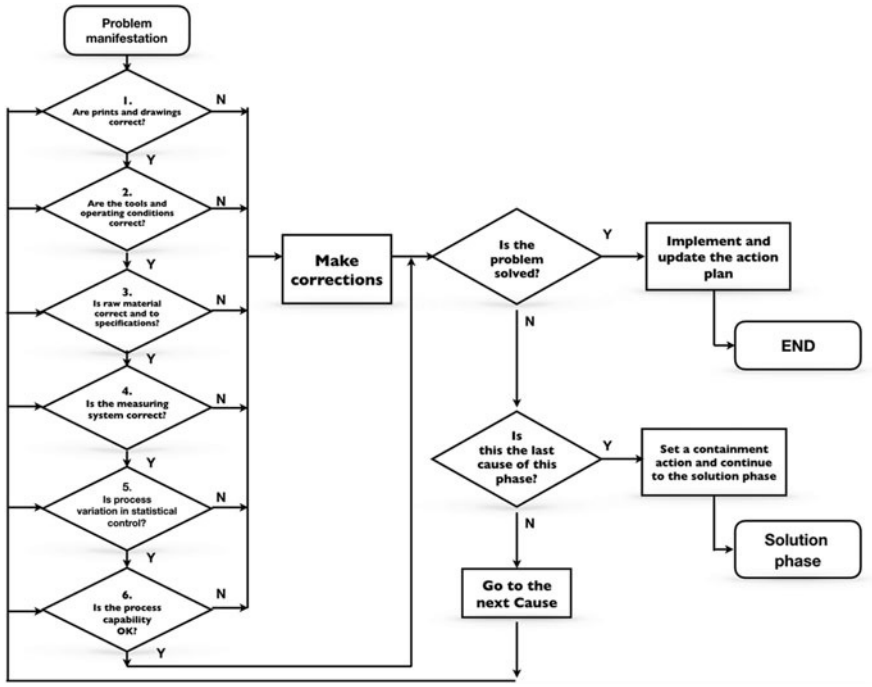

Fig. 14.3 Schematic diagram of the E-Strategy Diagnostic Phase

6. *Is the process capability OK?* Take additional samples, and review the current capability of the process.

If after reviewing the described filters, and performing any corrections required, the problem persists, a containment activity is set at the process, the condition is classified as a complex problem, and the team moves on to the Solution phase, as depicted in Fig. 14.3.

14.1.3.2 The E-Strategy, Solution Phase

After the use of the diagnostic phase, the common causes are eliminated, and basic data from the product, the process, and the working conditions have been collected. If the problem persists, it means that it is a complex problem with a hidden root cause, and the need for a deeper analysis arises. For this situation, the E-Strategy solution phase is used and consists of five sequenced activities that have to be completed in order to solve the problem. Figure 14.4 depicts the Solution phase. The first step is identified as "*let the process speak (data)*", which means to collect current data from the operations involved in the problem.

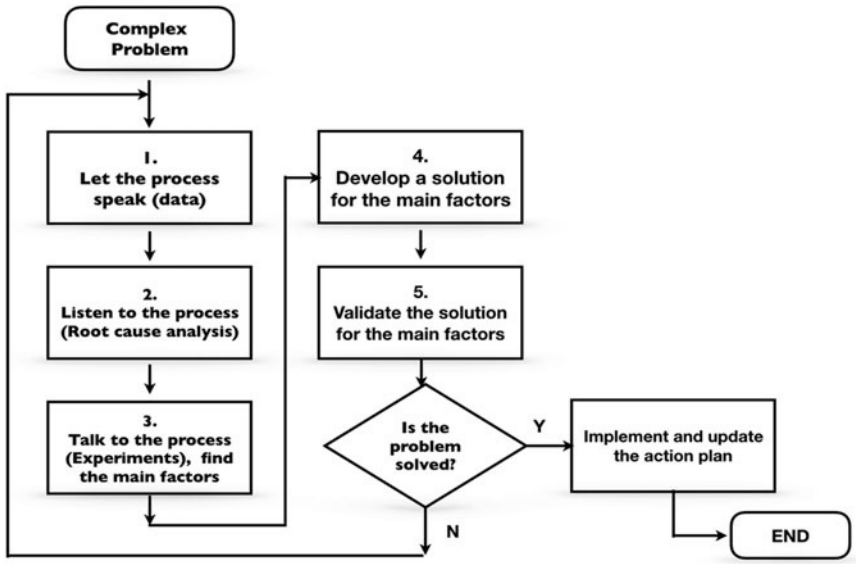

Fig. 14.4 Schematic diagram of the E-Strategy Solution Phase

The second step, "*listen to the process (root cause analysis)*" focuses on finding the potential causes of the problem and identifying the most likely to be the root cause. The next step "*talk to the process (Experiment), Find main factors*" requires running experiments to quantify the effect of the process variables in the critical characteristics of the output variable. The relationship between them and the possibilities for level adjusting and solving the problem.

Step four, "*develop a solution for the main factors*", deals with the integration of possible solutions and the selection of the most promising for solving the problem. In step five "*Validate the solution for the main factors*", the chosen solution is evaluated obtaining additional data from the process, using the chosen values for each factor, and performing statistical tests, and comparisons between the initial and final values. If such solution solves satisfactorily the problem, then the last step "*implement and update the action plan*" is documented, and the methodology concludes.

For illustrating the use of the E-Strategy, this chapter includes a case study of the integration of the E-Strategy to the Lean-Sigma approach. The example describes a condition where the deliveries cannot wait, and the quality levels are not as expected from the process. In this case, with the aggravate that it is a new product in this facility at Juarez, Mexico and the equipment and production setup are under validation for launching. During the solution process, these authors used the most efficient tools and methodology of Lean-Sigma for following the two phases of the E-Strategy and give a solution in 3 days after the problem was described by the management.

14.2 Case Study: Equipment Validation Process for New Product Introduction

14.2.1 Case Study Scenario

A manufacturing facility that produces midget fuse blocks is starting production under a tight-time scenario. The process is scheduled to start producing, and shipping to the customer in parallel to the installation and validation of the equipment. Up to the second day of the week, all the quality assurance tests of the equipment comply to specifications, but the crimping force at the fuse end caps, which show values below the specifications.

After several attempts to correct the problem without a positive outcome, the production line is stopped, and classified as not ready for mass production. The case is presented to the continuous improvement team to find the causes and create a feasible solution, with the clear objective to have the production of conforming products as soon as possible.

14.2.2 Problem Description

The crimping machine used to perform the task is a four-station turn-table (as seen in Fig. 14.5a). The stations are sequenced as follows: in the first station the fuses are loaded; the second station is used for crimping the upper side of the fuse, the third one for crimping the other side of the fuse, and the last station is used to unload the fuses. The crimping stations consist of a set of clamps which is closed by the force of a pneumatic cylinder, create notches on the end caps of the fuses to keep them in place during use. The quality of this operation is checked by measuring the retention force using the instrument shown in Fig. 14.5b. This instrument includes a load cell in the upper portion, and a motor that creates the separation movement.

The basic procedure for this test is described as follows: (1) The lower end cap of the fuse is held to the fixed base of the instrument, (2) The upper end cap of the fuse is attached to the load cell, (3) When the motor starts an upper movement of the load cell, a tension force is created on the fuse. As this force increases the fuse breaks, or either one of the end caps fall out when the product crimping force is overpassed. The maximum force used before breakage, or detachment of the fuses, is registered by the load cell, and is identified as the "maximum disassembly force".

The validation documentation of the crimping machine, submitted by the manufacturer, shows evidence that the machine is in compliance to the pull test specification, which suggests that the problem may come from the actual setup of the machine.

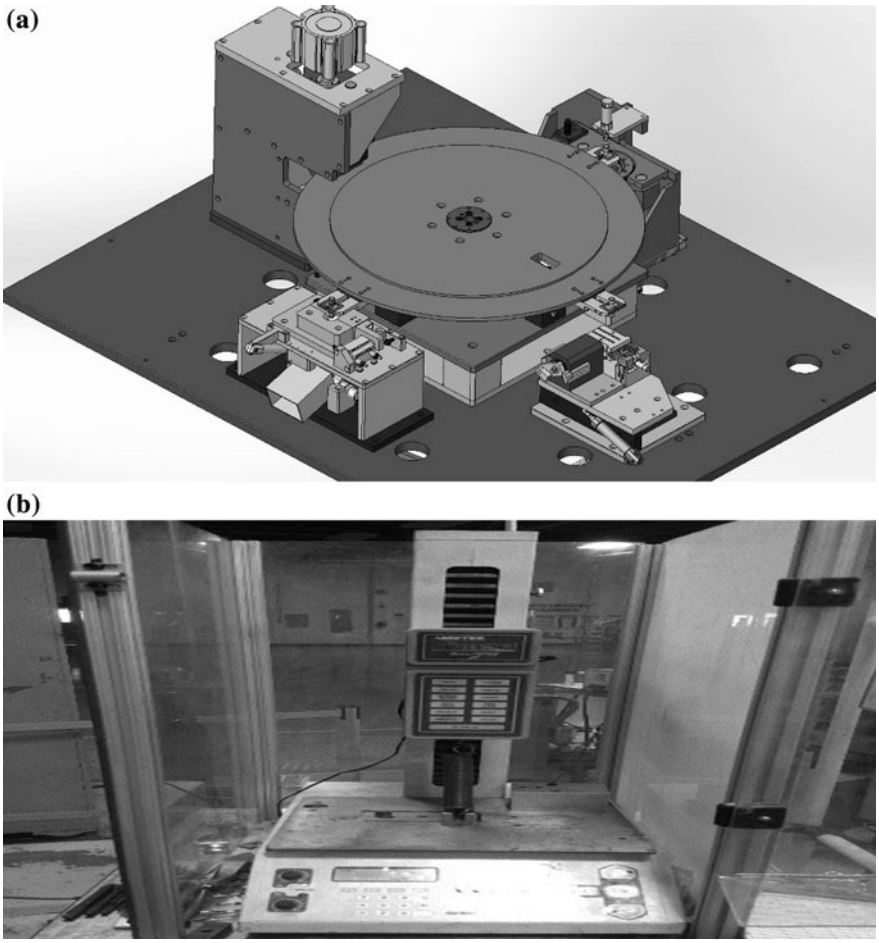

Fig. 14.5 **a** Partial drawing of the crimping machine, **b** Pulling testing equipment used for these experiments

14.2.3 Methodology

The E-Strategy, as depicted in Figs. 14.3 and 14.4, is used as the guiding methodology for addressing the problem. Details of the application of all the steps of the methodology are provided below.

14.2.4 The E-Strategy, Diagnostic Phase. Identify and Measure the Problem

The problem is described as the pulling force test of the fuses does not conform to specification. Several data points from current samples are below the lower specification limit of 150 N, as shown in Table 14.1.

The Diagnostic Phase of the E-Strategy, specifically focuses on six potential causes, and reviews one at a time. For this case, the critical information gathered during this stage is summarized as follows:

1. Prints and drawings for all the components and equipment are up to date and used correctly.
2. Tools and operating conditions for the crimping machine are set up according to manufacturer's specifications.
3. The raw material is within specifications, however shows some variation in three critical characteristics: the diameter and length of the component identified as melamine tube, and the diameter of the end caps.
4. The calibration of the testing equipment is found to be acceptable.
5. The pull force testing data shows no evidence of special cause variation (see Fig. 14.6), showing that the process is stable, predictable, and has a normal distribution as shown in Fig. 14.7a.
6. The capability of the process is found not acceptable, with a Cpk value of −0.15 as shown in Fig. 14.7b. The process has an overall performance of 683,576 ppm, which is equivalent to a sigma level of 1.1.

Since the process cannot be corrected to achieve the target using the manufacturer's recommended operating parameters, the situation is diagnosed as a complex problem, and requires the Solution phase of the E-Strategy.

Table 14.1 Data for samples after crimping and pulling testing

No.	Max pulling force (N)	No.	Max pulling force (N)
1	185.10	11	110.35
2	120.85	12	111.55
3	113.10	13	185.05
4	96.05	14	165.05
5	169.90	15	89.50
6	75.10	16	130.40
7	102.95	17	185.73
8	114.95	18	126.13
9	202.85	19	103.98
10	143.50	20	113.24

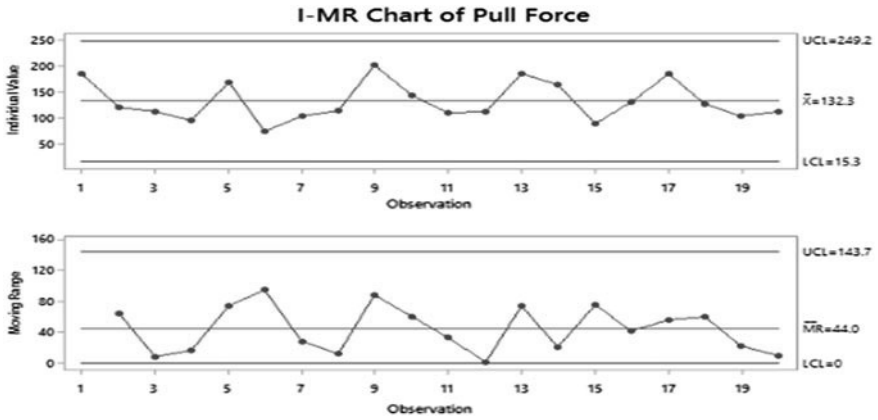

Fig. 14.6 Control chart of data after pulling force testing

14.2.5 The E-Strategy, Solution Phase. Root Cause Analysis

The solution phase of the E-Strategy requires the collection of additional information in order to allow the process to speak, understand its behavior, and identify all potential causes of the problem. Three principal components are involved when performing the pulling test: A melamine tube, and two end caps, the latter are identified with the same part number. Two of the characteristics that may potentially influence the pulling force resistance are identified in the melamine tube as: the diameter and the tube length, and one is identified in the end cap as the diameter. For the initial characterization of the variability of the incoming components, data from 100 pieces of each is used to calculate a capability analysis for each characteristic.

Figures 14.8 and 14.9 depict the measured behavior for the three characteristics. As seen in the mentioned figures, the values observed (Cpk) are 0.81, 0.68, and 1.01 for the tube diameter, tube length, and the cap diameter, respectively. These capability studies show that the components are coming from processes that are generating parts under and above the specification limits with expected defectives as: 1.3, 2.8, and 2.4% for the tube diameter and length and the cap diameter, respectively, however, these components are filtered in the incoming inspection, so most of the received parts are within the specification limits when received at the process.

From the data shown in these figures and the incoming inspection for these components, it is accepted that these are within specifications. Accepting also that the variation within the component's dimensions is considered as part of the common cause variation, even though some combinations at extreme values of the components may fall out of specifications and may create undesirable results. Also, it is accepted that such conditions are not the main and root cause of the crimping problem.

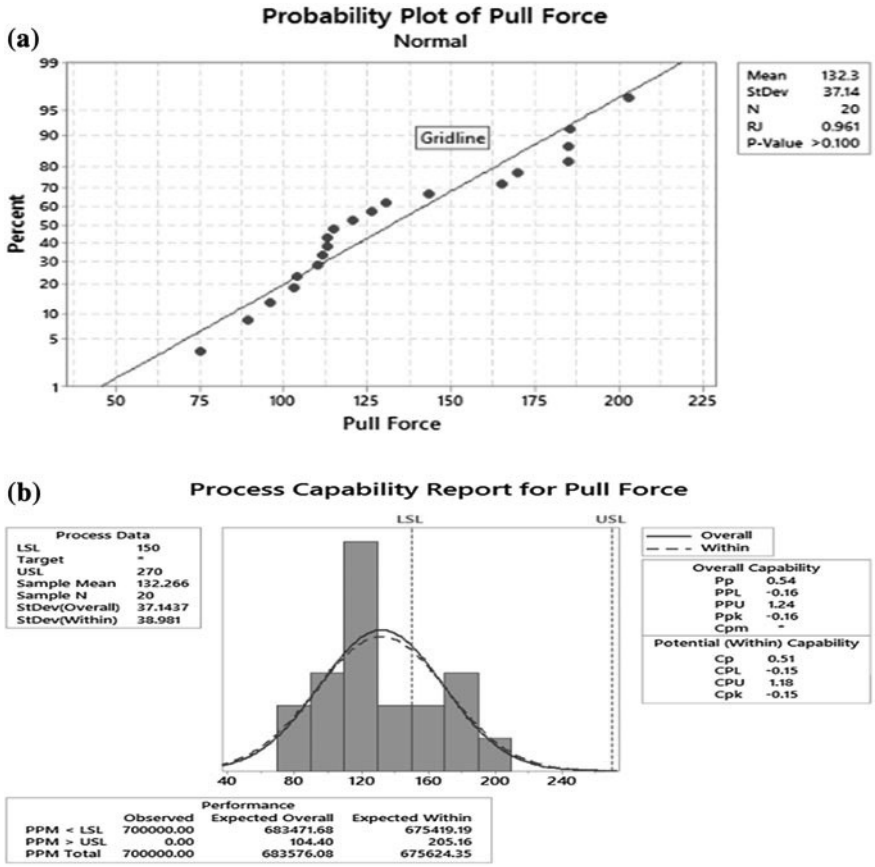

Fig. 14.7 **a** Normality test after pulling force testing, **b** Initial capability analysis after pulling force testing

As mentioned before, the designer and integrator of the crimping equipment recommended operating conditions that includes options for clamping with clamps according to the end cap model. Also, the crimping machine has a control for adjusting the distance traveled by the piston before closing the clamp over the cap. Also, the time the clamp remains closed and the air pressure can be adjusted.

In summary, the potential factors affecting the outcome of the crimping process, as shown in Table 14.2 are: the type of clamp, the piston travel distance, the time the clamp remains closed, and the air pressure. All these factors may be adjusted and controlled during the operation. Additionally, the characteristics of the components may also affect the outcome, but such variation, as long as it remains within specification, is beyond the control of the operation, for that reason they are considered as non-controllable (see Table 14.2).

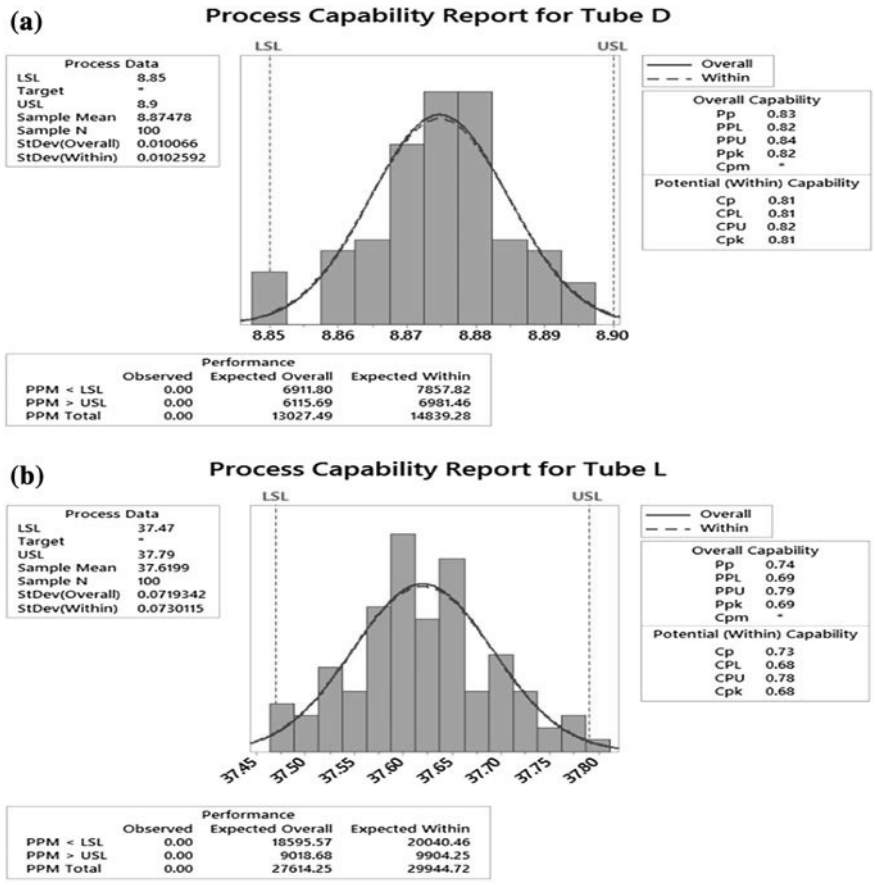

Fig. 14.8 **a** Capability analysis for tube diameter, **b** Capability analysis for tube length

14.2.6 Developing a Solution

Once the main factors have been identified, the next step in the E-Strategy methodology is to develop a solution. For this case, an experiment that includes both, controllable and non-controllable factors are designed to explore which factors are primarily impacting the pull force, and at the same time investigate the operating conditions that may help maintain the process robust against the non-controllable factors. A Taguchi Robust Parameter experiment is designed using an L9 array for the three controllable factors (see Table 14.3) and an L4 array for the three noise factors shown in Table 14.4.

Based on the crimping process characteristics and mechanical tolerances given, the experiment includes different levels, for the controllable factors three levels are assigned (see Table 14.3) and for the non-controllable factors two levels as shown

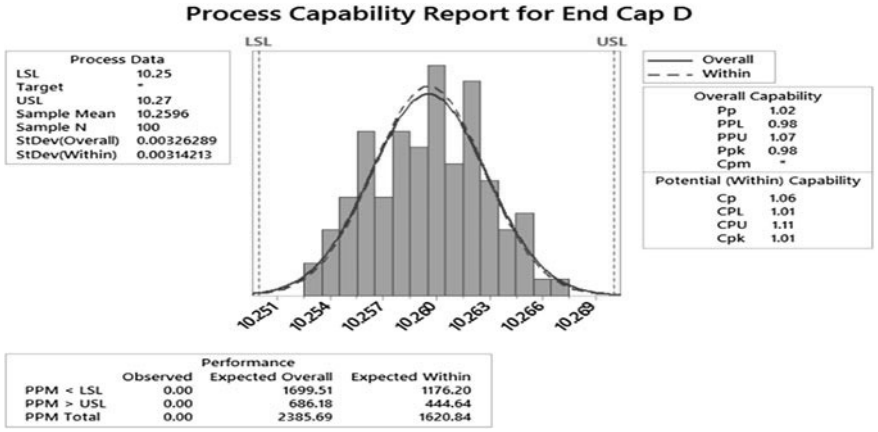

Fig. 14.9 Capability analysis for the end cap diameter

Table 14.2 Experimental identification of affecting variables divided as controllable and non-controllable

Controllable	Non-controllable
Type of clamp	Melamine tube diameter
Piston travel distance	Melamine tube length
Time clamp remains closed	End cap's diameter
Air pressure	

Table 14.3 Controllable factors and levels proposed for the experiment

Factor	Level 1	Level 2	Level 3
(*A*) Piston travel distance (mm)	15	17.5	20
(*B*) Time clamp stays closed (s)	0.5	1.5	2.5
(*C*) Air pressure (psi)	40	75	90

Table 14.4 Levels proposed for the non-controllable factors

Factor	Level 1	Level 2
(*O*) Melamine tube diameter (mm)	8.85	8.90
(*P*) End cap diameter (mm)	10.25	10.27
(*Q*) Melamine tube length (mm)	37.47	37.79

in Table 14.4. The final experimental arrangement for both, the L9 for the controllable and the L4 for the non-controllable variables are presented in Table 14.5.

From such arrangement and by crossing the two arrays, a total of 36 different combinations are generated and were tested obtaining the results as shown in Table 14.6. With the data summarized in Table 14.7, the Signal-to-Noise (*S*/*N*) table

Table 14.5 L9 array for controllable factors

Run	(*A*) Piston travel	(*B*) Time clamp close	(*C*) Air pressure
1	15	0.5	40
2	15	1.5	75
3	15	2.5	90
4	17.5	0.5	75
5	17.5	1.5	90
6	17.5	2.5	40
7	20	0.5	90
8	20	1.5	40
9	20	2.5	75

Table 14.6 L4 array combinations for non-controllable factors

Factor	Combinations			
	1	2	3	4
(*Q*) Tube length	37.47	37.79	37.79	37.47
(*P*) End cap diameter	10.25	10.27	10.25	10.27
(*O*) Tube diameter	8.85	8.85	8.90	8.90

Table 14.7 Results of the experiment for the pulling force testing (values in Newtons, N)

Run	Combination			
	1	2	3	4
1	199.30	168.00	178.80	176.05
2	173.45	179.25	185.30	159.30
3	177.80	159.30	177.15	151.10
4	176.30	192.50	188.70	205.30
5	210.00	190.60	164.15	186.00
6	185.10	169.90	202.85	185.05
7	120.85	75.10	143.50	165.05
8	113.10	102.95	110.35	89.50
9	96.05	114.95	111.55	130.40

is calculated, as shown in Table 14.8, containing the levels for each controllable factor, then, considering for the decision the combination that reports the highest values during the pulling force testing for choosing as the possible solution (see Table 14.8).

In this case, the proposed solution is based on the Signal-to-Noise (*S*/*N*) Table shown in Table 14.8, and the levels of the controllable factors are selected from those with the highest value s in this table, as follows: for factor *A*, level two is selected, for the factor *B*, level one is chosen, and for factor *C*, level two is the best option. The corresponding values for the levels selected for each controllable factor, as shown in Table 14.9 are: for the piston traveling at a distance

Table 14.8 Signal-to-noise ratio (*S*/*N*) values

Level	(*A*) Piston travel	(*B*) Time clamp close	(*C*) Air pressure
1	44.74	43.82	43.55
2	45.42	43.46	43.76
3	40.66	43.54	43.52

Table 14.9 Selected values for controllable factors

Factor	Selected value
(*A*) Piston travel distance (mm)	17.5
(*B*) Time clamp remains closed (s)	0.5
(*C*) Air pressure (psi)	75

value of 17.5 mm, for the time of keeping the clamp closed 0.5 s, and finally keep the pneumatic (air) pressure in 75 psi.

14.2.7 Verify the Solution

Once a solution is selected, in order to verify that the selected values for the controllable factors solve the problem, the E-Strategy requires the crimping machine to be run using the selected values. In this case, 40 pieces are run, and the corresponding pull force test data is collected. The verification is performed by comparing the pull force results obtained with the original settings versus the results obtained with the proposed settings. This comparison is validated by using a statistical hypothesis testing. Table 14.10 shows the results for the confirmation run.

The I-MR chart shown in Fig. 14.10 shows a graphical representation of the data for the pulling test before and after using the solution obtained with the

Table 14.10 Data of the confirmation run after the pulling force testing

No.	Force	No.	Force	No.	Force	No.
1	199.8	11	194.1	21	229.5	31
2	203.3	12	192.8	22	203.6	32
3	193.2	13	203.8	23	226.2	33
4	179.2	14	204	24	210.6	34
5	219.7	15	208.5	25	221	35
6	226.4	16	217.8	26	191.3	36
7	184.8	17	213.3	27	214.4	37
8	198.7	18	179.2	28	208.4	38
9	218.5	19	219.3	29	189.7	39
10	186.3	20	199.3	30	207.2	40

methodology. As seen in the figure, the left portion of the chart represents the behavior of the data before applying the solution and the right portion of the chart shows the behavior of the data after applying the selected values for the controllable factors. A visual comparison shows that the mean values increase, and the variation is reduced.

A noticeable shift in the process is observed in the I-MR Chart (Fig. 14.10), and it also shows that the process is still stable and predictable, and therefore, it is considered to be in a state of statistical control. The pulling force mean value, as shown in the upper portion of Fig. 14.10, moves from 132.3 to 202.7 N after using the selected solution. Meanwhile, the UCL and LCL (Upper and Lower control limits) shift from 15.3 and 249.2 N to 161.6 and 243.9 N, respectively. The moving range of the data, as depicted in the lower portion of Fig. 14.10, also shows a considerable reduction in the variability of the data. The mean value of the range goes from 44.0 to 15.5, which represents a 64.7% reduction in the variation of the process outcomes. At the same time, the UCL and LCL limits shift from 0 and 143.7 N to 0 and 50.5 N, respectively.

A capability analysis for the pulling force after applying the selected values for the controllable factors of the crimping machine is elaborated and depicted in Fig. 14.11. This study shows that the proposed solution puts the process within the specification limits achieving a Cpk value of 1.28 and a Ppk value of 1.33, which represents an expected overall performance of 33.35 ppm.

A Capability Analysis comparison for the pulling force, using the data before and after applying the solution, is depicted in Fig. 14.12, facilitating the discussion and comparison of the performance before and after the implementation.

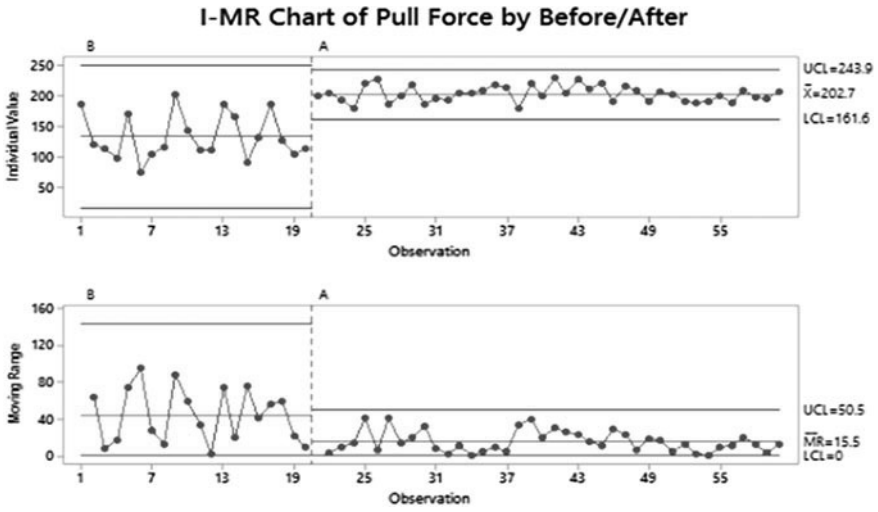

Fig. 14.10 I-MR chart comparing the before versus after implementation data for the pulling force testing

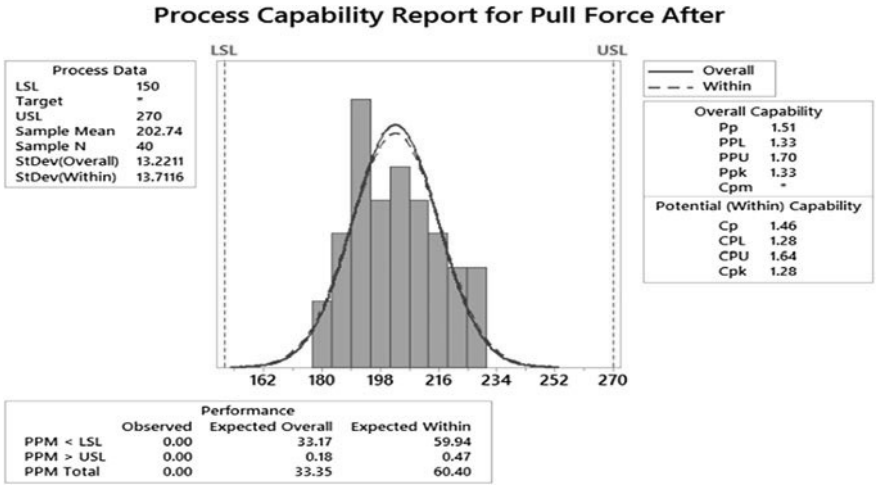

Fig. 14.11 Capability analysis for pull force after changes

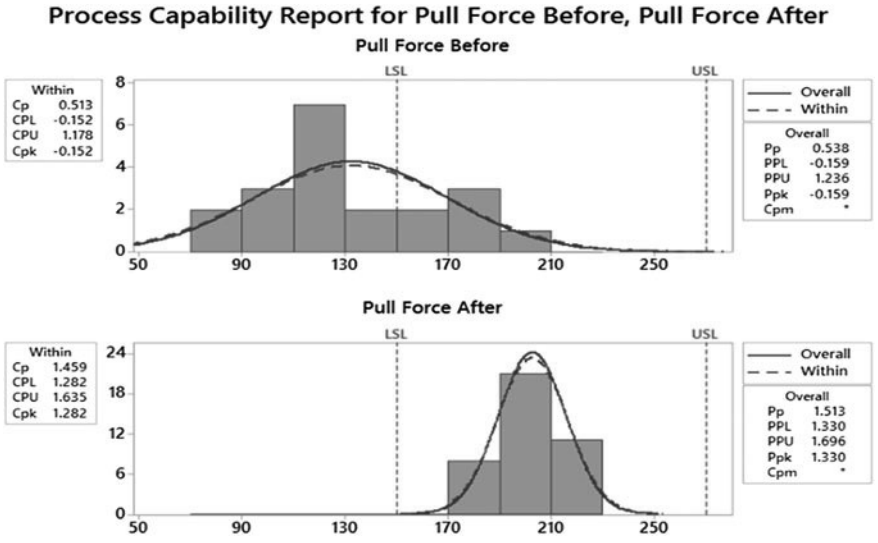

Fig. 14.12 Before versus after comparison of the capability analysis for the pulling force testing

The upper portion of the chart shows the process capability of the data before applying the solution, and the bottom portion of the chart shows the behavior of the data after applying the selected values for the controllable factors in the crimping process. The capability analysis shows that before applying the solution, over 60% of the parts had values below the LSL, with a predicted overall performance of 683,576 defective parts per million (see Fig. 14.12). While, after applying the

One-Sample T: Confirmation

```
Test of μ = 150 vs > 150


Variable       N    Mean  StDev  SE Mean  95% Lower Bound      T      P
Confirmation  40  202.74  13.22     2.09           199.22  25.23  0.000
```

Fig. 14.13 Pulling-force testing data for the confirmation run using the hypothesis test

Two-Sample T-Test and CI: Pull Force Before, Pull Force After

```
Two-sample T for Pull Force Before vs Pull Force After

                     N   Mean  StDev  SE Mean
Pull Force Before   20  132.3   37.1      8.3
Pull Force After    40  202.7   13.2      2.1


Difference = μ (Pull Force Before) - μ (Pull Force After)
Estimate for difference:  -70.47
95% upper bound for difference:  -55.74
T-Test of difference = 0 (vs <): T-Value = -8.23  P-Value = 0.000  DF = 21
```

Fig. 14.14 Pulling-force testing data comparing before versus after implementation using the hypothesis test

solution, the performance reduces to a value of 33.35 defective parts per million. Data also shows that the process capability shifts from a Cpk with a negative value of −0.152 to a positive value of 1.282. In other words, the mean of the process is now within the specification limits and it is centered.

As part of the verification step, the mean value of the response variable (pulling force) is compared to the lower specification limit using a one-sample t-hypothesis test. Figure 14.13 shows the results of the hypothesis test. With a p value <0.0001, the test suggests that there is enough evidence to support that the mean value of the crimping process will pass the pulling test with values larger than 150 N.

A second hypothesis testing is used for supporting the graphical evidence that there was an increase in the mean of the process after applying the solution. For this, a Two-Sample t test is conducted, and the results are shown in Fig. 14.14. With a p value <0.0001, the test suggests that there is enough evidence to support that the mean value of the pulling testing of the product coming from the crimping process is greater after using the selected values to the controllable factors of the crimping process.

14.2.8 Control Plan

The last step of the E-Strategy focuses on the update, and implementation of the control plan. In this case, the team updated the working instructions, the visual aids, and the control plan to include the adjusted operating parameters. This step also includes transferring the knowledge, and lessons learned to the rest of the organization. This is achieved by posting the results, and making available a document describing the details of all the steps used to achieve the final improvement.

14.3 Conclusions

Several researchers and practitioners have proven that in a restrictive environment it is possible to successfully implement state-of-the-art methodologies for problem-solving and continuous improvement, as exemplified by several technical reports. Lean-Sigma has become a fast response and effective methodology for problem-solving. The Lean-Sigma strategy of "do it at the speed of Lean with the depth of Six Sigma," can be structured for solving situations in the restrictive environment of Latin America and give solutions in a short-term span. This chapter describes the E-Strategy which is divided into two phases, the diagnostic and solution phases, and speeds up the process to reach a solution by hierarchically eliminating the most frequent causes of problems in the industries. It helps to solve the problems by adapting and using the most efficient set of tools, and depending on the complexity of the problem, the sequence of tools gets more specialized and elaborated.

The case presented in this chapter is an example of how the E-Strategy is used. The case scenario describes a situation where a manufacturing process is installing and validating assembly and test equipment in parallel to starting production of a new product. The situation gets complicated when a crimping machine does not achieve the expected value for the pulling force test using the manufacturer's recommended settings. At that point, the E-Strategy is used to solve the problematic situation, and allow the process to continue with the mass production.

Initial process data shows an overall performance of 683,576 ppm, which is equivalent to a sigma level of 1.1. This is, over 68% of the pieces out of specifications having a mean of 132 N and a standard deviation of 37 N.

After following the E-Strategy and running a Taguchi experiment, which includes an L9 array for the controllable factors and an L4 array for the uncontrollable ones, the pulling testing data permits to identify as potential solution the following values for the controllable factors: (*A*) Piston Travel distance 17.5 mm, (*B*) Time clamp remains closed 0.5 s, and (*C*) Air pressure 75 psi. After using the selected solution, data shows that, the process is stable, predictable, and, therefore, considered to be in a state of statistical control, with a mean value of 202.7 N (which is above the LCL of 150 N) and a noticeable variation reduction as seen in

the change of the standard deviation (from 37 to 13 N). Also, the quality of the outcome measured in 64% defective (a sigma level of 1.1) was drastically reduced to an overall performance of 33.35 ppm, which is equivalent to a sigma level of 5.5. As a highlight of this case study, the whole solving process was completed over a period of 3 days from the problem description to the control plan trying to keep the lead-time as short as possible.

Finally, it can be concluded that the use of the Lean-Sigma approach in Latin America's competitive environment is an efficient methodology. Especially, if it is oriented as a problem-solving technique instead of a project-based methodology. Complemented with the use of the E-Strategy, Lean-Sigma is a straightforward solution process that keeps the characteristic flexibility of Lean manufacturing, but flexible enough to move quickly to the deep statistical analysis characterized by the Six Sigma methodology. The combination of Lean-Sigma and the E-Strategy helps in achieving efficiently the quality goals, while providing a fast solution, and maintaining a short lead-time, as proven by this case, during initial validation of manufacturing equipment.

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