Achieving Customer Specifications Through Process Improvement Using Six Sigma: Case Study of NutriSoil – Portugal

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Tolerance limits are essential in production process management, as they determine consumer satisfaction. The use of statistical quality control tools allows for process improvement and the c_{pk} *index enables its measurement. Above all, the adoption by businesses of lean tools has been crucial in reducing the variation of a process or a product, satisfying the consumer's specifications, eliminating defects, reducing operating costs, and, in short, increasing profitability.*

The NutriSoil Company in Portugal, a small and medium-sized enterprise (SME), sells fertilizer in bags. The company has had problems with its filling process due to excess weight of the bags. Results show that by implementing Six Sigma combined with the 5S program, NutriSoil achieved an improvement in its c_{pk} *index for this process, which increased consumer satisfaction and a highly significant cost savings. This resulted in increased competitiveness.*

Key words: c_p *and* c_{pk} *capability index, process capability, process improvement, Six Sigma, SME, statistical quality control*

INTRODUCTION

The basic objective of this study is to explore, using a case study, the benefits of implementing the strategy of Six Sigma combined with the 5S program in NutriSoil, a Portuguese small and medium-sized enterprise (SME) struggling to retain profitability. NutriSoil had high production costs, a situation that is common to many SMEs.

The specifications or tolerance limits define the difference between acceptable and unacceptable products, and producing within these limits is critical to consumer satisfaction. The ability to consistently distribute products within specifications determines whether the supplier will continue to do business with the consumer. A company can improve a production process by efficiently coordinating the specifications and the design process. Process capability measures how the process meets specifications.

True process capability cannot be determined until x-bar and R control charts have reached optimum quality improvement without significant investment in new equipment. A key aspect of process improvement is to recognize that regardless of the depth of this monitoring, there is always variation. This variation is well defined when a process is statistically controlled. A modern definition of quality states that "quality is inversely proportional to variability" (Montgomery 2009). It is recognized that variability reduction directly results in lower costs. Variability reduction means fewer repairs, fewer consumer complaints, less rework, and reduced time waste, all of which imply less effort and money spent during the process.

Six Sigma is a powerful business strategy that employs a disciplined approach to tackle process variability using a rigorous application of statistical and nonstatistical tools and techniques (Hamon 2010; Evans and Lindsay 2005). Six Sigma is an initiative that aims to eliminate the defective items in any product, process, or transaction.

Even though Six Sigma has proved to be effective in many situations, other lean tools such as the 5S framework also offer the ability for organizations to improve rapidly. Lean thinking emphasizes maximizing value through reduction of waste, variation, and overburden within processes (Womack 2011). Lean promotes the attitude of make it better now, make it perfect later (Toussaint and Gerard 2010).

LITERATURE REVIEW

The c_p and c_{pk} process capability indices represent the ability to combine people, machines, methods, materials, and measurements to produce a product that consistently meets the requirements or expectations of the consumer. The process capability indices continue to be used as process tools, even though there is "a growing recognition that these tools are limited and, in particular, the capability standard indices are appropriate only with measurements that are independent and distributed in a reasonably normal manner" (Rodriguez 1992, 176). The popularity of process capability indices, although in many cases these indices are flawed tools, has led to ongoing research in this area, which has recently been evaluated by Wu, Pearn, and Kotz (2009).

However, a high c_p value does not guarantee that a production process is within the limits of the specifications because the c_p value does not imply that the current state of the process coincides with the dispersion permitted, that is, with specification limits. It does, however, have a flaw; it assumes that the process average is centered in the range of specifications. In fact, it is not always so.

On the other hand, the c_{pk} index takes into account the level of acceptable risk, the product variation, and gives a quick overview of the actual process performance. It measures the capability of the current process. This measure is in line with the positioning of the average case.

Sigma describes the variability of a process that produces similar products or services (Dedhia 2005). A quality level sigma provides an indicator of the occurrence frequency of defective items, whereby a higher quality level indicates a process with less possibility of creating defective items. Consequently, with the increased level of sigma quality, the product reliability improves the need for testing and inspection declines, product cycle time decreases, costs are lower, and consumer satisfaction is increased.

Six Sigma is a process capability condition defined as the ability of a process to produce a good product. It establishes a relationship between product specifications and process variability, measured in terms of process capability indices: c_p and c_{pk}. A process that operates the Six Sigma has a $c_p = 2$ and a $c_{pk} = 1.5$ (Kumar 2002). Six Sigma is an initiative that aims to eliminate the defective items in any product, process, or transaction.

Motorola was the first organization to use the term "Six Sigma." In 1992, it reduced defective item levels by a factor of 150 (*The History of Six Sigma* 2007). Honeywell began this program in the early 1990s and is said to have saved more than 600 million euros in 1999 (Pande, Neuman, and Cavanagh 2003). A study from Lucier and Sheshadri (2001) shows that General Electric was able to save $2 billion in three years, after implementing Six Sigma in 1996 (Antony and Banuelas 2002). Reports of Buss and Ivey (2001), Feo and Bar-El (2002), McClusky (2000), and Weiner (2004) also show the benefits gained by companies such as Raytheon, Dow Chemical, DuPont, Texas Instruments, Johnson and Johnson, Toshiba, Boeing, and others.

Many of the success stories on the implementation of Six Sigma belong to large organizations, particularly multinationals. Very few publications refer to the implementation of Six Sigma in SMEs. Six Sigma has been criticized by people saying that it requires a large investment and resource-intensive programs that only large companies can provide (Calcutti 2001). However, an SME may have fewer complications than a large company in terms of company size, the nature of its projects, effort for building teams, and training employees, so it can be argued that the implementation of Six Sigma in SMEs is easier, except for the cost of investment.

The Six Sigma philosophy consists of management by facts and not by opinions (Nanda and Robinson 2011). Antony, Kumar, and Madu (2005) found that Six Sigma provides executives and managers with the strategies, methods, tools, and techniques to change their organizations. Many organizations recognized that the Six Sigma methodology provides a set of practices designed to improve the production process, and the methodology quickly spreads to different functional areas such as marketing, engineering, purchasing, distribution, and administrative support (Ray and Das 2009; 2010).

Magnusson, Kroslid, and Bergman (2003) found that Six Sigma is a business process that allows companies to dramatically change and improve their basic organization through the design and monitoring of daily business activities so as to minimize waste and resources while consumer satisfaction is increased in some of its components. Franken (2007) emphasizes that when the internal operations of a company are not well structured, this company will find it difficult to create value and be highly competitive. Six Sigma begins as a focus for improving internal operations, but Zucker (2007) notes that the work of Six Sigma is usually done through cross-functional teams to manage the project. The benefits are well documented for manufacturing industries and growing service industries (Wright and Basu 2008).

In the last two decades Six Sigma has evolved from a focus on metrics to a level of methodology and finally to the design and development of management systems. As far as metrics are concerned, when a process is operating at a Six Sigma level, it produces noncompliance (defective items or errors) at a rate of not more than 3.4 defective items per million opportunities. As a methodology, Six Sigma leads to an improvement of the business process focusing on the understanding and management of customer expectations (Brewer and Eighme 2005; Rudisill and Clary 2004). As a management system, Six Sigma is used to ensure that critical efforts for improvement developed through the methodology and metrics are aligned with the company's business strategies. In the late 1990s, about two-thirds of *Fortune* 500 organizations had undertaken Six Sigma initiatives with the aim of reducing costs and achieving improvements.

Although Six Sigma proved to be efficient when applied to big companies, few reports provide success factors, guidelines, tools, and techniques for implementing Six Sigma in the context of SMCs (Antony 2011; Antony, Kumar, and Madu 2005; Wessel and Burcher 2004).

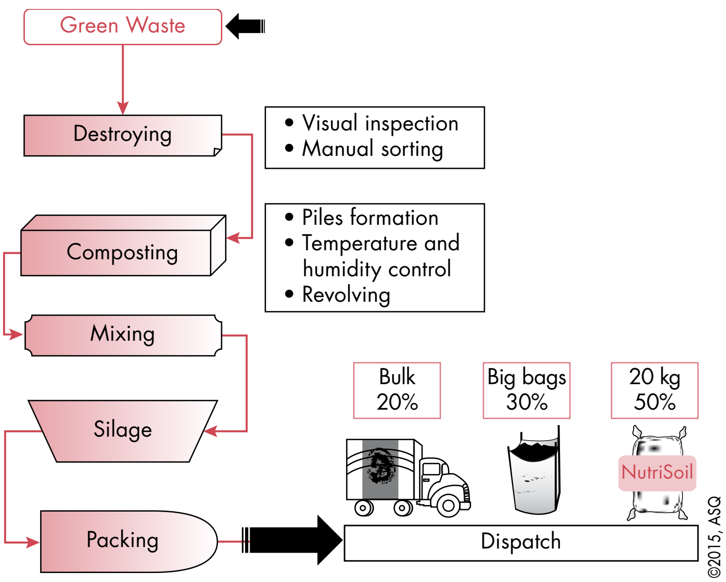
METHODOLOGY

c_p and c_{pk} Capability Index and Six Sigma

In their study the authors used c_p and the c_{pk} as the main metrics in this cycle of the improvement process. If they compare the c_p process metric with the c_{pk} metric, they are able to detect which is the opportunity improvement that exists in the process. By reducing process variation, the supplier increases the ability to meet the specifications and also reduces the number of products that do not meet the specifications. A $c_{pk} = 2$ represents a Six Sigma level, with 3.4 defective items per million opportunities, with quality costs less than 10 percent of sales and configures a benchmark of "world class" (Mike 1998).

It should be noted that although a process produces a quality feature with a capability index higher than 2.5, the needless precision makes it very expensive. The process capability must be

Figure 1 NutriSoil production process diagram



re-evaluated periodically to ensure that the process average has not changed and that process variation has not increased. The minimum recommendation for re-evaluation is six months.

The NutriSoil Company implemented a Six Sigma strategy to pursue its goal of reducing costs, which is vital to its survival. The company sought to:

- Exert a continuous effort to achieve stable and predictable results of a process (reduction of process variation), which is of vital importance to the success of a business
- Recognize that production and business processes have characteristics that can be measured, analyzed, improved, and controlled
- Obtain commitment to improvement from the entire organization, particularly from top management

Case Study – NutriSoil Company

The name of the NutriSoil Company is fictional to preserve confidential information in an industrial context, but the case is real. NutriSoil is a company that produces and sells organic fertilizer in bulk bags of 500 and 1,000 kilograms (big bags) and plastic bags of 20 kilograms. All bags have a label containing formula, lot, date, and other information from the manufacturer.

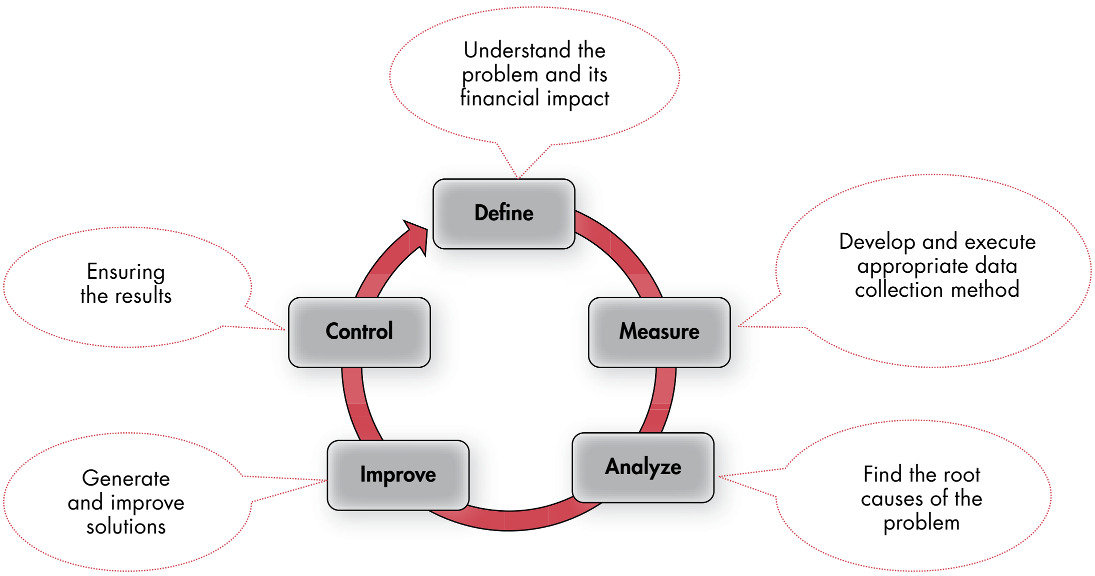
This SME was established in 2005, employs 32 workers, and is committed to developing and producing fertilizer. The main customers of NutriSoil are supermarkets and other stores geared for farming and gardening. The company annually produces 40 million tons of fertilizer. Socio-environmental issues are extremely important for NutriSoil; therefore, the company's involvement with the environment is a constant concern. The NutriSoil production process is presented in summary form in Figure 1. All raw materials come from domestic suppliers and arrive in bulk to NutriSoil by road. The material is crushed by a shredding machine and is sent for composting. Then the nutrients and other supplies are blended and the fertilizer goes to the silo where it is stored. Later the weighing is done and the formulation is forwarded to the bagging machines where it is packed.

NutriSoil operates in a highly competitive market, where the cost-price factor is crucial. To improve profitability, NutriSoil adopted a simplified version of the Six Sigma process (see Figure 2) in an attempt to reduce production costs. This sketch was developed after meetings with the company owner and with top and middle-level managers. Also, the operators' concerns were fully considered in the definition of all procedures.

Define

A team was created consisting of operators, production and quality engineers, the marketing department, and the company owner. This team spent many hours in the production area to collect data and understand the production and packing mode

Figure 2 Six Sigma process adopted by NutriSoil



of fertilizer bags. Team members were encouraged to identify the vital characteristics of the production process based on the "consumer voice."

Measure

To determine the defective items that occurred in each production phase, the team was divided into small groups in order to identify the vital procedures of each phase of the production process. A brainstorming session was conducted to develop the data collection plan. The data for defective products were collected and analyzed in order to measure the current performance in each of the workstations. Before the data collection it was decided to validate the measurement system, namely studying the measurement system's contribution to the variation in the form of repetition (the same product measured repeatedly by the same instrument) and reproducibility in the process (the same product measured by different operators).

Analyze

In the analysis of causes for defective items, a classification of defective items and the respective contribution to the total defective items was made: the authors used the Pareto diagram to determine the importance of the causes and the cause and effect diagram to detect the causes of variation. Control charts for average (x-bar) and the amplitude (R) were used to determine the assignable causes of variation.

Improve

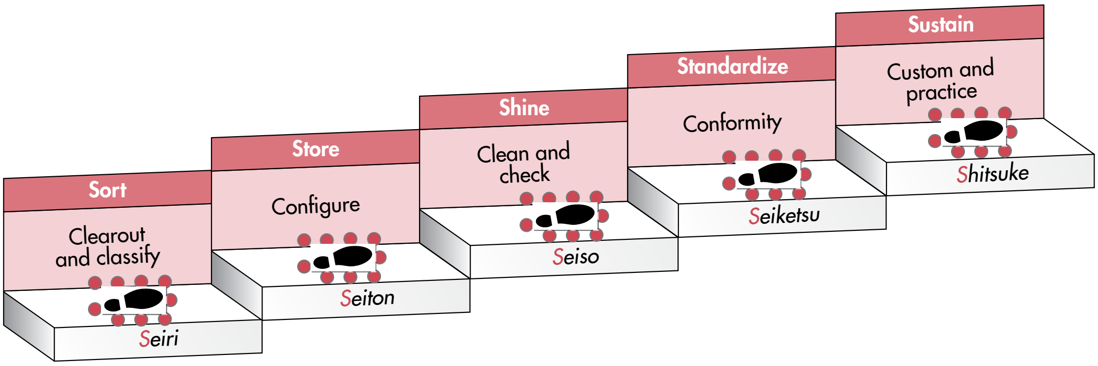
A program of organization and standardization, 5S (see Figure 3), was gradually and systematically implemented with a view to increasing the safety and efficiency of labor and productivity.

The purpose of the 5S methodology is to improve efficiency through proper disposal of materials (separate what is necessary from the unnecessary), organizing, cleaning and identification of materials and spaces, and maintenance and improvement of the 5S.

This methodology develops a systematic plan for sorting, cleaning, and ordering, enabling as a result greater productivity, security, organizational climate, and motivation of employees, with the consequent improvement of organizational profitability.

A program of buildings and equipment maintenance, total productive maintenance (TPM), was

Figure 3 5S methodology



Source: Adapted from Coutinho (2006)

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also implemented. The objective of this program is to increase both production and morale and employee satisfaction (Ismail 2013; Jain, Bhatti, and Singh 2014). Maintenance is no longer seen as a nonprofit activity, and downtime to perform maintenance began to be scheduled as part of the daily production. The goal is to keep emergency and unplanned maintenance to a minimum.

Control

Teams were formed to discuss production problems that may cause errors, failures, and defective items. The customer complaints analysis was also used to identify potential problems. The creation of production process control charts was implemented in order to keep employees aware of their process performance in real time:

- *p* chart : to control the evolution of the fraction of defective 20-kilogram bags
- *c* chart: to measure the evolution of the number of defective items produced per 20-kilogram bag

A training program was implemented in each of the production stages with the purpose of bridging the gaps found. To compare the performance of the production process before and after the introduction of the Six Sigma strategy, defective products reported by the entire production process made use of the following benchmark (see Equation 1):

Equation 1

$$\%\text{ Defective bags} = \frac{\text{Number of defective bags}}{\text{Number of processed bags}} \times 100$$

An additional measure used to assess the evolution of the production process in general was the defective items per unit rate (DIUR) (see Equation 2):

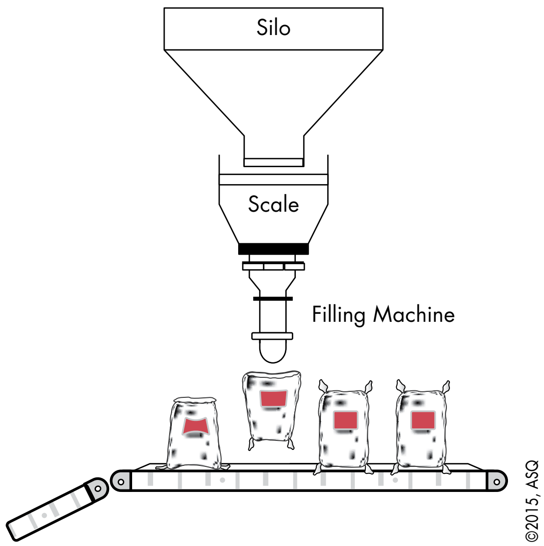
Equation 2

$$\text{DIUR} = \frac{\text{Total number of defective items found in 20-kg bags}}{\text{Number of processed bags}}$$

In this introductory phase of the Six Sigma strategy, the packaging process of 20-kilogram fertilizer bags deserved special attention, especially those sold in malls with high-quality requirements. It was confirmed that, to avoid noncompliance with the specification 20 kilograms with a tolerable minimum variation of 2 percent, there was a need to add additional fertilizer to bags, to respect the weight of the minimum specification, which constituted a significant cost.

An ABC analysis revealed that the packing process of 20 kilogram fertilizer bags, given that they represent 50 percent of sales and moreover intended for a market extremely demanding in terms of quality control, deserves priority, since there lies an opportunity for improvement that could significantly contribute to an increase of the competitive advantage of NutriSoil and its profitability.

Figure 4 Weighing and packaging process of 20-kilogram bags



Packaging Process: Before the Introduction of the Six Sigma Process

The packaging process (see Figure 4) consists of two bagging machines and bags 1,008,000 fertilizer bags annually (a daily average of 3,360 bags) in 20-kilogram plastic bags, which are sold on the market for 15 euros. The problem detected, and the urgent need to act immediately, is that to comply with the minimum specification NutriSoil is filling the bags with an average of 20.93 kilograms, which equates to an annual waste of 699,693.67 euros; that is, 46,646 bags are held back, and 90.74 percent of all bags produced are overweight. However, it is generally recognized that for the company to remain competitive and profitable the overfilling should be minimized.

The specifications are imposed by legal rules, so the bags must contain at least more than 19.6 kilograms of fertilizer. Bags that do not meet the minimum specifications are again inserted for reprocessing into the production process, resulting in average unit cost of 2 euros. In addition, bags found on the market weighing less than the minimum specification are subject to heavy fines, and 2.88 percent of the bags, that is, 29,071.72 bags, were packed with a weight below the minimum specification, which corresponded to a cost of reprocessing of 58,143.44 euros.

To monitor the process progress and calculate the c_p and c_{pk} capability index for the weight of 20-kilogram bags, control charts for average (x-bar) and amplitude (R) were implemented and put next to the bagging machines. Every hour, four bags are randomly packed and inspected and the respective weight is recorded. If more than two bags display underweight according to the minimum specification limit, all bags produced since the last acceptance are retained and corrective actions are taken if necessary.

In addition, a laborer carefully monitors the passage of the bags on the conveyor belt, and from time to time, removes a bag that weighs less, is torn, or is badly sealed, and puts it in a pile to be reprocessed. In the initial stage of the study the process was considered to be stabilized, but its variability was unable to meet the specifications.

The customer may receive more fertilizer but never less than nominal. This excess weight is unnecessarily expensive. The problem was identified and a versatile team was formed consisting of technical services, plant operators, and quality personnel. The investigation revealed that the filling machine needed improvements and that it was appropriate to develop a training program for employees. The team worked closely with operators to achieve a reduction in process variation with a consequent improvement.

In order to find the causes associated with the high variation of the bag weight, the authors used a cause and effect diagram (see Figure 5).

RESULTS

Table 1 summarizes the results of the indicators used to assess the impact of the actions taken when implementing the Six Sigma strategy.

Control charts for 20 kilogram bag weight average (x-bar) and amplitude (R) are presented in Figure 6, before the Six Sigma strategy. Control charts for 20-kilogram bags weight average (x-bar) and amplitude (R) after the Six Sigma strategy are presented in

Figure 5 Cause and effect diagram for the weighing and packaging process of 20-kilogram bags

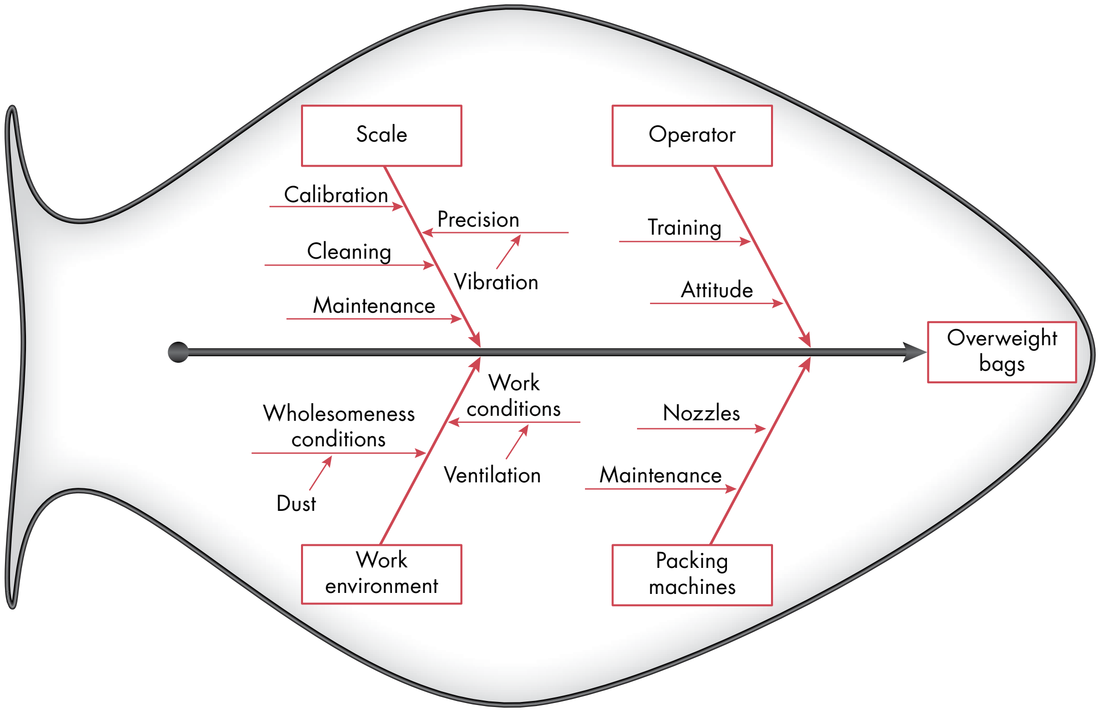


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Table 1 Metrics employed

Key metrics employed	Before the introduction of Six Sigma	After the introduction of Six Sigma	Improvement (%)
Percent of defective bags produced	4.50	2.17	51.77
Defective items per unit rate (DIUR)	4.24	2.12	50.00
c_{pk} – Process capability	0.63	1.02	61.90
Process average (kg)	20.93	20.05	4.20
Process standard deviation (kg)	0.70	0.15	78.90
Percent of bags weighing more than 20 kg	0.907	0.6337	30.20
Percent of bags weighing below the minimum specification – 19.60 kg	0.0288	0.0011	96.10
Bags lost per year – overweight	46,646.24	2,542.88	94.50
Cost (€) of extra weight – 20 kg bags	699,693.67	38,143.16	94.50
Bags under weight – year	29,071.72	1,142.82	96.10
Cost (€) of underweight – 19.60 kg bags	58,143.44	2,285.65	96.10
Percent of machine downtime	5%	3%	40.00
Percent of work-related accidents	1%	0.2%	80.00

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Figure 7. Figure 8 shows the *p* control chart, for fraction of defective produced 20-kilogram bags, for a period of one year of the Six Sigma strategy. Figure 9 shows the *c* control chart, used to monitor the evolution of the total number of defective items per 20-kilogram bag for the one-year period of the Six Sigma strategy.

DISCUSSION

The introduction of the Six Sigma strategy in NutriSoil resulted in considerable savings, which allowed the company to improve its competitive advantage. The increased c_{pk} index (from a low value

Figure 6 Chart for 20-kilogram bag weight average and amplitude before the Six Sigma strategy

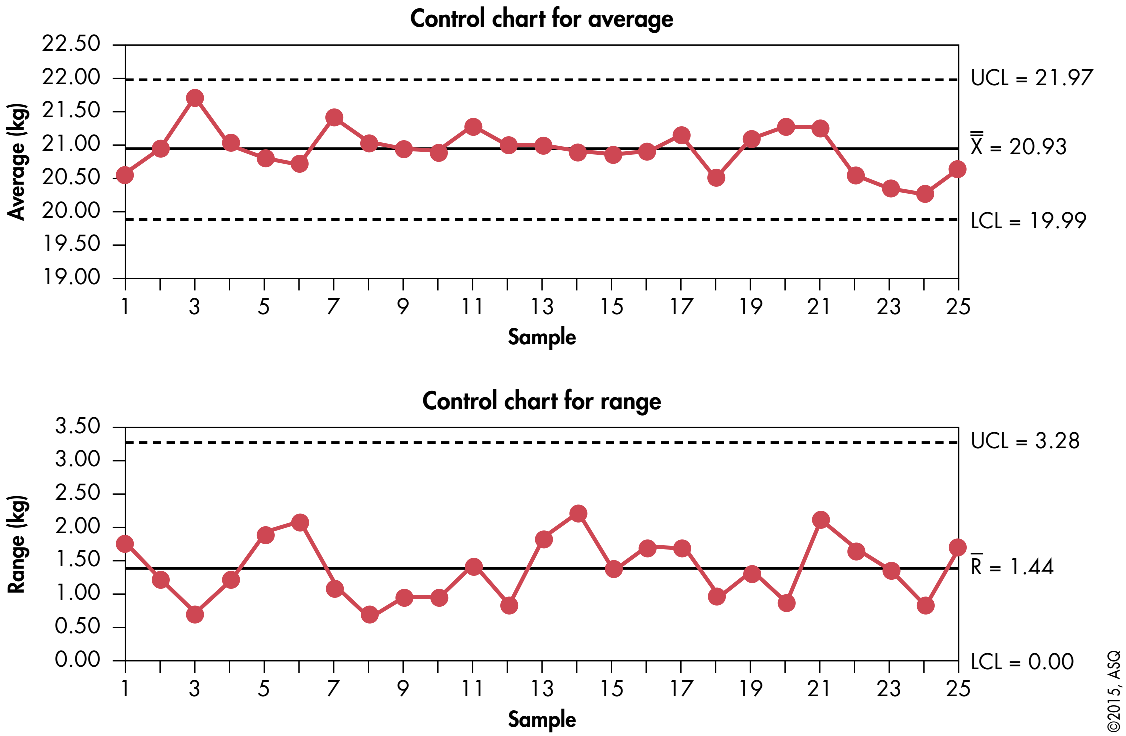


Figure 7 Chart for average and amplitude after a year of the Six Sigma strategy

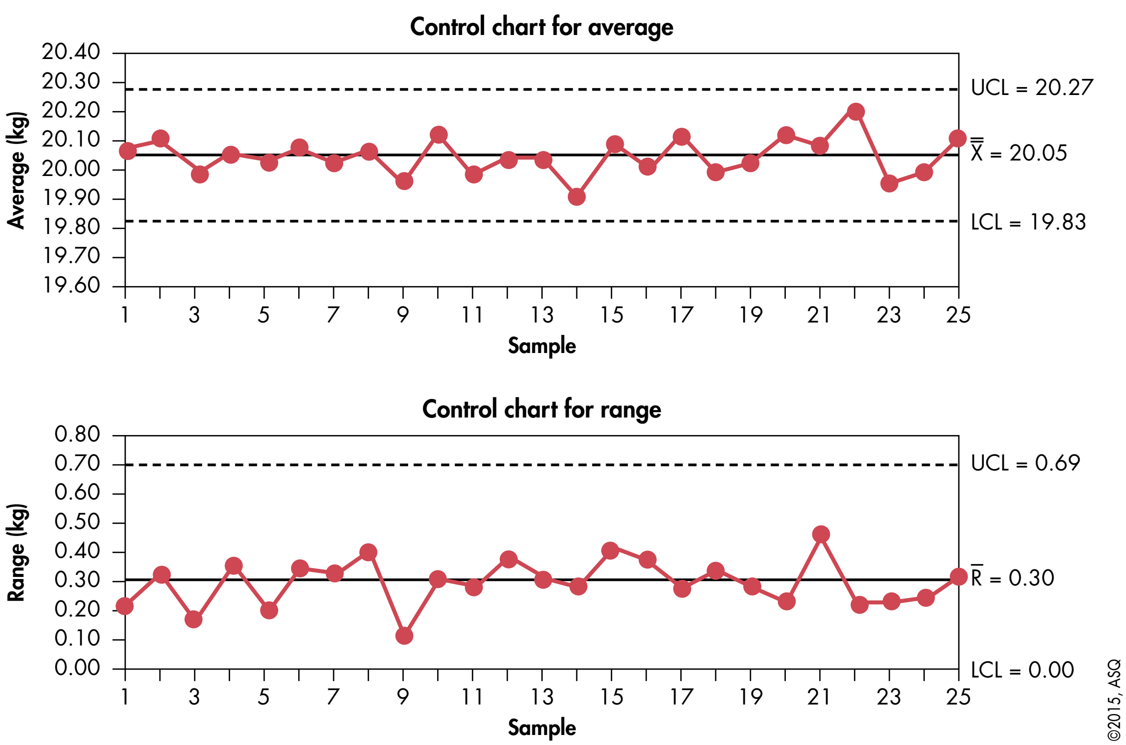


Figure 8 *p* chart at the beginning and the end of a period of one year of the Six Sigma strategy

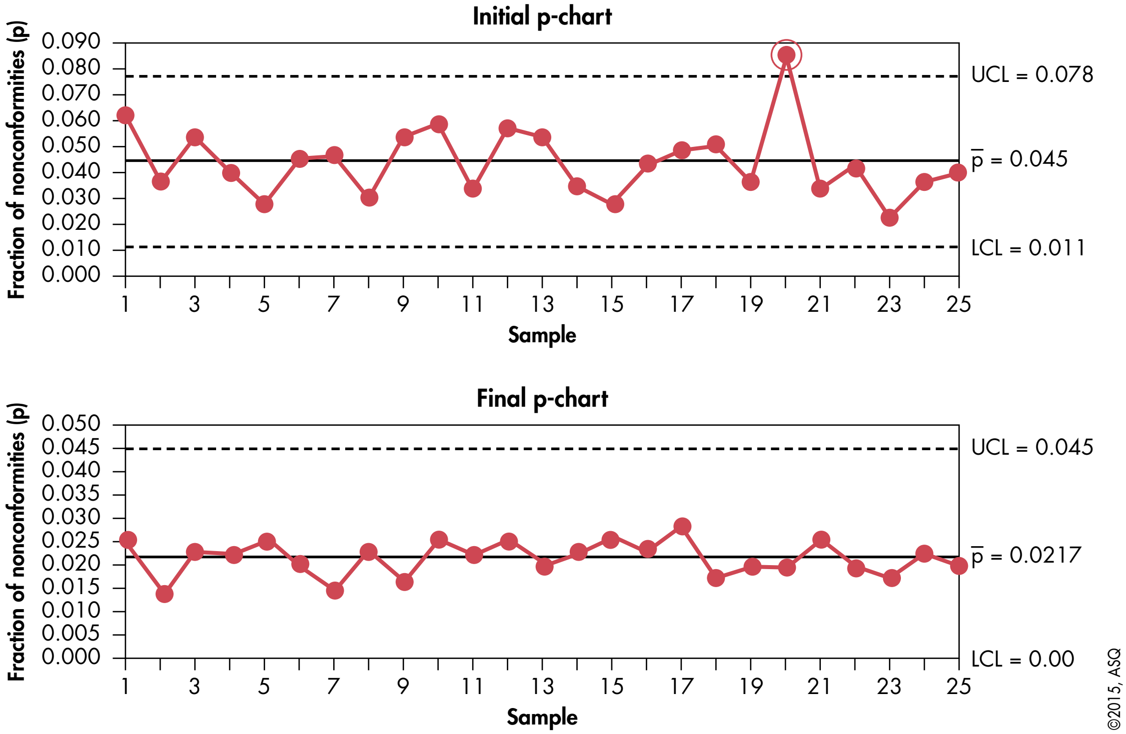
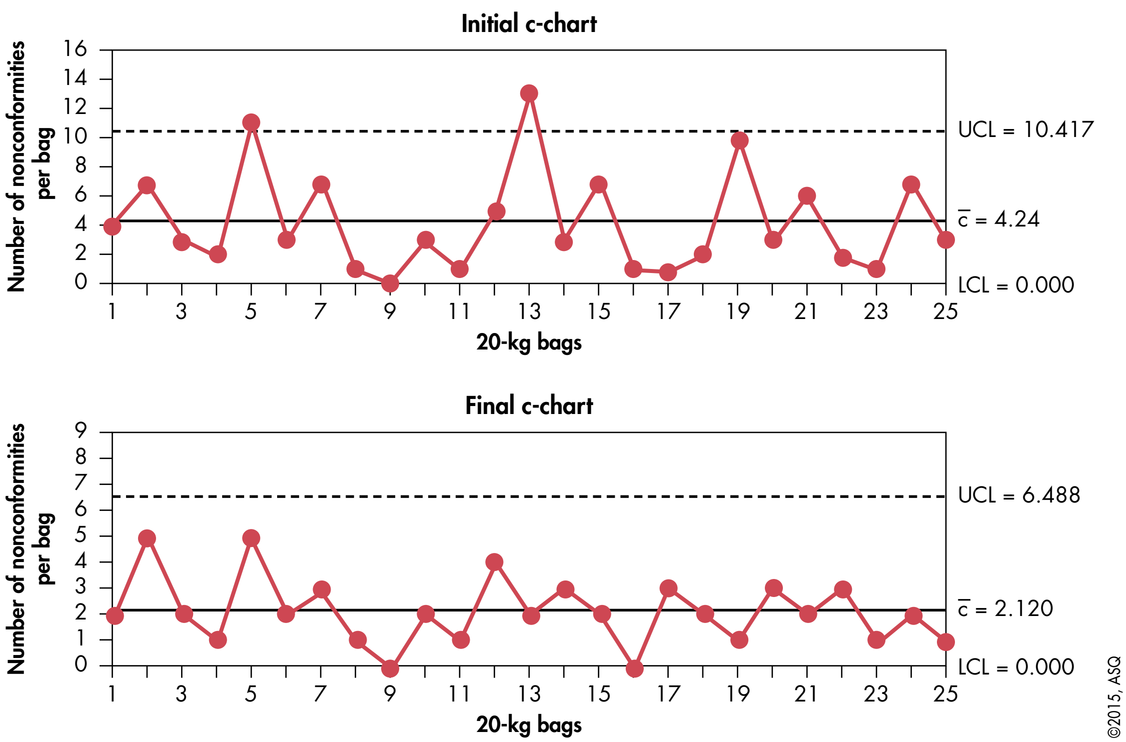


Figure 9 *c* chart at the beginning and the end of a period of one year of the Six Sigma strategy



of 0.63 to 1.02) for the of the 20-kilogram bags was an improvement of 60.8 percent. This demonstrates the value of Six Sigma for SMCs. Using Six Sigma in the process of packing 20-kilogram bags, annual savings in the order of 717,408.31 euros were achieved, corresponding to 4.74 percent of the sales value for this type of product. Managers accepted that the Six Sigma strategy combined with the 5S procedure created, for one year, above all, a change in the organizational culture of NutriSoil.

Today the authors can perceive in NutriSoil a greater sense of participation, commitment, and awareness of the importance of working in order to exceed the requirements of the consumer. The involvement and commitment of all employees, measured by absenteeism and voluntary turnover, facilitated the implementation of the Six Sigma strategy both within the production process and in the reduction of defective items that occur in the final product. Specific gains of NutriSoil were:

- Reduced variation in bag weight from 0.70 kilograms to 0.15 kilograms, that is, a decrease of 78.9 percent. The control charts for average (x-bar) and amplitude (R) introduced in the packaging process helped to determine and correct the root causes of abnormal variation and improvement on this process. The weighing and bagging machines, in particular, were subjected to significant improvements. TPM was determinant in increasing productivity while increasing the morale of employees and their job satisfaction. The time machine downtime due to breakdown decreased from 5 percent to 3 percent, in particular because of properly scheduled preventive maintenance.
- The average weight of the bags went from 20.93 to 20.05 kilograms, which equates to an annual saving of 661,550.51 euros. Currently, 2,542.88 bags are wasted due to overfilling, compared to the initial 46,646.44.
- There was a reduction in the number of the bags weighing less than the minimal weight. This resulted in savings of 55,857.79 euros in reprocessing costs and a decrease in the probability of paying fines. Only 1.13 per thousand bags had a weight lower than that mentioned in the specifications against an initial 28.84.
- The inclusion of *p* control charts for each stage of the production process kept employees aware of the performance of their process in real time and was crucial in improving the defective bags produced fraction of 51.34 percent.
- Using the c control chart helped in reducing the number of defective items per bag from 4.24 defective items to 2.12, which was an improvement of 50 percent.

The 5S program of organization and standardization tidied up the workplace, storage in particular, resulting in an 80 percent decrease in work-related accidents, which had as a consequence decreased absenteeism and increased worker morale.

Implementing the Six Sigma strategy provided several valuable lessons when promoting new projects. First, it was necessary to educate management that investing in quality means increasing the cost of production. This barrier was overcome by showing the NutriSoil owner the savings achieved. Also, management had to be shown that 5S tidied the factory, which reduced accidents and reduced the idle time of machines and operators. This in turn generated savings. A training plan that included all NutriSoil employees was necessary to overcome active resistance to change. Employee anxiety triggered by change was minimized with an effective communication campaign. The communication began with an explanation of the Six Sigma strategy; why the company adopted it; the anticipated benefits of implementing Six Sigma; dissipation of fears by explaining the development plan; how the employees would be affected; and what training and support was available:

- Communication of the training plan, training schedule, and reporting of training evaluation, as well as the benefits of implementing the project, proved to be highly motivating.
- The improvements already made were publicly recognized and celebrated in order to maintain and strengthen the commitment to Six Sigma.

Capitalizing on this progress, the NutriSoil Company is launching the certification process based on ISO 9001:2008, and living up to its respect for the environment; they would like to obtain environmental certification ISO 14001 – Environmental Certification, in the short to medium term.

CONCLUSIONS

The Six Sigma program combined with 5S proved to be an effective, simple way to design and improve a productive process. By following these systematic lean approaches, and applying them to Nutrisoil, the authors achieved not only a substantial reduction in costs and in the work-related accident rate, but also a decrease in turnover and absenteeism in a relatively short period of time.

Further research is needed to evaluate the effectiveness of these approaches in other SMEs in various settings. The main difficulty encountered was the owners' resistance to sharing decision-making power. This was overcome by demonstrating how Six Sigma generated money for the company. The Nutrisoil owner said after implementation that "a change is visible in the organizational culture of NutriSoil, based on the 'consumer voice' and the adoption of the best practices, allowing the company to face the future with more optimism."

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