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Reducing the percentage of broken drops using the lean six sigma methodology

Sordan, J.E[1], Oprime, P.C. [1], Moura, M.C.[2] Rosa, I.C.[2], Chakraborti, S.[3]

[1] Federal University of São Carlos, SP, Brazil

[2] University Center of South of Minas, MG, Brazil

[3] Federal University of Alfenas, MG, Brazil

[4] University of Alabama, Tuscaloosa, AL, United States

ABSTRACT

Purpose – This paper aims to demonstrate the empirical study regarding the implementation of a Lean Six Sigma project through the DMAIC method to reduce the percentage of broken drops in the manufacturing process of a food factory.

Design/methodology/approach – The research was carried out through a single and longitudinal case study, where the interviews followed the sequence of steps and practices observed in the theoretical framework.

Findings - The analysis performed in this project indicated that the presence of bubbles in the dough had influenced the percentage of broken drops. The main root causes of the problem were identified as conveyor belt, nozzles, and cold chamber. The project allowed an increase of 4.79% in the final process yield index and the sigma level evolved from 2.87σ to 3.25σ.

Research limitations/implications - The research results are limited to a single case study, and it is not intended to generalize the results to other types of industry.

Practical implications – This paper can be used as a reference guide for researchers and practitioners to implement operational excellence projects in their organizations, following the steps presented in this study.

Originality/value – This paper is a real case study on Lean Six Sigma practices in a food factory. This sector still lacks empirical studies regarding the implementation of operational excellence strategies.

Keywords: Lean Six Sigma, DMAIC, Operational Excellence, Food Industry.

Paper type: Case study.

INTRODUCTION

The implementation of operational excellence strategies in industrial organizations has generated significant results in terms of cost, quality, and speed. The adoption of principles, techniques, and tools inherent to Lean Six Sigma (LSS) methodology is directly associated with this type of strategy. It requires the implementation of improvement projects with financial impact implemented by *ad hoc* teams and led by professionals with proficiency in the various techniques inherent in this approach. Currently, the adoption of this strategy has enabled companies to meet and exceed customer expectations in a changing and competitive global environment (Byrne et al., 2007).

While the Lean Manufacturing (LM) approach discusses the importance of waste across all process and focusses on speed and time, the Six Sigma (SS) methodology focusses on reducing defects and process variability as well as reducing costs, which makes it evident that the joint-use LSS strategy offers a solution that creates more robust, flexible and cost-efficient process (Andersson et al., 2014). The integration of these two approaches (LSS) increases the possibility of efficiency and effectiveness gains. It helps to achieve superior performance faster than the implementation of each strategy in isolation (Salah et al., 2010).

The food industry can be characterized by technological product disruptions and incremental improvements associated with the acquisition of new process technologies (Raimundo et al., 2017). Moreover, the perishability of food products and the distances traveled in the supply chain, demand innovations in the areas of logistics, organization, production, and marketing (De Mori, 2011). Factors such as food safety, quality, and level of services are fundamental in this sector, where industrial costs must be carefully controlled to maintain organizational competitiveness (Dudbridge, 2011).

LSS projects have been widely applied to a variety of industries including automotive assembly processes (Lee-Mortimer, 2006; Pugna et al., 2016), telecommunications (Psychogios et al., 2012; Andersson et al., 2014), pharmaceutical industry (Goodman, 2012), health products (Jirasukprasert et al., 2014), and so on. However, the literature on the implementation of LSS projects in the food industry highlights some specific applications, for example, initiatives to reduce the variation in the weight of processed food (Desai et al., 2015; Dora and Gellynck, 2015), lead time and customer complaints reduction (Nabhani and Shokri, 2009), as well as the reduction in the dimensional variation of the product (Seow et al., 2004). Given these considerations, studies with applications aimed at reducing breakages in food products are scarce in the literature on LSS.

The purpose of this article is to present an empirical study regarding the implementation of an LSS project through the DMAIC method, whose objective is to reduce the percentage of broken drops in the manufacturing process of candies and drops factory. Based on the investigation performed, the paper reveals the activities carried out in each stage of the DMAIC method, as well as the tools and techniques implemented in these stages. Therefore, this paper can be used as a reference guide for researchers and practitioners to implement operational excellence projects in food industries.

This article is structured as follows. In the next section, a previous literature review on LSS is presented. Section 3 describes the methodological procedures defined to achieve the objective of this study. Section 4 presents the results of the empirical research following the sequence of steps performed in the implementation of the LSS project. Finally, the last section presents the main insights and conclusions, as well as suggestions for future work.

LITERATURE REVIEW

The LM approach gained worldwide popularity after the publication of the book *The Machine that Changed the World*, written based on research on trends in the automobile industry, with emphasis on the efficient Toyota Production System (TPS) developed at Toyota by Taiichi Ohno after the Second World War in the 1940s (Womack et al., 1990). LM principles focus on the value stream analysis to identify and eliminate seven forms of waste (*muda*) on the shop floor: over-production, defects, unnecessary inventory, inappropriate processing, waiting, motion and excessive transportation (Womack and Jones, 1996).

The Six Sigma methodology was conceived at Motorola in 1987 to improve the quality of its products dramatically. Two years after this initiative, the company received the Malcolm Baldrige National Quality Award in recognition of the results obtained with the program (Pande et al., 2001). However, the success of this approach was reinforced in the following decade, based on the results obtained at General Electric, under the leadership of Jack Welch, who at that time held the position of CEO (Chief Executive Officer) at the company (Black and Revere, 2006). Since then, this approach has been adopted by several organizations to improve products, services, and processes (Evans and Lindsay, 2014).

LSS approach can be defined as "a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom-line results" (Snee, 2010). The proposal for integration between the two approaches was presented in the book *Lean Six Sigma: Combining Six Sigma with Lean Speed* (George, 2002). Although these approaches have different origins and can be differentiated by their specificities, the effectiveness of complementarity between them has become common sense among practitioners and researchers.

The isolated application of the SS techniques cannot remove all types of waste from the process and applying only LM principles cannot control the process statistically and remove variation from the process (Corbett, 2011). Regarding the organizational structure, it is observed that SS techniques are implemented by few trained individuals in the company, while LM principles cover all levels and require that all employees should receive training and empowerment to identify and eliminate activities that do not add value (Higgins, 2005).

The programmes SS prescribe that improvement actions are performed in a project-by-project fashion (De Koning and De Mast, 2006). However, projects that involve LM tools implemented for existing products and processes through the DMAIC (*Define*, *Measure*, *Analyze*, *Improve*, and *Control*) methodology are recognized as Lean Six Sigma Projects (Snee, 2010). Still, for product and process development activities (Design for Six Sigma), the DMADV methodology (*Define*, *Measure*, *Analyze*, *Design*, and *Verify*) is recommended (Mehrjerdi, 2011). Thus, the logical sequence of actions for implementing an LSS project in existing processes includes five phases (De Koning and De Mast, 2006; Montgomery and Woodall, 2008; Ismyrlis and Moschidis, 2013):

(1) *Define*: Establish the characteristics-specifications of product that satisfy the customer. Defines the problem to be solved, including customer impact and potential benefits. Develop project charter and build a team.

(2) *Measure*: Translate the problem into a measurable form. Identify potential root causes. Develop and validate measurement systems. Estimate the short-and long-term process capability and determine the sigma performance level.

(3) *Analyze*: Identify key process variables that cause defects. Benchmarking key product performance metrics (gap analysis). Formulate, investigate, and verify root cause hypotheses. Find areas that need to be addressed.

(4) *Improve*: Design an effective and efficient solution to the process to improve the performance of the CTQs. Verify and gain approval the final solution.

(5) *Control*: Implement a mistake-proof process. Monitor and control critical process. Develop out of control action plans. Transfer responsibility, share learning, and best practice.

Critical Success Factors (CSF) are very important for the effectiveness of operational excellence strategies in companies. In this context, Jeyaraman and Teo (2010), highlight the following CSF: established LSS dashboards; effective training program; projects stories, best practices sharing and benchmarking; project prioritization selection; frequent communication and assessment on the result;

company financial capability; competency of MBB/BB; reward and recognition system; management engagement and commitment; and organization belief and culture.

RESEARCH METHODOLOGY

In order to achieve the objectives of this research, a single and longitudinal case study was carried out. Because it is characterized as a qualitative approach, the case study can be essentially interpretive, where the researcher describes the scenario through a constructivist perspective, using data analysis to identify themes or categories through a personal lens (Creswell, 2007). This type of research is recommended for studies that have as characteristics the need to find answers to the “how” and “why” questions, little or no control over the event by the researcher, and focus on contemporary problems within a real context (Yin, 2009).

The research was carried out in the second half of 2019 at a company that produces candies and cookies, which will be called “Alpha”. The company is located in the State of São Paulo, Brazil and has more than 500 direct employees. The selection criteria considered the current context of the company, which in recent years has implemented several LSS projects and provided green belt, black belt, and lean practitioners training. A case study protocol was developed to structure the data collection. Semi-structured questionnaires were used to capture the interviewees' perspectives. Thus, only people who had active participation in the execution of the project were interviewed.

Data were collected and recorded through interviews involving employees who participated in the project and document analysis. The interviews were conducted in a semi-structured manner. The application of a case study must cover the development of a conceptual framework based on the literature on the research topic and explain narratively the main elements of the research, including the variables involved, the main constructs and possible causal relationships (Voss et al., 2002). An analysis regarding “how” the company has implemented the LSS project was carried out as well as the sequence of activities and the techniques and tools used. The analysis was guided by the DMAIC model and contrasted with the recommended practices in the relevant literature.

RESULTS

In the last five years, Alpha has implemented several actions related to the LSS approach as part of its operational excellence strategy to reduce quality costs, due to failures in the manufacturing process, and increase customer satisfaction. This strategy includes the internal training of green belts, black belts, and lean practitioners. The green belt program certification at Alpha includes an 80-hour training program, the application of a theoretical test, as well as the implementation of a project with a financial impact on the organization. These projects follow the steps of the DMAIC method where project teams can use various techniques and tools present in the LSS toolbox. The project to reduce the percentage of broken drops emerged from this context and its breakdown will be presented below.

Define phase

LSS projects must include the definition of metrics and key indicators to guide the selection of the project and identify its objectives, as well as the definition of a specific problem of the process to be improved (Snee, 2010). These actions were recorded in a project charter that presents a clear definition of the problem observed, the Project Team (PT), the scope of the project, the Critical to Quality (CTQs) factors, the expected benefits and the schedule of the steps provided for in the DMAIC method. Table 1 summarizes the information contained in the project charter.

Table 1 – Project Charter.

Project title	**Reduction the percentage of broken drops**
Problem Statement	Broken drops represent a significant quality defect generated during the manufacturing process, which causes imperfections in the packaged product and contributes to the increasing waste in the manufacturing line. This problem has generated some complaints from Alpha' customers for not receiving the product as expected.
Project team	1 trainee (project leader), 3 machine operators, 1 maintenance supervisor, 1 process analyst, and 1 quality assistant.
CTQs	*Broken / Chipped Drops*. Non-conformity noticeable to the naked eye and which can be caused due to the fragility of the product or incorrect processing.
Expected Benefits	Reduction of quality costs related to product disposal, reprocessing, and returns. Increased customer satisfaction.

The project started in April 2018 and was completed in February 2019. Seven people from different areas participated in the project, which was led by a trainee, who during the project's execution period, was a candidate for green belt certification at the company. After the production director has approved the project charter, the first step was to visualize the data on the historical percentage of broken drops (%BD) in a time series plot shown in Figure 1.

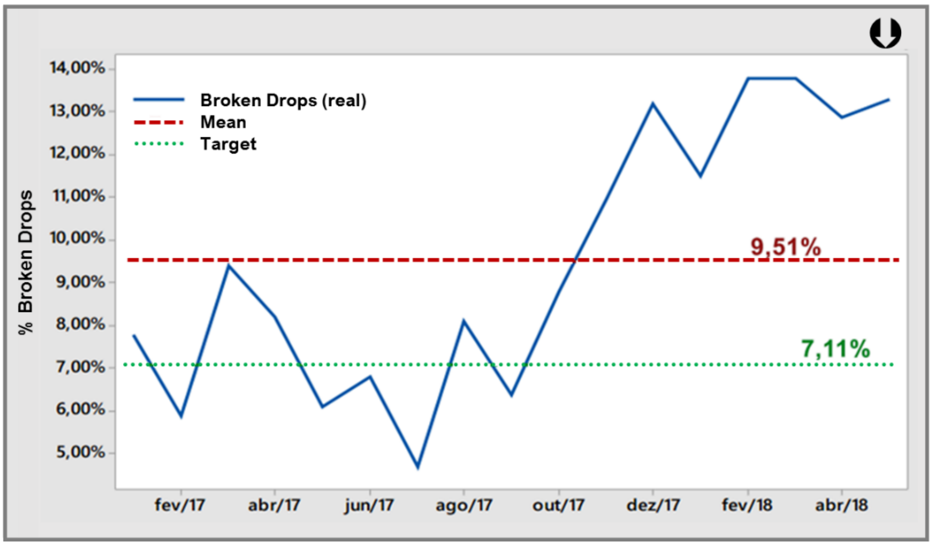


Figure 1 – Percentage of broken drops.

The time series plot was elaborated by PT to understand the historical nature of the average of the percentage of breakage in the drops. Figure 1 shows data from February 2017 to April 2018. Thus, there is a significant increase in the percentage of BD from July 2017. The investigation then focused on verifying this hypothesis, finding ways to understanding the causes, and finally mitigating the causes to improve the process so that the BD percentage is reduced to a level where the company can be more successful in marketing its products.

To define the goal of the project, PT carried out a gap analysis between the current performance of the process and a benchmark value. The target was then defined considering a subtraction of 50 percent of that reference value from the average observed in the period. Therefore, the final goal established for the project was "*reduce the percentage of broken drops from 9,51% to 7.11% by the end of February, 2019*". Define phase was concluded after PT has prepared a SIPOC matrix (Suppliers, Input, Process, Output, and Customers) to identify the main activities related to the manufacturing process as well as their inputs (x's) and outputs (Y's), as shown in Table 2.

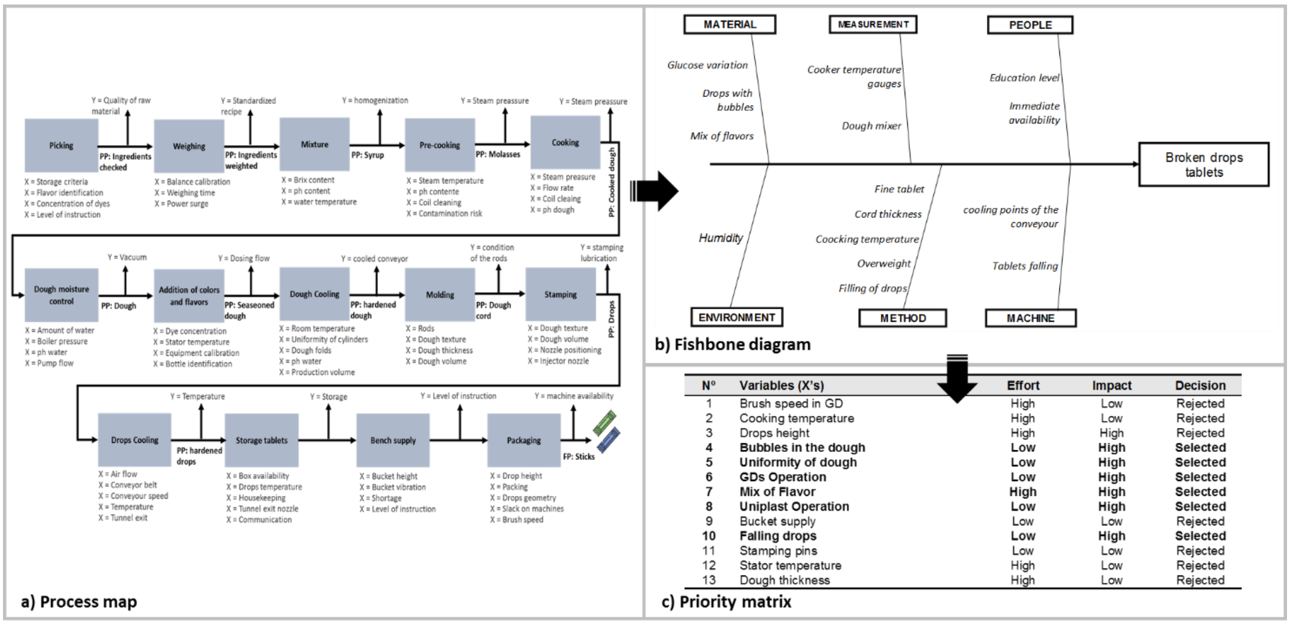
Table 2 – SIPOC matrix.

Suppliers	***Input***	***Process***	***Output***	***Customers***
Warehouse	Approved recipe / raw material	Weigh	Ingredients weighted	Cooker 3,000
Scale / pot	Ingredients weighted and picked up	Cooking the dough	Dough cooked	Uniplast
Cooker 3,000 / Uniplast	Dough cooked and folded	Stamp drops	Drops stamped	Cooling Tunnel
Stamping / Chiller	Drops stamped	Cool drops	Crystallized drops	Packing machines GD's
Cooling Tunnel / Warehouse	Crystallized drops and packaging	Pack drops	Finished drops	Storage

Measure phase

Measure phase includes the translation of the problem addressed into a measurable and quantitative way as well as the measure and estimation of the current performance of the process through the sigma level. An essential activity in this phase is the formulation of the transfer function, which can be explained in mathematical terms such as $Y = f(x_1, x_2, \ldots x_n)$, where the root causes "x's" represent the inputs of the process that are converted into outputs "y's" (Pyzdek and Keller, 2003).

The activity of identifying and selecting the root causes for the formulation of the transfer function was carried out systematically by PT. Figure 2 illustrates the sequence of steps performed for this purpose. The first step was performed during a brainstorming section where the participants developed a high-level map (Figure 2a) identifying the process parameters (PP) for each stage of the process as well as their inputs (x's) and CTQs (Y's). Then the section was directed to the construction of a fishbone diagram (Figure 2b) to complement the identification of the variables inherent to the project problem. Among the 41 variables identified, 13 were submitted to a prioritization matrix (Figure 2c), where six key variables were finally selected: x_1 – *bubbles in the dough*; x_2 – *uniformity of dough*; x_3 – *GDs operation* (packing machine); x_4 – *mix of flavor*; x_5 – *uniplast operation* (product molding machine); and x_6 – *falling drops*.



Nº	Variables (X's)	Effort	Impact	Decision
1	Brush speed in GD	High	Low	Rejected
2	Cooking temperature	High	Low	Rejected
3	Drops height	High	High	Rejected
4	**Bubbles in the dough**	**Low**	**High**	**Selected**
5	**Uniformity of dough**	**Low**	**High**	**Selected**
6	**GDs Operation**	**Low**	**High**	**Selected**
7	**Mix of Flavor**	**High**	**High**	**Selected**
8	**Uniplast Operation**	**Low**	**High**	**Selected**
9	Bucket supply	Low	Low	Rejected
10	**Falling drops**	**Low**	**High**	**Selected**
11	Stamping pins	Low	Low	Rejected
12	Stator temperature	High	Low	Rejected
13	Dough thickness	High	Low	Rejected

Figure 2 – Steps to identify and select root causes.

The next activity was to estimate the current capacity of the process through the sigma level. However, to validate the quality of the data collected, the PT performed an "Attribute Agreement Analysis" with three inspectors in each work shift. Inspection by attribute implies a binary classification of the type "approved" or "failed". Analysis Between Appraisers can be performed using Minitab software by examining the frequency with which each inspector agrees with the classification made by the other inspectors or by the Fleiss Kappa coefficient of correlation. According to Bass and Lawton (2009), this coefficient is within the range of -1 to +1. If it is equal to +1, there is a perfect agreement and if it is -1, there is complete disagreement. Besides, the Kappa value of 0.7 indicates an acceptable measurement system.

A total of 30 samples randomly chosen were examined by three inspectors, revealing a low agreement between the appraisers (Kappa coefficient equal to 0,3162). To solve this problem, the PT developed an operational definition and instructed all inspectors in this standard. After performing this training, a new study revealed that the new Kappa coefficient was equal to 1, thus evidencing agreement between appraisers and measurement system reliability.

The calculation of the sigma level must be performed according to the type of data referring to the characteristic of the measured quality. For continuous data, the sigma level can be obtained from process capacity indices (Cp and Cpk). For discrete data, which refer to the percentage of samples that contain one or more defects, measures of defect proportion and Final Process Yield are used, according to expressions (1) and (2).

$$Proportion\ Defective = \frac{Number\ \ of\ defective}{Number\ \ of\ units} \tag{1}$$

$$Final\ Yield = 1 - Proportion\ Defective \tag{2}$$

The sigma level correspondent to the final yield was obtained from a query on a conversion table between final yield and sigma levels that consider the “discount” of 1.5σ, considering the hypothesis that in the long term the process it can deviate by more or less 1.5σ (Pande et al., 2001). A sample of 3,000 units was randomly taken from the process, and 253 defectives (broken drops) were identified. Thus, the current sigma level for the drops manufacturing process was reported as 2.87σ since the final yield is equal to 0.916.

Analyze phase

The main objective of the Analyze phase is the identification of the root causes of broken drops through data analysis techniques. The data analysis approach used at Alpha encompasses the application of LM tools, Failure Modes and Effects Analysis (FMEA), as well as statistical analysis through basic graphics and hypothesis testing. After selecting the probable causes that affect the *“Y”* of the project, the PT conducted a sequence of analyzes involving statistical techniques appropriate to the characteristics of the project.

Considering that two of the potential causes are categorical variables (x_1 – *bubbles in the dough*; and x_4 – *flavor mix*), the PT has considered that the most suitable hypothesis test for the project would be the chi-square test (χ^2). To perform the tests, random samples were taken in different work shifts, according to an operational definition. According to Berenson et al., (2002) the χ^2 test statistic is equal to the square difference between the observed and expected frequencies, divided by the expected frequency in each cell, added over all cells, as shown in expression 3:

$$\chi^2 = \sum \frac{(f_0 - f_e)^2}{f_e} \quad (3)$$

Where f_0 is the frequency observed in the real count in a given cell of a contingency table, and f_e is the expected or theoretical frequency, that is expected to be found in a given cell if the null hypothesis is true. A first test was performed to verify the hypothesis that the various types of flavors (x_4) influence the percentage of broken drops. The null (H_0) and alternative (H_1) hypotheses for conducting this test are shown below:

H_0: *The occurrence of broken drops is independent of the flavor mix.*

H_1: *The occurrence of broken drops is dependent of the flavor mix.*

Once formulated, the hypotheses were tested through the Chi-Square test for association running on Minitab software. According to Montgomery and Runger (2010), the independence hypothesis must be rejected if the value of the χ^2 statistic test is too large. Moore et al., (2009) point out that the *p-value* represents the rejection when this value is less than a significance value. As seen in Table 3, Pearson's Chi-square statistic is 4.278 (*p-value* = 0,370) and the Likelihood Ratio Chi-Square statistic is 4,111 (*p-value* = 0,391). Thus, with a 5% significance level, the EP did not reject the null hypothesis and so there was not enough evidence to conclude that the percentage of broken drops depends on the flavor mix. Furthermore, Table 3 also presents the contribution values for the Chi-square statistic (contribution χ^2), which represents the squared standardized residues for each cell. These show that the largest difference between the frequencies observed occurs in the case of strawberry flavor but the overall difference, considering all flavors, is not statistically significant.

Table 3 – Chi-Square test for association between broken drops and the flavor mix.

		Strawberry	Eucalyptus	Cherry	Melon	Grape	All
Broken	*Count*	12	6	12	8	7	45
	Expected count	7,61	9,51	11,73	7,61	8,56	
	Contribution χ^2	2,538	1,293	0,006	0,020	0,283	
Not broken	*Count*	228	294	358	232	263	1375
	Expected count	232,39	290,49	358,27	232,39	261,44	
	Contribution χ^2	0,083	0,042	0,000	0,000	0,009	
All		240	300	370	240	270	1420

Pearson Chi-Square = 4,278; DF = 4; P-Value = 0,370
Likelihood Ratio Chi-Square = 4,111; DF = 4; P-Value = 0,391

A second statistical analysis involved other hypothesis test considering the possibility of an association between the breakage of drops and the presence of bubbles in the dough. This hypothesis was formulated by PT, who considered that the formation of bubbles (x_1), which can occur at different stages of the manufacturing process, could make drops more fragile and susceptible to breakage. The hypothesis pair was formulated as follows:

H_0: *The occurrence of broken drops is independent of the presence of bubbles in the dough*.

H_1: *The occurrence of broken drops is dependent of the presence of bubbles in the dough*.

The data were submitted to the chi-square test for the statistical confirmation of the formulated hypotheses. Table 4 shows that Pearson's Chi-square statistic is 146,597 (*p-value* = 0,000) and the Likelihood Ratio Chi-Square statistic is 108,831 (*p-value* = 0,000). Both *p-values* are smaller than the 0.05 significance level. This time the EP rejected the null hypothesis concluding that there is statistical evidence to conclude that the percentage of broken drops depends on the presence of bubbles in the product. It is seen that the frequency of products with bubbles observed in the broken drops is 3.66 times the expected frequency and in fact the cell Chi-squares are all significantly large, which indicates a strong relationship between the type of the drop (broken or not) and the whether or not there were any bubbles.

Table 4 – Chi-Square test for association between broken drops and bubbles.

		With bubble	Without bubble	All
Broken	*Count*	57	32	89
	Expected count	15,57	73,42	
	Contribution χ^2	110,18	23,37	
Not broken	*Count*	118	793	911
	Expected count	159,43	751,58	
	Contribution χ^2	10,76	2,28	
All		175	825	1000

Pearson Chi-Square = 146,597; DF = 1; P-Value = 0,000
Likelihood Ratio Chi-Square = 108,831; DF = 1; P-Value = 0,000

Then, PT decided to investigate the percentage of breaks in the different control points of the process of cooling and packaging, which presented a higher incidence of bubbles and broken drops. Random samples of 100 drops were taken for each control point in the different work shifts. The results of this measurement were presented in the form of a Pareto chart illustrated in Figure 3. It is possible to observe that three specific points of the process (conveyor belt, cold chamber, and spout) are responsible for 85.3% of the broken drops. Therefore, these variables were selected as the main root causes of the problem addressed in the project. In addition to these variables, causes not treated statistically (x_3 – *GDs operation*; x_5 – *uniplast operation*; and x_6 – *falling drops*) were also considered as opportunities for improvement in the next phase of the project.

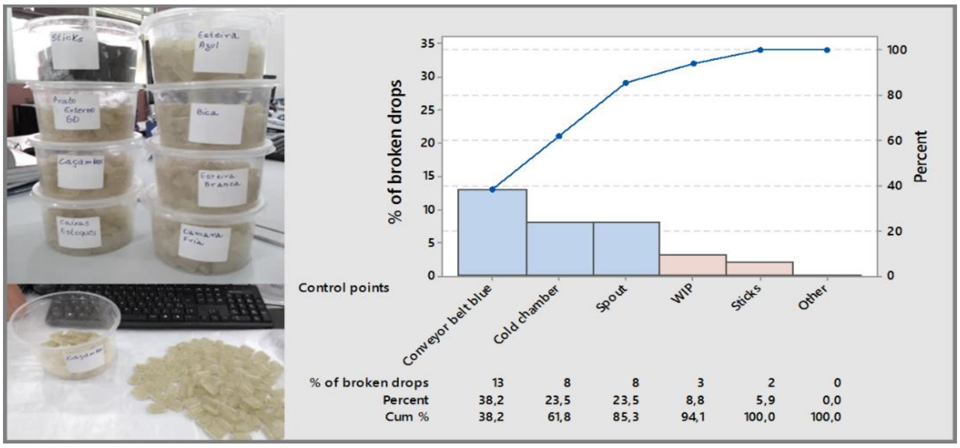


Figure 3 – Pareto Chart for percentage of broken drops.

Improve phase

After verifying and selecting the root causes of the project in the Analyze phase, the next step was the generations of ideas and solutions to act on these root causes to improve the performance of the process. The functionality of the actions characterizes this phase through the design and implementation of adjustments to the process to improve the performance of the CTQs (De Koning and De Mast, 2006). In this context, PT conducted a brainstorming meeting to discuss and select the best solutions. An action plan was developed to guide the implementation of the following actions:

- Replacement of the squeegee used to fold the dough.
- Implementation of conveyor temperature control.
- Adjustment of the spout.
- Review of the GD's operational standard.
- Implementation of one-point lessons at Uniplast 03.
- Implementation of a control plan for the adjustment of the nozzles and operation of the cold chamber.

It should be noted that part of these actions did not require any financial approval and was implemented through a *kaizen* event with the mobilization of operators. After carrying out all these actions, PT conducted a new study following the same procedure adopted in the Measure phase to estimate the new sigma level for the improved process, which evolved from 2.87σ to 3.25σ, resulting in a new final yield index of 95.99%. Although the percentage change for this index seems small (only 4,79%), it corresponds to a 52,57% reduction in the occurrence of defects per million opportunities, according to the six sigma conversion table previously cited.

Before starting the Control phase, PT prepared a time series graph to verify the sustainability of the improvements obtained with the project. Figure 4 shows the significant decrease in the percentage of broken drops from the implementation of the Measure, Analyze, and Improve phases started in June 2018. The target established for the project (7.11%) was reached in October 2018, and the percentage of broken drops remained below that value in the following months. This performance shows the effectiveness of the actions implemented.

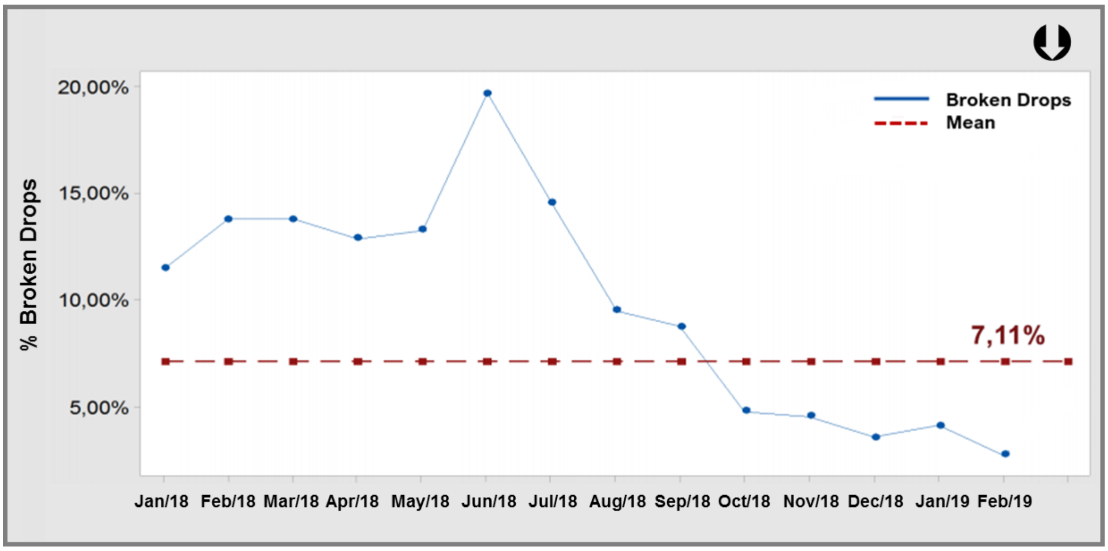


Figure 4 – Percentage of broken drops (after improvement actions).

Control phase

In the Control phase, the responsibilities assigned to the project team are transferred to the people who operate the process benefited by the LSS initiative. During this phase, it is necessary to implement actions that ensure the control of activities to avoid deterioration of the process in the long term. Therefore, the activities carried out in the Control phase are directed towards the establishment of standards measures to maintain the performance, and correct any possible problem, as needed (Ismyrlis and Moschidis, 2013).

The first action implemented in this phase refers to the implementation of a control plan for the operation of the nozzles and the cold chamber in the cooling stage. This plan included a visual inspection method in the cooling stage, clarifying the inspection points (spout and GD's), those responsible for this activity, the new measurement method, and its frequency, as well as the corrective action procedure when deviations are observed. Besides, a review of the inspection plan was carried out where those responsible for this activity receive training in the new standard.

To monitor the proportion of defects and identify any special causes of variation a *P* Chart was elaborated according to the expressions (4), (5), and (6), where: *D* is the number of defective units (broken drops) in a random sample of size *n*, and *P* is the proportion estimated from preliminary samples. The control limits (Upper Control Limit and Lower Control Limit) are estimated based on ± 3 standard deviations for a binomial distribution.

$$\overline{P} = \frac{D}{n} \tag{4}$$

$$UCL = \overline{p} + 3\sqrt{\frac{\overline{p}\,(1-\overline{p})}{n}} \tag{5}$$

$$LCL = \overline{p} - 3\sqrt{\frac{\overline{p}\,(1-\overline{p})}{n}} \tag{6}$$

The implementation of Statistical Process Control (SPC) involves two distinct phases, known as Phase I and Phase II (Chakraborti et al., 2009). While Phase I is retrospective in nature and the primary interest is to understand the process better and assess process stability, Phase II (monitoring phase), consists of trying to bring a process in control by analyzing historical or preliminary data to eliminate any assignable causes of variation. However, in the context of implementing LSS projects, control charts are used to ensure that the improved performance of the process is sustained after the PT has completed its work and moved onto another project (Snee, 2010).

Regarding these considerations, the *P* Chart was initially developed to verify the stability of the process after the implementation of the improvement actions (Phase I). Figure 5 shows a *P* chart running on Minitab software, referring to 25 samples of 30 drops randomly taken from the packaging process. When the calculation of the lower control limit (LCL) results in a negative number, LCL is assumed to be equal to 0. Therefore, it is possible to verify that the percentage of defects varies around the average proportion (4.13%) without the presence of special causes or points outside the control limits. Also, there is no trend line formed by consecutive points close to any control limit, which shows a process under statistical control.

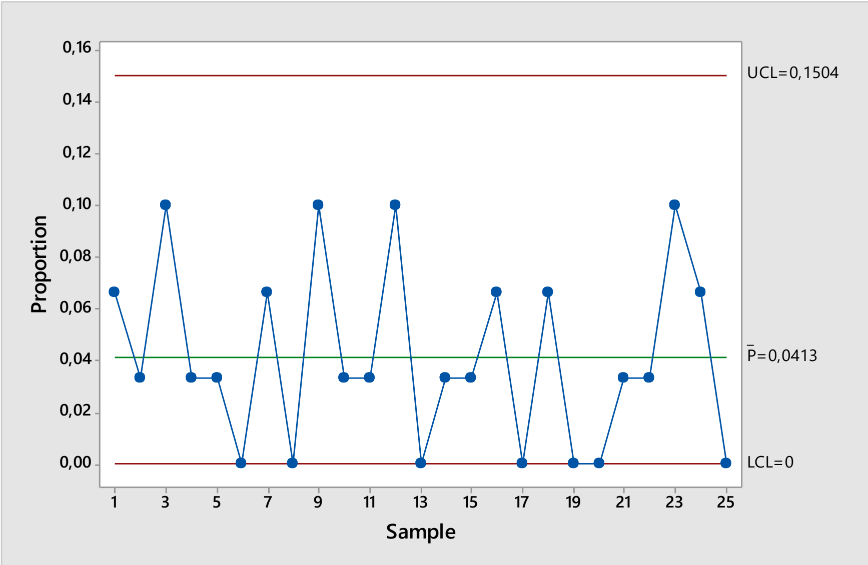


Figure 5 – *P* Chart for monitoring the percentage of broken drops.

After the end of the project, the statistical monitoring of the proportion of broken drops started to be conducted daily in the packaging process in a standardized way to verify the occurrence of assignable causes of variation (introduction to Phase II).

CONCLUSIONS

LSS approach is understood as a useful strategy of operational excellence suitable for the food industry and able to improve the organizational performance in terms of quality, cost, and speed. The current study started with the aim of reducing the percentage of broken drops in a Brazilian food factory. To achieve this objective, the company implemented an LSS project according to the DMAIC method. The project was defined from a bottom-up perspective, as part of a green belt certification program at the company.

The actions carried out in the Measure and Analyze phases revealed that some variables inherent to the manufacturing process contribute to the increase in the percentage of broken drops. These variables represent the following factors: (i) presence of bubbles in the dough; (ii) conveyor belt temperature; (iii) GD's operation; (iv) nozzle adjustment at Uniplast; and (v) operation of the cold chamber. The investigation also highlights the use of statistical tools to solve problems. The implementation of improvement actions resulted in a 66% decrease in the defective drops. As a result, the sigma level evolved from 2.88σ to 3.35σ.

This research is limited to the implementation of a single case, where some statistical techniques were used at a basic level. It can be assumed that operational excellence strategies differ in other companies and industries. However, although this study does not intend to generalize the results, this paper can be used as a reference guide for researchers and practitioners to implement operational excellence projects in food industries.

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