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CASE STUDY

Using DMAIC for in-plant logistic activities improvement: an industrial case study in cement manufacturing

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ABSTRACT

Goal: In-plant logistics activities are important for increasing the performance of the supply chains, so our research aims to study the application of Six Sigma tools for in-plant logistics activities in the cement industry. Our research contributes to the literature by developing a real case study that provides insights into the practical implementation of continuous improvement programs.

Design / Methodology / Approach: This study uses the Industrial Case Study in a large cement plant, a branch of a multinational business group, in Brazil's Middle-west region. This research applies Define, Measure, Analyze, Improve, Control (DMAIC) guidelines with Statistical Process Control tools for solving a real problem for out-control processes. From this, we propose an improvement plan to correct flaws in the in-plant cement loading and unloading process (in-plant logistics).

Results: The results suggest that based on the control chart, the studied in-plant logistics activities were out of control. These processes exhibit a high variability, between 3σ and 5σ, presenting 26 problems with causes related to machine, measure, and human resources. An out-control action plan was proposed aiming for improvements to solve these problems.

Limitations of the investigation: On the out-control action plan, this study presents an improvement proposal. The action plan does not fully develop the control step for DMAIC.

Practical implications: Managers in the cement industry can use our case for insights and learning about improvement programs, especially for the in-plant logistics activities addressing processing-based manufacturing environments.

Originality / Value: Our research contributes a real case study that applies the DMAIC methodology, with a specific focus on in-plant logistics activities. By developing the application of improvement programs within the cement industry, our study offers practical insights into how processing industries can effectively implement such programs.

Keywords: Cement industry; Statistical process control; Continuous improvement; DMAIC; Six Sigma Logistics.

1. INTRODUCTION

Cement industries demand several raw materials in their manufacturing process and efficiency in customer service. From that, the transportation in-plant logistics, i.e., the loading, and unloading activities of materials and products, can be drivers for meeting consumer expectations

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(Naqi and Jang, 2019). In-plant logistics aggregates the loading and unloading costs, representing a considerable product's final price value. Therefore, internal logistics have a decisive impact on revenues and competitiveness (Saez-Mas et al., 2020). In-plant logistics activities are essential for the cement supply chain (Diliberto et al., 2020). In-plant logistics improvements are vital for increasing the performance of the supply chains in the cement industry (Agudelo, 2009). The application of continuous improvement programs in logistics can improve logistics operations, enhance customer satisfaction, reduce lead time, and save costs (Trakulsunti et al., 2023).

Continuous improvement programs contain practical solutions to solve problems, even for logistic activities. One program is the Six Sigma philosophy that uses a simple methodology through steps: Define, Measure, Analyze, Improve, and Control (DMAIC) to improve logistic operations (Srinivasan et al., 2016). Srinivasan et al. (2016) report some successful cases from DMAIC applications. Adeodu et al. (2023) applied this methodology in a logistics company and the process cycle efficiency improved by up to 70%. As an improvement program, Six Sigma Logistics (SSL) uses DMAIC to guide the improvement actions (Carvalho et al, 2017; Pinto et al. 2017). However, DMAIC presents criticism in some applications, especially when managers do not understand how to implement it to obtain results (Albliwi et al., 2014). Continuous improvement initiatives in the cement industries which are based on repetitive and large manufacturing processes seem scarce (Sharma and Khanna, 2020). This problem appears to be shared in the logistics process of the cement industry.

In this subject, Akinyemi et al. (2021) present an interesting empirical study about technology retrofit economic issues and sustainability (reduction of CO2) in Nigeria. Kamble et al. (2011) researched a real case of in-plant logistics process reengineering case in India. Kamble et al. (2016) extended their previous study, simulating in-plant logistics and aiming to optimize it for business process engineering. However, no study was identified proposing Six Sigma improvements to the internal logistics of cement companies. Therefore, lacks in Operations Management/Industrial Engineering literature, and empirical studies such as industrial case studies addressing the use of Six Sigma in in-plant logistics of the cement industry. Our research addresses this gap.

Consequently, this study aims to answer: *How to improve the internal logistic activities in a cement manufacturing company using DMAIC methodology into a Six Sigma Logistics initiative*? For this, an industrial case study shows an application of logistic activities in a cement manufacturing company. Our study focuses on in-plant logistic activities to analyze losses and failures identified in the loading and unloading process from a Six Sigma Logistics approach (Carvalho et al., 2017). We applied the statistical control charts technique to detail the improvement process in the selected process. After this step, we diagnosed the sigma level for in-plant logistics regarding the processes and their inputs. Lastly, we present a proposal for an action plan.

In the following Section 2, this article presents the theoretical background and related concepts. Section 3 exhibits the methodology. The findings are presented in Section 4. Lastly, Section 5 presents the conclusions of the study.

2. THEORETICAL BACKGROUND

2.1 logistics quality management and the Six Sigma Logistics (SSL)

Logistics performs its activities at all times, both upstream and downstream companies. In-plant logistics' operational responsibility is to dispose of raw materials, semi-finished products, and finished products' stocks at the lowest possible cost (Bowersox et al., 2019). A company that obtains efficiency in the logistics chain has a superior competitive advantage over other organizations (Sandberg, 2021). Besides, the case study developed by Gutierrez (2016) shows that SSL contributes to improving performance in a logistics environment and achieved explicit benefits such as process improvements and flow time reductions.

Transport logistics encompasses all physical distribution and supply processes, from raw materials acquisition, transportation to industry, in-plant logistics, and these products flow to the final consumer (Mamede et al., 2017). The general objective of physical distribution is to provide the right products, to the right places, at the right time, and with the desired service level, at the lowest possible cost (Ballou, 2007; Daugherty et al., 2019). The same objective is to supply logistics but focused on supplies and raw materials (Tellini et al., 2019). The materials flow, internal services, transportation, and internal processes management (materials, products, parts, and raw materials/supplies) comprise materials logistics or materials management activities or in-plant logistics (Reis et al., 2017). Transportation can be considered the logistical activity that holds a supply chain's links together and provides the in-out stream for in-plant logistics (Simchi-Levi et al., 2016).

Another essential managerial function for organizational competitiveness is quality management (QM) (Jacobs et al., 2018). The QM provides mechanisms for adapting the product or service, enabling the production process to avoid defects or failures from Statistical Process Control (SPC) and continuous improvement tools, such as Six Sigma and DMAIC (Lee and Li, 2018). According to Şişman (2023), a successful SSL implementation requires an integrated approach to the company. Managers must look at underlying patterns and trends as well as the consequences of changes in how they affect the company by applying such an integrated SSL management approach.

Efficiency, effectiveness, and consequently, quality in-plant logistics are factors that present a high level of contributions to profitability (Lee and Li, 2018), since the expenses with logistics vary between 5% to 35% of sales value, depending on the type of activity, the geographical area of operation and the weight and value ratio of products and materials (Bowersox et al., 2019).

In logistics, four positive values types are aimed at the end-consumer: (i) eliminate process steps that only generate time losses and consequently unnecessary costs; (ii) streamline the logistics process; (iii) involvement of all human, material, technological, and information elements, and finally; (iv) optimization search of resources and the improvement of service levels, thus generating quality management in supply chain logistics and related services (Novaes, 2021). These values can be reached in cement industries from capable, predictive, and balanced processes.

2.2 DMAIC methodology

DMAIC is based on the methodology used in the Six Sigma philosophy. The Six Sigma philosophy seeks to improve the company's results effectively by implementing a better project and controlling the activities/processes performed (Pyzdek; Keller, 2018). The sigma scale determines the quality level in a numerical term/measure. Sigma (σ) commonly represents the population's standard deviation. The higher the standard deviation, the greater the variability of the process. A process is considered within a Six Sigma level when it has 99.9999998% of operations, products, or services without failures, errors, or malfunctions, i.e., two failures or defects per million units produced (Werkema, 2016). Therefore, along with operations, an objective is to minimize the process's variability, thus obtaining a low or natural standard deviation (Werkema, 2016).

Decisions in Six Sigma initiatives might be made on data and based on a structured DMAIC tool (Gomes et al., 2017). The DMAIC deployment offers a company a higher success probability when it achieves the full commitment of the organization's top management. Using DMAIC, it is possible to identify and solve problems that occurred in operations, processes, products, or services, to satisfy internal and external consumers of the company (Pophaley; Vyas, 2015; Pinto et al., 2017).

The DMAIC guideline consists of five steps, according to Khan (2020):

(i) D (Define): Define precisely the scope of the process

(ii) M (Measure): Determine the location or problem focus

(iii) A (Analyze): Determine the causes of each priority problem

(iv) I (Improve): Propose, evaluate, and implement improvements for each priority problem

(v) C (Control): Ensure the goal's achievement is maintained over the long term.

2.3 Statistical control process

Statistical Process Control (SPC) is a collection of tools that, when applied, identifies the variability, thus enhancing the reach of a stable process whose capacity can be improved (Ali et al., 2021). Capability is the producing concept according to specification, or generically, doing with quality (Oakland; Oakland, 2018).

SPC can be applied to any manufacturing or service process, such as in-plant logistics companies (Lizarelli et al., 2016). SPC's main objective is to statistically diagnose the process, maintaining it in a state of statistical control and supporting improvement in production capacity (Oakland; Oakland, 2018). The SPC uses commonly seven tools to analyze processes (see Montgomery et al., 2011). However, will be listed in following only those used in our plan proposal/study:

- Process Map: process mapping is the graphic display of stages, events, and operations, which constitute a manufacturing process representation. (Six Sigma Institute, 2021).
- Control chart: these charts aim to verify if the process is under statistical control, identifying measures with unusual causes of variances (Montgomery; Runger, 2020).
- Diagram of cause and effect: this tool represents the significant relationship between an effect and its possible causes, considering the following categories (it is known as 6 M): 1. labor/manpower; 2. machines; 3. methods; 4. Materials; 5. environment/mother nature, and; 6. Measure;
- Improvement plan for OCAP: this tool seeks to reach how the process must "*to be*". For this, eight systematic steps be performed:1. Solution parameter; 2. Generate possible solutions; 3. Screen against musts and wants; 4. Conduct cost-benefit analysis; Step 5. Failure mode effect analysis (FMEA); 6. Pilot solution implementation; Step 7. Validate measurement system; 8. New

process capability /mapping (Six Sigma Institute, 2021).

For the control charts, the most used variables are the $\overline{X}$ -R (mean and range), $\overline{X}$ -S (mean and standard deviation), $\overline{X}mean$ and R (median and range) as Western Electric (1958) proposed. The $\overline{X}$ R charts are the most used, but it often becomes desirable to directly estimate the standard deviation rather than indirectly using the range (R). In general, the $\overline{X}$ -S charts are preferred to their peers $\overline{X}$ -R, when (Montgomery, 2020): (i) Sample size *n* is moderately large (*n*> 10 or 12), as the range for estimating the standard deviation loses statistical efficiency for large samples; (ii) When the sample size *n* is variable, to calculate the Upper Control Limit (UCL), Control Limit (CL), and Lower Control Limit (LCL). The $\overline{X}$ chart uses the following equations and parameters:

$$UCL = \overline{\overline{x}} + A_3\overline{s} \tag{1}$$

$$CL = \overline{\overline{x}} \tag{2}$$

$$LCL = \overline{\overline{x}} - A_3\overline{s} \tag{3}$$

In the S chart, the parameters are:

$$UCL = B_4 * \overline{s} \tag{4}$$

$$CL = \overline{s} \tag{5}$$

$$LCL = B_3 * \overline{s} \tag{6}$$

Where:
UCL – Upper Control Limit
CL – Control Limit
LCL – Low Control Limit
$\overline{\overline{x}}$ – Mean $\overline{X}$
$\overline{s}$ – Mean S
A_3 B_3 B_4 – Table constants (see Montgomery, 2020).

On identifying and eliminating attributable causes, it is necessary to discover the root causes of the problems. Control charts help to identify when a process is out of control. If the process is not under statistical control, it is recommended to use the Out-of-Control Action Plan (OCAP). The OCAP is a flowchart or activities sequence description that occurs after an out-of-control point or signal, consisting of survey points, potential attributable causes, and corrections, which are actions taken to resolve the out-of-control condition, control, and eliminate attributable causes. Figure 1 exemplifies the systematic of this study using Statistical Process Control (SPC) as the basis (Montgomery, 2020). The DMAIC guidelines are the basement for the proposed OCAP plan (Santos and Martins, 2008).

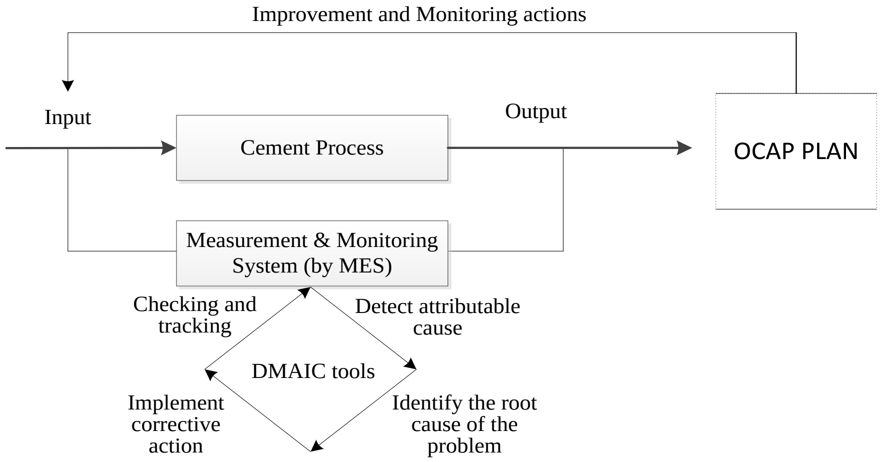


Figure 1 - Flowchart of planning, conducting, and analyzing from DMAIC/OCAP (Adapted of Montgomery, 2020).

For control charts, there are eight tests to identify special causes (Montgomery, 2020):

1. One point more than 3σ from the center line
2. Nine points in a row on the same side of the centerline
3. Six points in a row, all increasing or all decreasing
4. Fourteen points in a row, alternating up and down
5. Two out of three points more than 2σ from the centerline (same side)
6. Four out of five points more than 1σ from the centerline (same side)
7. Fifteen points in a row within 1σ of the center line (either side)
8. Eight points in a row more than 1σ from the centerline (either side).

Test 1 to 4 applies for both the media and standard deviation charts. Test 5 to 8 applies to the media chart only. The tests reflect practical rules to identify if the measured variable does not fit the normal distribution.

3. METHODOLOGY

We used an industrial case study to investigate the statistical process control of in-plant logistics activities in a large-size cement company. We collected data from a cement plant located in the Middle-West region of Brazil. We analyzed the in-plant logistics processes from statistical process control tools, precisely from $\overline{X}$ -S charts. Thus, we proceed to elaborate an Out-of-Control Action Plan (OCAP) for qualification and continuous improvement of in-plant logistics processes.

3.1 Industrial case study

The industrial case study is a research method characterized by an in-depth and exhaustive detailing of one or more cases focused on industrial environments, focused on problem-solving (Mills et al., 2010). This method allows for expanding broad knowledge of the study (Ketokivi and Choi, 2014). The Industrial case study uses only some traditional case study research elements, as Miguel (2012) presented. Figure 2 shows the selected steps for this method: defining a conceptual framework, planning the case, collecting data, analyzing data, and generating reports.

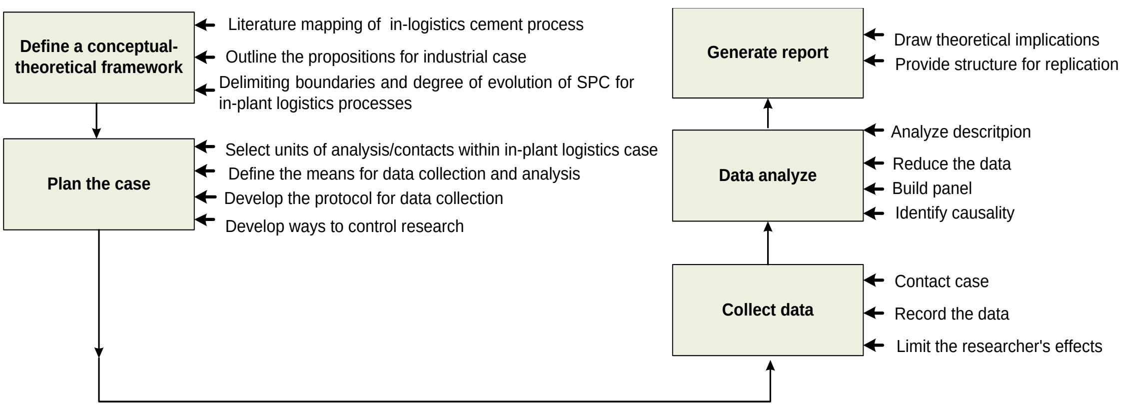


Figure 2 - Steps for industrial case study conducting (Adapted of Miguel, 2012).

3.2 Data-collection and analyze

We collected data on the in-plant logistics activities of a large cement industry through the company's Information Management System (IMS) and Manufacturing Execution System (MES). These data were stored in MS Excel spreadsheet format and reports such as digital files. Enterprise features data were collected in documentary research (strategic planning documents, plant indicators, historical data) and direct observation between 2015 and 2016. The parameters monitored in that period were historical events of the plant, product mix changes, production processes and their fit, and organizational context. Besides that, we also collected the in-plant logistics data concerns to the time intervals related to input values (raw material) values and for forwarding and exiting trucks for loading and unloading cement and inputs. Some of these data were recorded daily in the company's expedition and their hours of occurrence. The "entry" data includes when the truck enters the company's parking lot and records its arrival on the expedition. The data that have reference "forwarding" is regarding the truck being called to load or unload, that is, when the truck is weighed and enters the yard of the industrial production area. The "output" data includes the values indicated when the truck is weighed, leaves the production area's yard, and is free to continue the journey.

The cement loading process occurs in three ways: Manual, Palletized, and Bulk. On the other hand, the raw materials or supplies unloading process comprises all the inputs that are unloaded in the company for use in cement production, being: coke, crude oil, rice straw, tires, glycerine, plaster, diesel oil, among other inputs of less volume and generated by the company.

From the loading and unloading processes data collection, we calculated the indexes of AWT (Average Waiting Time), ALT (Average Loading Time), and ACST (Average Customer Service Time). The AWT (Equation 7) is the time interval in which the truck arrives at the company's yard and records the shipment until the forwarding time for loading or unloading. ALT (Equation 8) is the time interval in which the truck is loaded or unloaded until the truck leaves the yard. ACST (Equation 9) is the time interval for entering and leaving the truck, that is, the time between it arriving at the company's parking lot and recording an expedition until the truck is released or exited to its destination.

$$AWT = \text{Forwarding} - \text{Entry} \tag{7}$$

$$ALT = \text{Exit} - \text{Forwarding} \tag{8}$$

$$ACST = \text{Entry} - \text{Exit} \tag{9}$$

Where:
AWT: Average Waiting Time
ALT: Average Loading Time
ACST: Average Customer Service Time
Entry: Time recorded when the truck arrives at the company
Forwarding: Time recorded when the truck enters the company's yard
Exit: Time recorded when the truck leaves the company's production yard

According to unloading and loading procedures, the data type collected was subdivided: manual, palletized, and bulk. These processes represent all the loads/unloads carried out in the company during the study period. Unloading is all input/parts/material unloading activities generally carried out within the company, so the calculation of AWT, ALT, and ACST was carried out for manual, palletized, and bulk loading and unloading data. The data were stratified and treated under daily averages, as there was a large amount of data (the information system collects data from all hourly loading and unloading activities). The maximum time limit stipulated by company A for ACST is two hours and forty-five minutes, i.e., the time limit for filing or unloading the truck at the industrial plant, from entry, loading, or unloading, to departure to destination.

According to data collected on the floor with the plant's Logistics Manager, its management set a time target to carry out loading and unloading activities: 40 minutes for ALT, 15 minutes for AWT, and 80 minutes for ACST. These values were based on a historical survey of data carried out by this study over historical records, validated as genuine by Industrial Case A and his team's logistics manager.

The data were analyzed using the Minitab Student (version 17) software to obtain control charts and diagnose whether the loading and unloading processes in Industrial Case A are under statistical control. To identify time losses within the in-plant logistic process, we applied the Six Sigma philosophy and DMAIC tool. From this, we found the corresponding sigma level for the in-plant logistic loading and unloading process.

We used an electronic spreadsheet executed with macro-VBA in MS Excel for calculating the sigma level. We used the table column for bilateral variables in the sigma level calculation. Then, we estimated the control chart parameters: the UCL and LCL limits.

The populate and data treatment criteria were:

• The “characteristic description” column informs the quantitative variables’ names or descriptions

• the “UCL” column informs the lower specification limit for each variable

• The “Target or LC” column informs the nominal value for each variable’s target or ideal theoretical value

• the “LCL” column informs the upper specification limit for each variable

• The “Average” and “Deviation” column informs the sample mean value and standard deviation for each variable

We presented a characterization of the cement industry studied and its manufacturing process in section 4.1.

In the Measure stage, we collected the data and developed the control charts. Second, we made the data treatment in the Analysis stage, obtaining and interpreting the control charts and the sigma level metric. Third, the Out-of-Control Action Plan (OCAP) for Industrial Case A was developed for the Improving stage. The company in the study aimed to stabilize their in-plant logistic processes by the improvement plan and monitoring of the process, getting enhancements feedback. The Controlling stage was applied between 2015 and 2018’s years.

4. FINDINGS

The findings show the industrial case characterization, the studied plant’s industrial processes flowcharts, and the in-plant logistic flow for the main products. Lastly, we present the analysis from the control charts (SPC) and DMAIC/OCAP tools/plan.

4.1 Industrial case: cement industry characterization and processes

Large groups dominate the cement industry market in Brazil, and the company studied belongs to one of these groups (Cimento.Org, 2018). The group to which the studied unit belongs is classified as a large-size company (BNDES, 2018) with net revenue of around R$ 8.5 billion annually (US$ 1.7 billion), with 11 thousand employees in 2015-2018. The industrial unit directly employs around 150 employees and around 300 employees of third-party service providers.

The industrial unit studied has been part of a group producing cement in Brazil since 1933 and is the country’s market leader in the 2010 decade. The plant studied covers the Midwest of Brazil, Rondônia State (Brazil), and Bolivia. Cement is a hydraulic binder consisting of calcium, silicon, aluminum, and iron compounds. This compound hards when mixed with water in proportions and exposed to air as a mix (Aragaw, 2018). Figure 3 shows a summarized flowchart of the main cement production stages in Industrial Case A.

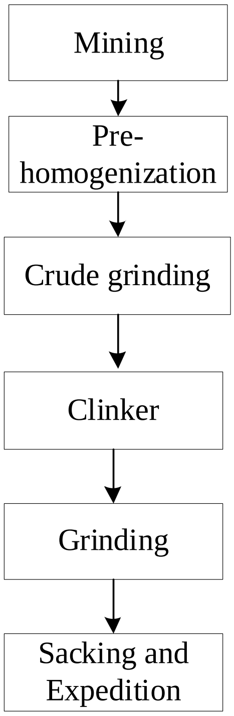


Figure 3 - Cement processing flowchart in Industrial Case A

Limestone is extracted from mines near the manufacturing units through detonation. It produces a wide range of materials necessary to pass through crushers. Later, they are stored in a yard for the purpose of a pre-homogenization of limestone material (Aragaw, 2018). In this stage, there is also the first quality control by analyzing the chemical composition of limestone through the levels of calcium, silicon, iron, and aluminum (Aragaw, 2018).

Pre-homogenization occurs through lime storage in piles that maintain raw mill feed without much variation in its chemical composition (Gomides, 2010). Raw grinding is the process of reducing the material size in ball mills, being carried out by the action of gravity and rotation of the mill, that is, the interaction between grinding bodies and the material through impact, understanding, and friction performing the particle size reduction (Aragaw, 2018). In the grinding of raw material, the drying and grinding processes transform into a fine flour mixture.

The flour produced by the ball mill passes through a separator where the fine material goes to a storage silo that contains a system of continuous homogenization, and the coarse ones return to the mill (Aragaw, 2018). Feed flour from the oven is transported to the cyclone tower via an airlift blower, with a thermal exchange between the oven gases and the flour. The core function of cyclone towers is material decarbonization. The oven is responsible for burning and clinker flour through physical-chemical reactions, reaching a temperature of 1450ºC, with the final product being the clinker stored in silos (Gomides, 2010).

Clinkerization is a step that requires more environmental controls. Cement processing industries are responsible for a high impact of environmental pollution (Akinyemi et al, 2021). This factor has been at the center of ESG initiatives (environmental, social, and corporate governance) by cement industries in Brazil, for example, the adoption of circular economy practices into the production process by the Votorantim Cimentos, one of the largest cement manufacturers of Latin America (Votorantim Cimentos Relatório Integrado, 2022). For this reason, companies seek substitutes in coke burning, the main fuel for burning the oven, then implementing co-processing, burning alternative fuels such as rice husks, tires, sludge paints, and urban waste, among other inputs (Cement Plant, 2019).

For most cement types, the necessary raw materials are clinker, plaster, limestone, pozzolana, and slag. Clinker has an essential factor: cement strength, while limestone and pozzolan are central in minimizing production costs. The plaster is responsible for the time of “setting” the cement. The grinding of these materials occurs in the ball mill, which passes through separators to separate fine and coarse materials. The (fine) cement goes to a silo that supplies the baggers and bulk loading (Aragaw, 2018).

The cement is stored in silos, protected from environmental humidity, bagged in bags of 50 kg, and dispatched by manual loading, palletized, or shipped in bulk. There is constant control of raw materials’ chemical composition at all process stages. The cement industry (see Figure 4) detonates the limestone rocks transported by trucks from the mine to the primary crusher, passing through the secondary crushing and conveyor belts, and limestone piles formed the objective of better homogenization. A reclaimer transports it from the belts to a silo to supply the flour mill. In Industrial Case A, there is no clay mine, so the company acquires it from other suppliers. Piles homogenize the clay l, and there is strict control of the clay's chemical composition so that there are no problems in the following steps. The separators' purpose is to separate the fine and coarse materials, the fines go to the storage silo that feeds the clinker oven, and the coarse materials return to the mill (Aragaw, 2018).

Clinker is the main component of the company's cement. Its manufacture is what generates a higher cost. The kiln is responsible for the manufacture of clinker that can reach up to 1450 ºC, where the cyclone tower aims to decarbonate the flour that enters the kiln for chemical-physical transformation, producing clinker, which passes through the cooler and a crusher, then finishing the clinker manufacturing stage, which goes to the storage silo. The cement produced by the company is composed of clinker, plaster, pozzolana, and limestone. These materials are ground in the ball mill that passes through separators. The fine material goes to the silo that supplies the baggers and the bulk load. The cement produced by the Industrial Case is dispatched and bagged through manual loading, palletized, and bulk loading (Aragaw, 2018). Figure 4 exhibits the detailed process map.

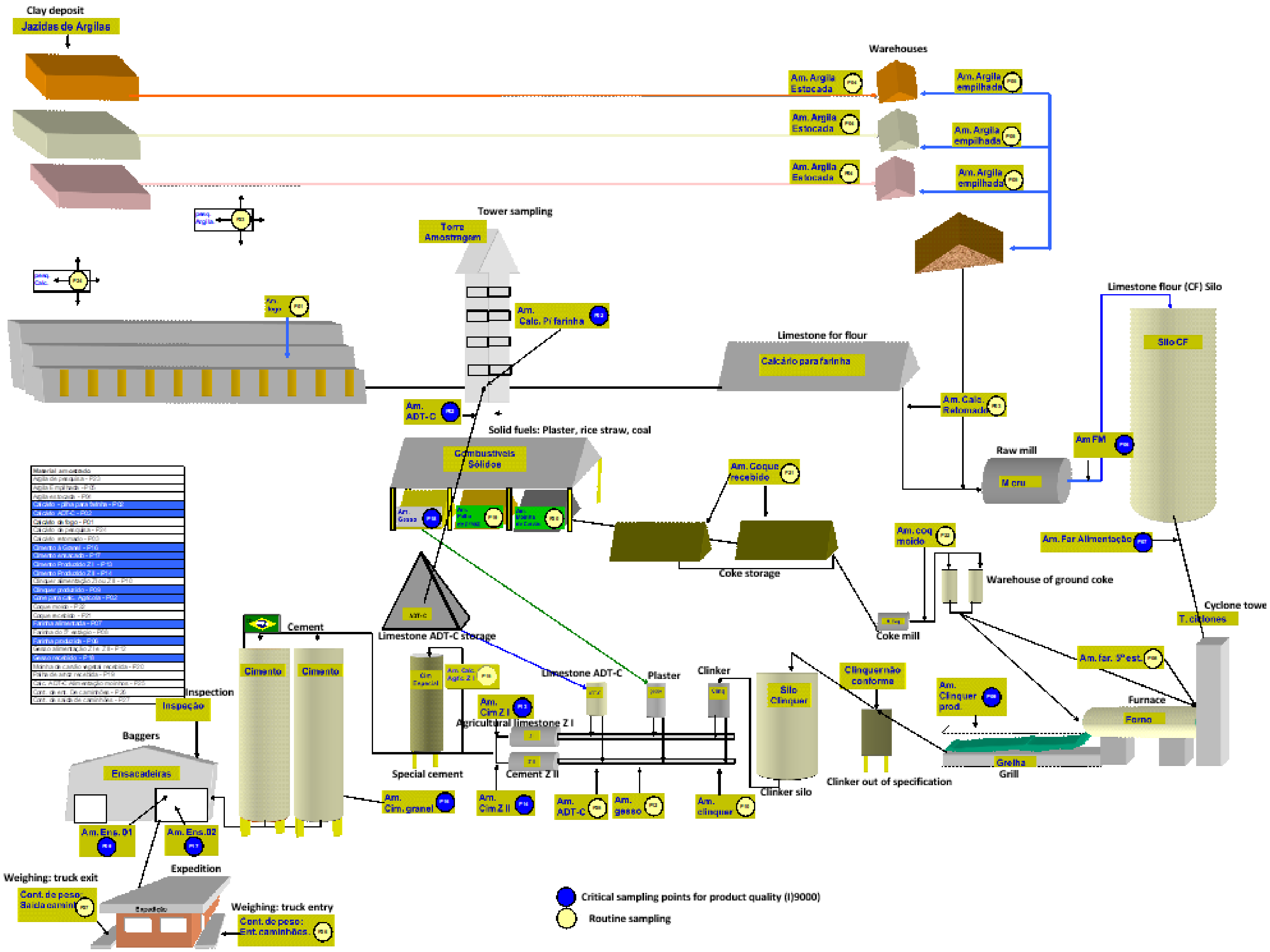


Figure 4 - Industrial Case A: cement manufacturing process flowchart (mapping)

4.2 DMAIC application

The DMAIC methodology describes all the steps to be followed by Industrial Case A to apply to continue loading and unloading processes. Figure 5 shows the DMAIC methodology plan to develop continuous improvement. That figure also shows the steps to be followed to obtain the expected results, reduce the process's variability, and provide quality products for complete customer satisfaction (Pyzdek; Keller, 2018).

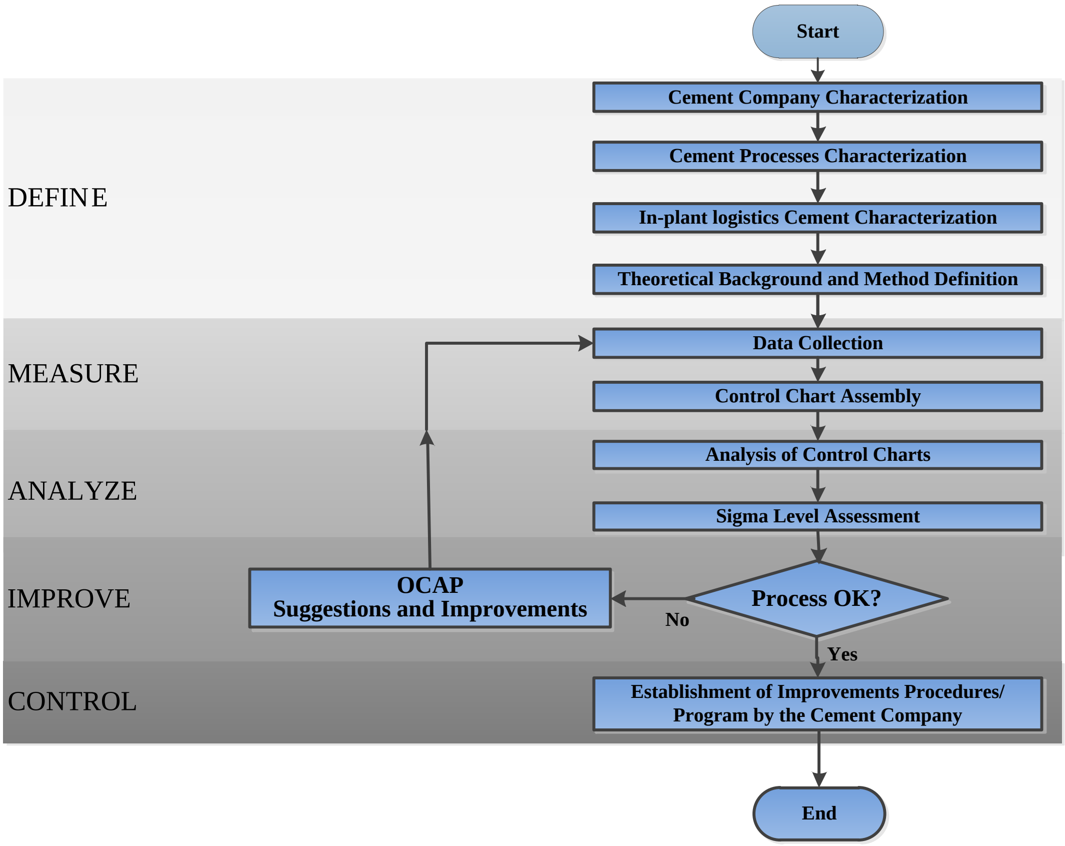


Figure 5 - DMAIC plan for Industrial Case A

4.2.1 Define step

The Define step presents the objectives for achieving process improvement, taking into account the suggestions of customers, stakeholders, and employees of Industrial Case A. The company's management defines the plan's guidelines taking into account customer satisfaction, profitability, and productivity, minimizing operational costs.

In the process of Industrial Case A, the reduction of unscheduled stops in the loading and unloading process appears to be the main problem. There are several eventualities: the oven stops, mining problems, the shutdown of cement and flour mills, and also other process problems, which generate a cascade effect on dependent functions, mainly logistics, the inclusion of Supply Chain Management principles, such as information sharing, internal integration, external integration, coordination, and collaboration, can be included in the plan and be the vector of potential improvements in the variability of times of logistical activities related to cement production.

4.2.2. Measure step

In the Measure step, we prepare the data collection plan. Industrial Case A made available the data collected through its Information and Communication Technology/Systems (MES/ERP), for example, the entry times, forwarding, and trucks exit for loading and unloading cement and inputs. We calculate the AWT, ALT, and ACST for each operation from these data. We stratified collected data using the daily average of each day made for the respective bulk loading, manual and palletized cement processes, and unloading inputs. The problems identification or anomalies in loading and unloading processes, i.e., the metrics to be used, were selected through the application of the control charts, to assess the processing time variability, where the times of AWT, ALT, ACST of bulk loads, manual, palletized, unloading and the respective sigma levels of the processes.

4.2.3 Analysis step

This section presents the analysis step for the bulk loading process, the manual loading, palletized loading, and unloading of materials.

– The bulk loading process

We calculated the daily averages of AWT, ALT, and ACST indexes from the plant's six months of observations (October to March of 2015-2016) according to the collected data. Thus, our study made the control charts set up in the software Minitab v.17 for bulk loading processes. The control charts have their limits based on three sigmas (3σ), three standard deviations from the mean. Figure 6 shows the pair of control charts for AWT, ALT, and ACST.

The first variable analyzed in Industrial Case A's logistical process was the Average Waiting Time (AWT). The AWT for manual bulk loading points with test 1 failed (points 1) within the control $\overline{X}$ chart (Figure 6). This sequence indicates a particular cause regarding the truck's problem requiring loading in a short time interval. However, the process is not under statistical control because several points failed on tests 2, 5, and 6. From this chart, we conclude that the process is out-of-statistical control. For the standard deviation (S) chart, there is a large variability, because some points failed test 1. This variation regards samples 65 to 73, where lows follow high peaks. In the $\overline{X}$ chart, several situations justify the process being out of control in the first points, and in the last samples, the average has high and low peaks.

The bulk loading control mean chart for ALT is not under statistical control. The chart has one point outside the control limits, failing test 1. This out-control point can be considered a special cause, but the process is not under control, because other points fail for tests 2, 5, and 6. The S chart for ALT shows a point outside the control limit; the variability of the process can explain this, i.e., it presents a standard deviation with great variation with high and low points. In bulk cargo, there is a high variation in time, i.e., there are trucks that take up to 4 hours inside the factory to load, and others load up to 40 minutes. That variation was more constant in March 2016. This situation can be explained by the lack of an operator for bulk loading, truck drivers' lack of knowledge about the loading location, mechanical and electrical problems in equipment, lack of cement, and climatic conditions.

ACST is one of the main means of evaluating the loading process, as it is the difference in the entry time and exit of trucks. The control $\overline{X}$ chart for bulk cargo ACST is not under statistical control. The chart shows how some points failed to test 1, 2, and 6. Samples 33 to 47 present a sequence of fails in tests 2 and 6. The standard deviation (S) chart has a non-random variance in the ACST. Thus, confirming the distance between one nominal value and another, indicates great variability, and the greater the loading process's variability, the greater the malfunctions, defects, or failures generated by it, as tends to extrapolate the control limits. The S control chart still has points that failed tests 1 and 4.

Between February 2016 (sample 18) and the middle of March 2016 (sample 45), there was a time goals stability of close to 02 hours and 45 minutes for internal logistic processes within Industrial Case A.

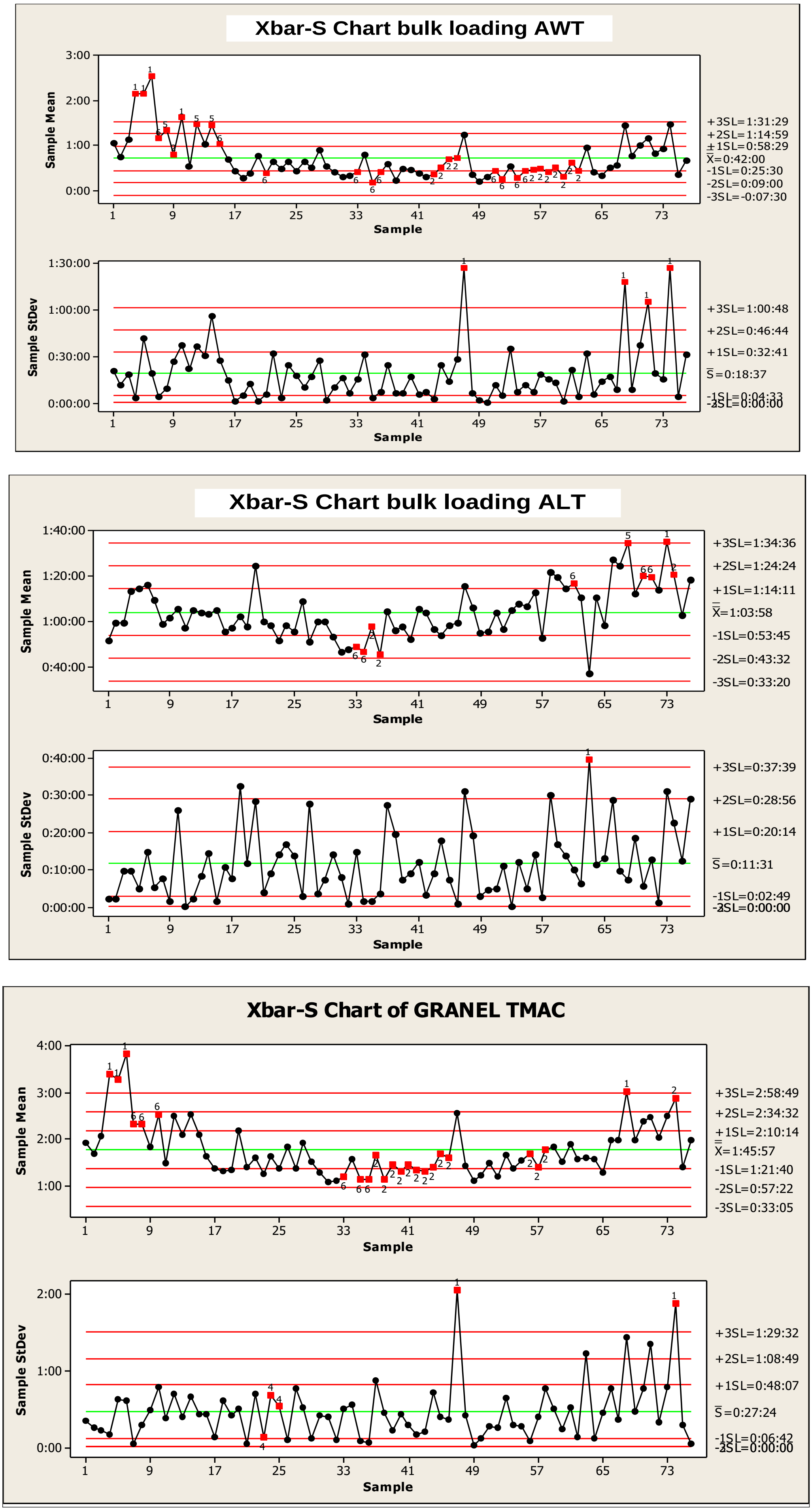


Figure 6 - Control chart for bulk loading (AWT, ALT, ACST)

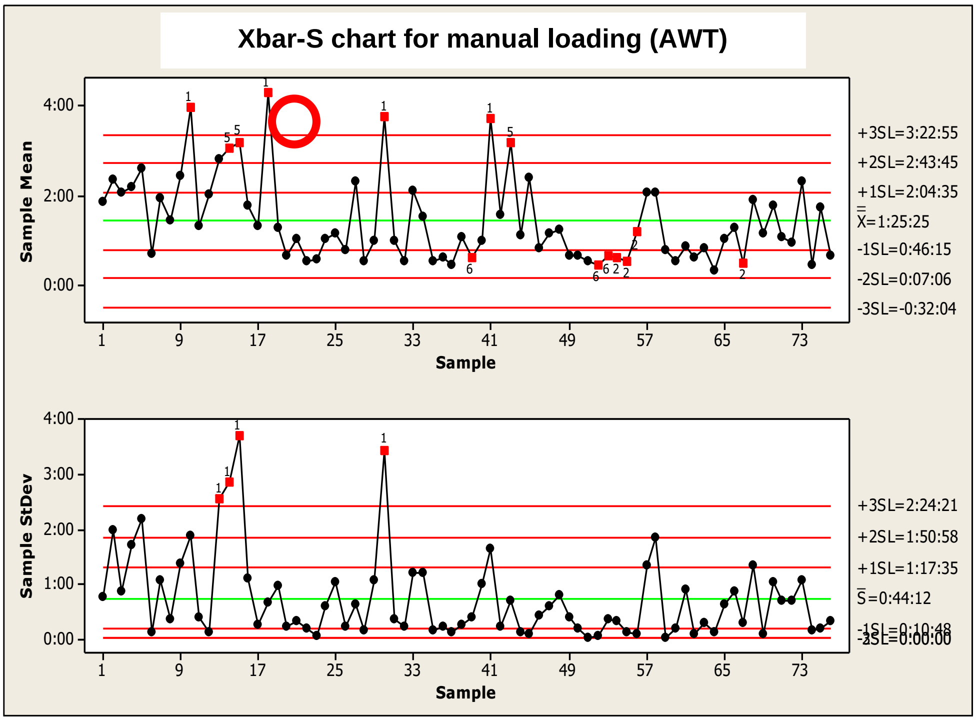
– Manual loading

We collected the data and calculated the daily averages of the AWT, ALT, and ACST indexes for the six months studied. Figure 7 shows the pair of charts for each index.

Manual loading had great variability in the process, according to Figure 7. The $\overline{X}$ control chart for AWT had four points outside the upper limit, failing test 1. The chart presents other points that fail in tests 2, 5, and 6. These reasons are sufficient, for we consider the manual loading process AWT being out of statistical control. The S chart presents four points outside the limit, failing test 1. AWT chart also presents cycles with a series of high peaks interspersed with a series of low peaks caused by operators' periodic rotation, systematic environmental changes such as temperature, and operator fatigue. It can be noted that now that these anomalies occurred, the graph showed times beyond the upper limit. Therefore, the AWT manual loading process has a non-random pattern, and a large variability; so the process is out of statistical control. These problems can be explained by the time for loading. Thus, this leads to an increment in the average waiting time and the truck loading accumulation.

The ALT for manual loading is not under statistical control. In the $\overline{X}$ control chart, tests 1, 2, 3, and 6 fail for some points. The S chart has three points below the control limits, failing test 1, and two points failing in test 2 (between samples 25 and 41 and 49 to 73), thus explaining that in the loading process, there is a constant variation of time. The factors that explain such patterns are the time taken to load a truck, standardization of trucks' size, the lack of operators for loading, operator fatigue, lack of cement, problems with bagging, lack of energy, and mechanical equipment failures.

Xbar-S chart for palletized loading (ACST) has a common characteristic both mean and standard deviation: abnormal variances and abrupt change in the process average. The ACST control chart for manual loading is out of statistical control, as there are four points (1) below the upper limits, there are several points (2) in sequence at the bottom and top of the central line, it also has two consecutive points two sigma (5) and four consecutive ones plus a sigma (6) from the central line. This process's abnormal variability is confirmed in chart S, three points outside the upper control limit and a large variance in the customer service cycle's total time. This situation can be explained by operators' fatigue, high employee turnover, trucks accumulation on the waiting list, and lack of product stock.



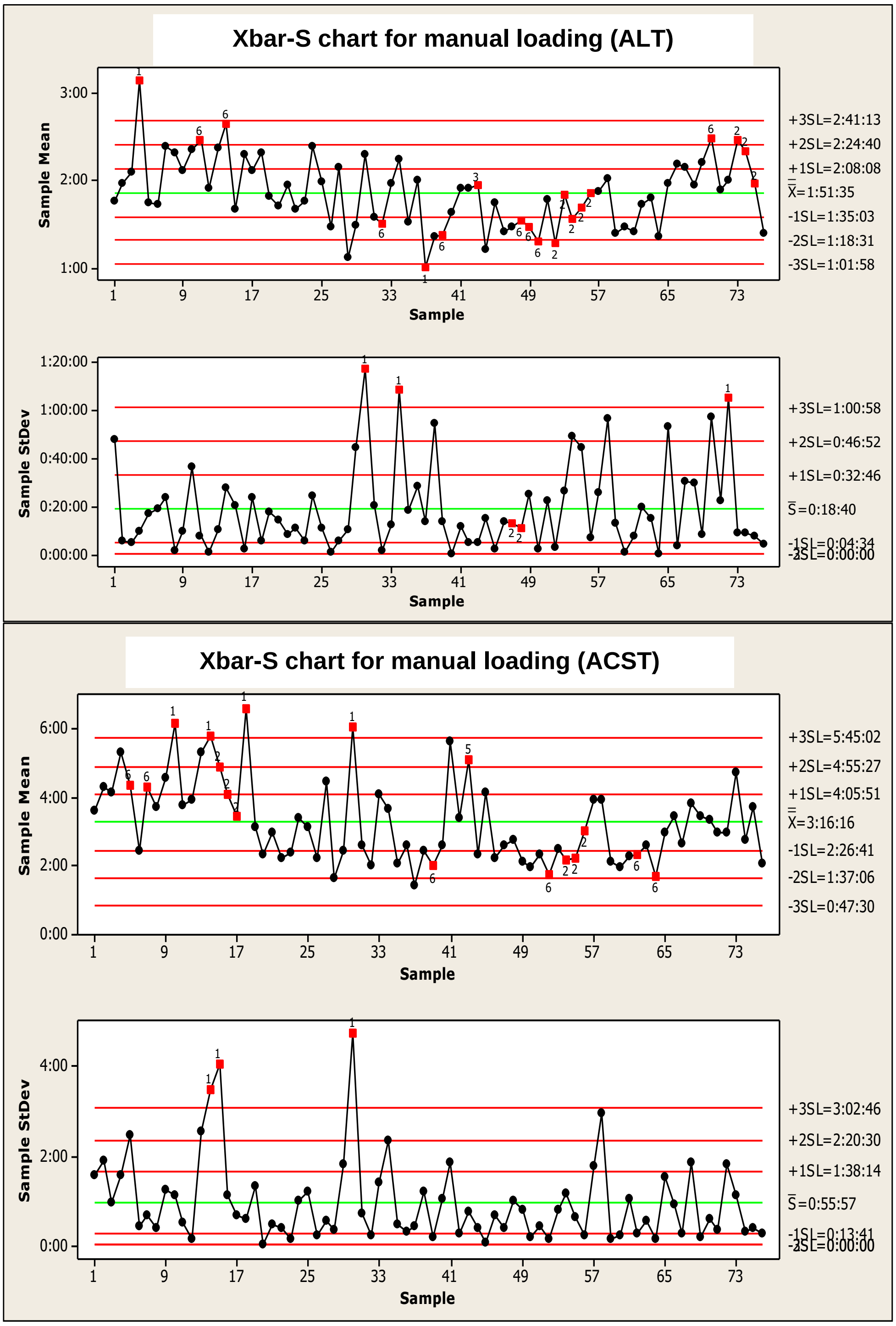


Figure 7 - Control chart for manual loading (AWT, ALT, ACST).

– Palletized loading

We collected the data and calculated the daily averages of the AWT, ALT, and ACST indexes for the six months studied. Figure 8 shows the pair of control charts for the index.

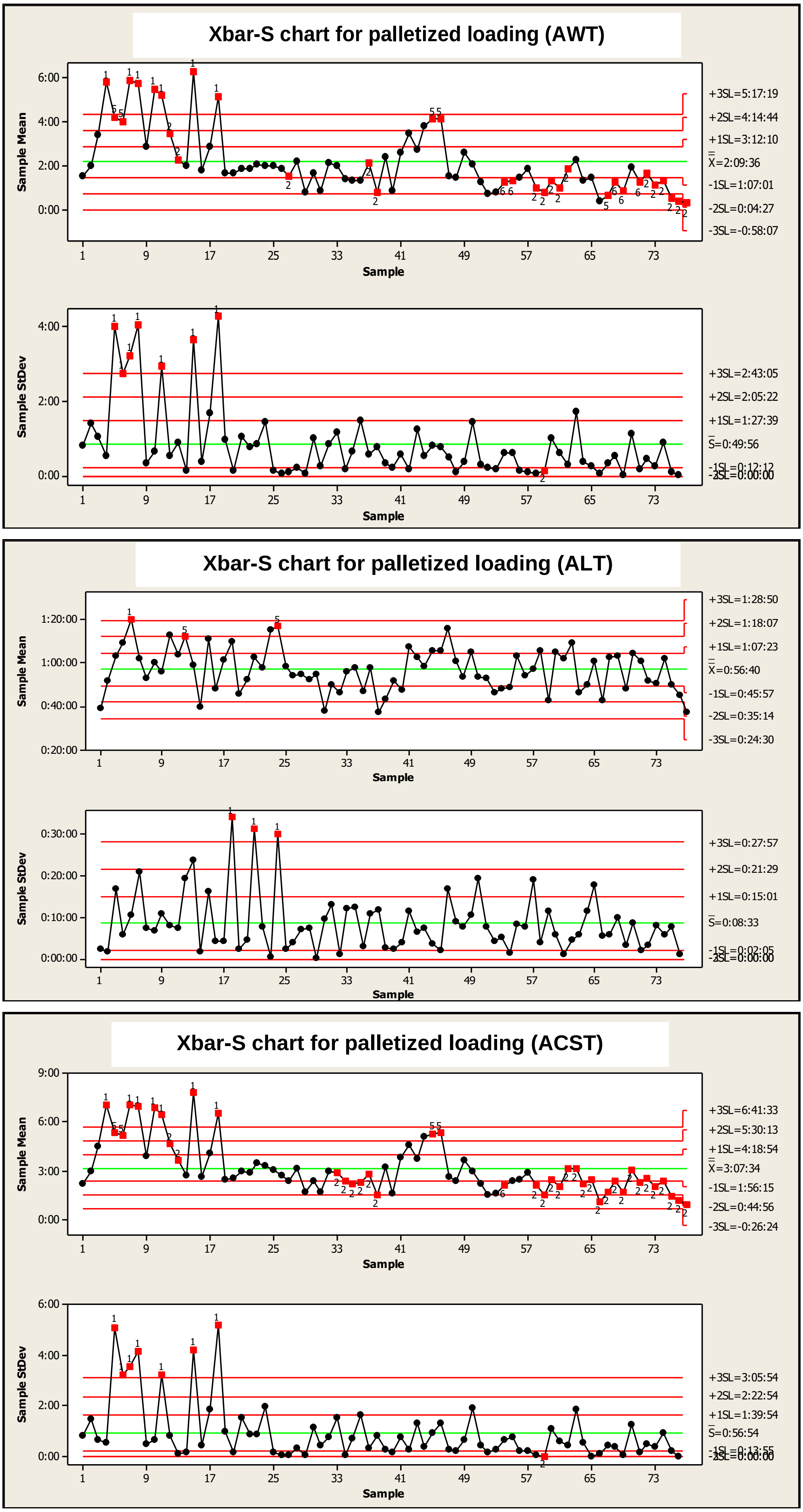


Figure 8 - Control chart for palletized loading (AWT, ALT, ACST)

The palletized AWT is out of statistical control. The $\overline{X}$ control chart shows several points that fail tests 1, 2, 5, and 6. The S chart shows seven that fail test 1, between samples 1 to 17. The factors that interfere with the waiting time for palletized loading are the lack of forklifts, increasing the loading time, and the waiting line. Other factors are mechanical or electrical defects in the palletizers and a lack of operators.

The palletized ALT chart is not under statistical control. The $\overline{X}$ control chart has points that fail tests 1 and 5. There are three points failing test 1 in the S chart, showing variability with high points followed by lows between samples 17 to 25 along of period analyzed. This case is explained by the lack of forklift and mechanical problems, pallet stock, and electrical and mechanical problems in palletizers. Palletized loading has less variability than manual and bulk loading, as it is easier to control because it presents a loading standard.

The control chart for the ACST palletized has a similar characteristic to the AWT control chart, so in the palletized loading process, which impacts the process to be out of control is the waiting time to be sent for loading. The $\overline{X}$ control chart of palletized ACST has several points failing tests 1, 2, and 5. From sample 57, data shows that the mean value may change. There is great variability in palletized loading time in the standard deviation (S) graph of samples 1 to 17, stabilizing from December 2015 to March 2016 (samples 17 to 73). This variability is due to the greater control of the loading process; even so, the Average Customer Service Time is not under statistical control due to characteristics already described in the graph.

- Unloading of materials/ supply

The inputs discharge is a determining factor for productivity in cement manufacture. They are essential raw materials in cement composition and burning energy sources such as plaster and coke. We collected the data and calculated the daily averages of AWT, ALT, and ACST indexes for the six months studied. Figure 9 shows the control charts for those indexes.

The AWT for the discharge process is not under control, because some points fail to test 1, 2, 5, and 6. Chart S is out of statistical control by presenting points that fail tests 1 and 2. The waiting time for unloading varies between 10 minutes to 3 hours. This variability is due to the most varied material and raw materials to be unloaded.

ALT Control Chart for the discharge is not under statistical control because the control chart has six points that fail tests 1 and 2. S chart presents a very large variability: four points failing test 1, and 14 points that fail test 2 because the unloading of inputs is the most varied, for example, plaster, coke, glycerin, entire, and chopped tires, thus being difficult to control in the process, and some discharges of material or raw materials be manual. The standard deviation S chart confirms the out-of-control characteristics of the graph described. The variability of samples 1 to 29 is high (from October to December 2015). This sample time is stable in the discharge inputs process.

The ACST for the discharge control graph shows points that fail tests 1, 2, 5, and 6. The control chart S exhibits points that fail tests 1 and 2. Several factors explain this situation: the lack of workers in the unloading of loads, the accumulation of trucks in the yard, mechanical and electrical problems in the equipment for unloading, such as in the unloading of glycerin in which the pumps are in trouble, saturated storage capacity, that is, silos and storage places filled with inputs. Therefore, these situations substantially impact ACST, as it causes long delays in unloading inputs.

The main index that measures the behavior of the loading and unloading process is ACST. It is the time from the truck's arrival in the company's yard to its departure to its destination. We can verify that the bulk, palletized and manual loading, and the inputs unloading are out of statistical control. This out control scenario is due to the process variability. As there are different operations, it is difficult to control the process that comprises all vehicles that enter the company's productive area, whether for loading or unloading.

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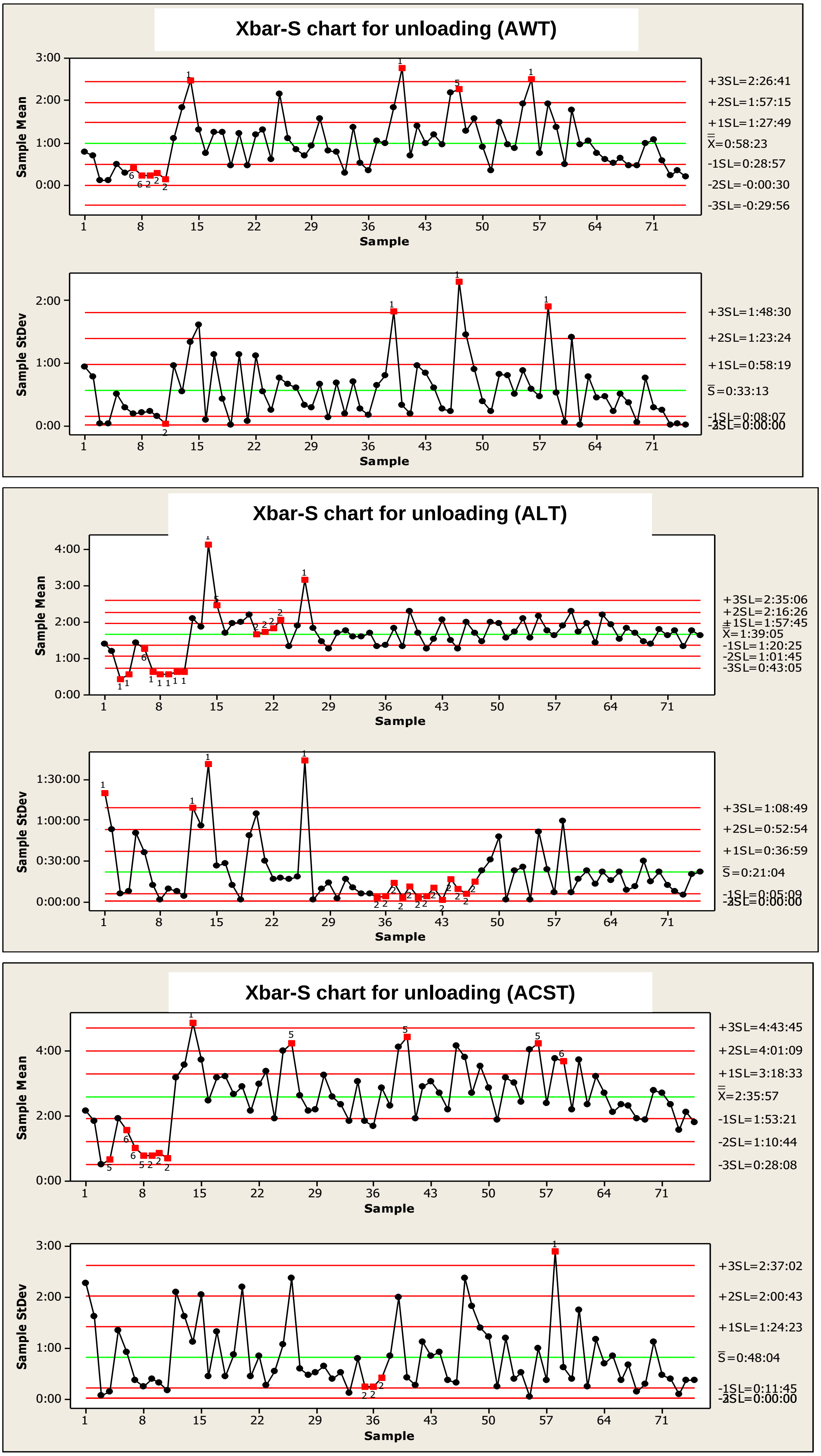

Figure 9 - Control chart of the unloading process (AWT, ALT, ACST)

4.3 Clarifying root causes for out-control and the sigma-level in the industrial case A

The loading and unloading processes for cement and raw materials presented through the control charts are all in the statistical out-control due to the characteristics described in the charts' analysis. Several factors impact the AWT, Average Loading and Unloading Time, and ACST, so it is necessary to identify root problems or failures to seek solutions or resolve them in the shortest possible time.

In cement and supplies loading and unloading, control charts appointed several indicators of flaws or problems in the company's procedures. Among the main points that can be improved or are opportunities for errors, we can highlight the following: stop for detonation in the mines of purple limestone; palletizers with problems or inoperative; bagging problems; lack of bags; truck delays in loading/unloading; bulk loading spout or trunk problems; the daily quantity of vehicles for loading/unloading; lack of forklifts; problems in the input and output balance; accumulation of trucks in the company's yard; lack of electricity; mechanical problems in the equipment; lack of cement stock; a discharge greater than the storage capacity; slow sap system; slowness in issuing invoices; lack of employees for manual loading/unloading; lack of employee training; employees without experience in the position; and adverse weather conditions.

After analyzing the control charts and the sigma level for the bulk, manual, and palletized loading/unloading process, the AWT, ALT, and ACST indexes were identified. To calculate the sigma level, use the following equations:

$$\text{DPMO}=\text{DPO}*1.000.000 \tag{10}$$

$$\text{DPO}=\frac{\text{number of defects}}{\text{number of opportunities}} \tag{11}$$

Where:
DPMO: Defects per million opportunities
DPO: Defects per Opportunities

Table 1 - Sigma level of the loading and unloading processes for Industrial Case A

Variable	Specification			Process		SPC			
	LCL (s)	Target (min.)	UCL (min.)	Average (min.)	Deviation (s)	DPMO*	Sigma level	Conformance percentual	Defects per million
Bulk AWT	0:00	1:20	1:31	0:42 s	0:18	13,057.55	3.72	97.710%	22,902.80
Bulk ALT	0:33	1:20	1:34	1:03	0:11	5,607.83	4.04	99.400%	5,995.39
Bulk ACST	0:33	1:20	2:58	1:46	0:27	7,258.95	3.94	99.041%	9,591.71
Manual AWT	0:00	1:20	3:22	1:25	0:44	30,608.57	3.37	95.573%	44,265.13
Manual ALT	1:01 min.	1:20	2:41	1:51	0:18	5,473.20	4.04	99.406%	5,944.59
Manual ACST	0:47	1:20	5:45	3:16	0:55	6,746.79	3.97	99.200%	7,999.23
Palletized AWT	0:00	1:20	5:17	2:09	0:49	4,808.39	4.09	99.432%	5,676.18
Palletizzed ALT	0:24	1:20	1:28	0:56 s	0:08	203.39	5.04	99.978%	224.82
Palletized ACST	0:00	1:20	6:41	3:37	0:56	677.26	4.70	99.800%	2,001.18
Unloading AWT	0:00	1:20	2:26	0:58 s	0:33	43,330.14	3.21	94.612%	53,877.11
Unloading ALT	0:43	1:20	2:35	1:39	0:21	7,846.07	3.92	98.870%	11,299.66
Unloading ACST	0:28	1:20	4:43	2:35	0:48	7,837.75	3.92	98.872%	11,276.26
						Unloading sigma level	3.68	97.452%	25,484.34

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Variable	Specification			Process		SPC			
	LCL (s)	Target (min.)	UCL (min.)	Average (min.)	Deviation (s)	DPMO*	Sigma level	Conformance percentual	Defects per million
						Loading sigma level	4.10	98.838%	11,622.34
						Global sigma level	4.00	98.491%	15,087.84

Table 1 shows the sigma-level performed the calculation, the DPMO (Defect per Million Opportunities) for each loading and unloading type, the sigma level, its percentage of process conformance, and the number of defects per million. They also present the sigma level for loading and unloading and the process's overall level (SNIC, 2020).

Sigma level could measure the companies' performance. Thus, most process companies practice the 3 and 4 sigma levels, corresponding to 66,800 and 6,210 defects per million opportunities (DPMO), respectively (Werkema, 2016).

The loading process, which includes the bulk, manual, and palletized processes, presented a sigma level of 4.1 with a 98.74% compliance. The discharge is working at a sigma level of 3.68 and a conform percentage of 97.45%. Industrial Case A presents a sigma level between 3 and 4. Therefore, it is within the performance standards, followed by the main companies that use the six sigma philosophy to monitor the quality of their in-plant logistics. A reduction opportunity in the cost of low quality for Case A has verified around 20% to 25% of the product's sales revenue if it reaches a process with a sigma level equal to 6.

For this reason, a cause-and-effect diagram was drawn up and used to point out the roots of the cause that affect the delay of loading and unloading, that is, that impact on AWT, ALT, and ACST. We seek to identify root problems and possible solutions in the Analysis stage, using statistical tools to analyze process performance.

The cause-and-effect diagram (Figure 10) helped identify the causes of problems that impact loading and unloading operations time. The diagram classifies the causes using the 6M (Measurements, machines, materials, methods, labor/human resources, and environment/mother nature). Among the leading causes, shown in the diagram, mechanical problems, lack of equipment such as forklifts, information flow between departments, and the number of employees are the factors that most cause delays in loading and unloading. That is, this is justified through unscheduled stoppages. Therefore, there must be a more efficient preventive maintenance program and better planning in carrying out the loading and unloading process activities.

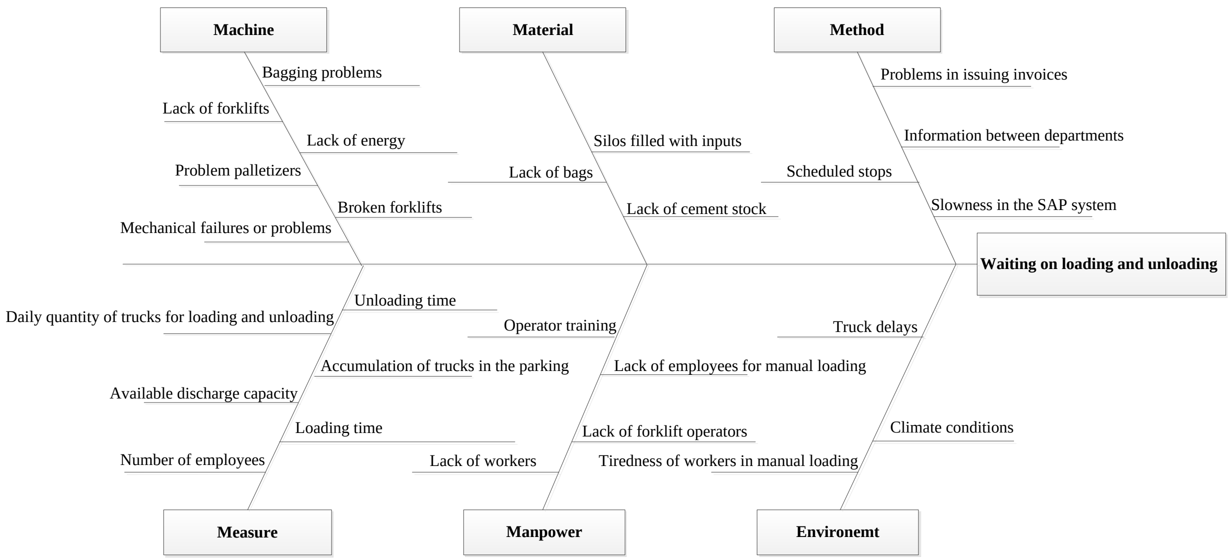

Figure 10 - Cause and effect diagram for in-plant logistics of the Industrial Case A.

4.4 Improvement step: OCAP: an action plan for industrial case A

Improvements in the loading and unloading processes will only be feasible if there is a commitment from all those involved in the system, especially the top management.

The main improvements to be made in company A are: hiring labor and constant training, carrying out preventive maintenance according to the problems history of all machines or equipment (forklifts, conveyor belts, palletizers, baggers, among others), acquisition of new forklifts, greater exchange of information between company departments, mainly between baggers and shipping, for example, if there is a problem with palletized loading, the expedition will not call the next truck for loading but instead wait to solve the problem, and if the problem is not solved it will not schedule shipments until the process anomalies are resolved.

Since the variability is high, there must be daily control of the time in its execution in the loading and unloading process. Thus, we proposed adopting an SPC chart integrated with an Out-Control Action Plan (OCAP) toward improvements. Besides, SCP and control charts only detect the out-control or under-control process. Thus, the OCAP presents the sequences of activities for eliminating attributable causes of variability and actions to solve out-of-control conditions, combating the problem's root cause, and eliminating possible rework.

The OCAP identifies the problems through the control charts, elaborated daily. With its analysis, it looks for anomalies and causes in the process. Changes are implemented in the search for continuous improvements of each point that interfere with or increase the process variability, i.e., what causes time delays for loading or unloading. Table 2 below presents a summary diagnosis of the main indicators of out-of-control points, the possible causes, and actions to solve the problems.

Table 2. The final diagnosis of the main points for improvement

Out-of-control indicators	Possible causes	Possible actions
Mechanical problems	Problems occurred in bagging due to a lack of maintenance Forklift problems due to lack of maintenance	Preventive and corrective maintenance on baggers and forklifts
Electrical problems	Lack of energy Lack of electrical maintenance	Planning for electrical maintenance
Truck delays	Poor planning or adverse conditions (rain and other unforeseen circumstances)	Carry out better planning to take into account delays
Lack of forklifts	Problems arising from the lack of forklifts and leasing it for other purposes within the company	Acquisition of new forklifts and preparation of a preventive maintenance plan
Loading capacity	Lack of planning and communication between departments	Develop ways to exchange information
Unloading capacity	Unloading greater than the stock capacity due to poorly executed plans	Better planning in unloading inputs
Lack of employees	Lack of employees to carry out activities	Hiring labor and training

4.4.1 Control step for the OCAP

The control step must implement the OCAP measurement and control plan and instruments. A key factor for the success of the action plan is training employees. As part f the control, the auditor needs to verify the correct use and maintenance of tools to seek continuous improvements in cement and raw material loading and unloading processes. At this step, the control charts must be updated to find special causes in the process.

The DMAIC tools were used to support and guide a strategic and efficient methodology for implementing an improvement plan in the cement industry. This plan can support and lead Industrial Case A to elaborate and identify problems, failures, and errors in the loading of cement and unloading materials.

5. CONCLUSION

First, our article clarifies and details a real cement production process in Brazil, establishing both a theoretical contribution to the behavior of continuous improvement tools (Six-Sigma/DMAIC), as well as evidence of the adequacy of these tools for process-based industries (bottom part of Hayes and Weelwright's 1984 product-process matrix). Secondly, regarding the practical contributions that practitioners and managers of cement industries have from our work, an empirical study shows positive results from applying the DMAIC methodology in internal logistics processes within specialized cement factories. Therefore, we realized that the application of continuous improvement tools based on Six Sigma and DMAIC are adherent to the solution of shop floor problems and the real increase in the efficiency of the cement production processes.

In the cement industry, there is a constant dependence on transport logistics, as the demand for inputs is dependent on the manufactured volume and this at the same time regulates the cement shipment flow, according to a determined demand. The most used modal is the road, justified by the small radius of cement commercialization due to its short-term validity and low value/price ratio, in addition to justifying the unique availability of this modal system type.

The indexes that measure loading and unloading efficiency were the Average Waiting Time, Average Loading Time, and Average Customer Service Time for bulk, manual, palletized loading, and unloading processes are out of statistical control. These indexes are related to the high process variability; there is no time standard for trucks to load cement and unload inputs. The points identified in the cause-and-effect diagram that most impact loading and unloading times were labor, machinery, and equipment. Based on these problems, guidelines were developed for continuous process improvement.

The processes sigma levels are within the world standard of 4 points, on a scale of 1 to 6. There is a better performance in the loading process due to this being more standardized than the discharge, i.e., in the loading are only palletized, manual, and in bulk. While in unloading, there are the most varied raw materials, such as whole and chopped tires, plaster, coke, glycerin, clay, and other general inputs. The loading process's sigma level has an average of 4.1 and a compliance percentage of 98.74%, and the discharge had a sigma level of 3.68 and a compliance standard of 97.45%.

The previous scenario implies that even in a global average of 4 points, the sigma level of Industrial Case A must be improved because when the volume produced is taken into account, and this level is compared to that of a six sigma process, the losses in profitability due to defects, failures, and anomalies are still potentially relevant, being the central concern of the present work, not only the detection and comparison of the company sigma level to that of companies in other productive sectors but the proposition and means that lead the processes and results of Industrial Case A, at the level of world-class companies, which usually have their processes or guide their strategies looking for a six sigma process, for this purpose the Improvement Plan presented was proposed.

Improvements in the efficiency of cement production processes represent for their manufacturing managers a valuable opportunity to establish a constant, balanced, routinized workflow, mainly avoiding unscheduled downtime and management guided by planning and management of the continuous process improvement.

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