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Use of Poka-Yoke to Prevent Losses in a Metallurgical Industry's Kit Packaging Process: a Case Study

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ABSTRACT

The prevention of human errors could be minimized using Poka-Yokes devices. This study aims to demonstrate the effectiveness of an electronic Poka-Yoke device through statistical data analysis of a dataset selected before and after the use of precision scales in a kit packaging process, comprising the counting and measuring of pieces of different sizes and quantities and assuring order traceability. The results showed a large fall in complaints about missing pieces over the case study's three-year period of observation, concluding that the use of the Poka-Yoke device implemented in a metallurgical company in São Paulo state, Brazil was very effective.

Keywords: Poka-Yoke, precision scales, effectiveness, statistical data analysis.

INTRODUCTION

Every society in the world aims to produce high-quality goods and services that satisfy customer requirements. There is not a single company or system, however, that never makes a mistake or never delivers a defective product to its customers. This is the great challenge that companies have to face on a daily basis: how to ensure that customers get the products and services they have specified, and how to detect possible non-compliance in quality, both in the initial phase and in the manufacturing process [22]. In this context, one practical approach to dealing with faults is the application of Poka-Yokes devices. These devices prevent mistakes from becoming a defect in operational service and being noticed by the customer. Poka-Yoke devices start from the simple idea that people do not make errors willingly, but for various reasons errors may occur and, in fact, occur involuntarily [11].

In the case study presented in this paper, the company had been getting a lot of complaints about parts that were missing from kits, caused by counting errors, which were causing customers a lot of trouble. This situation led to the implementation of an electronic Poka-Yoke device using precision scales, supported by information technology, to measure part sizes and varying quantities in the packaging and to ensure the traceability of each new customer order. The validation of this device could be based on standard existing statistical data analysis of the data observed before and after the implementation of the Poka-Yoke device.

POKA-YOKE METHODOLOGY

Poka-Yoke is a term used for a family of error-detection tools used by businesses. They were originally considered to be physical error-prevention devices. Currently this technique is defined as an anti-error device, seen as a quality control tool, or quality philosophy, whose main goal is to prevent errors [21,23]. The literature includes a large number of papers with different concepts associated with Poka-Yoke systems, such as:

- Devices that detect, correct and eliminate errors [1,9, 14].
- Procedures used to eliminate the trial and carelessly operating [7,12].
- Systems which detect and prevent the occurrence of defects [6,10].
- Poka-Yoke devices have applications in several segments, identified in the literature: for manufacturing systems [15,16], for services [20], or for software solutions [5].
- The concepts associate production stability with the use of Poka-Yoke [10,18].

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Poka-Yoke devices have been successfully used in many countries in companies operating in different areas. For example, [23] considered the use of Poka-Yoke in automotive component companies. A good review of Poka-Yoke devices is introduced by [17].

DATA SET AND INDUSTRY DESCRIPTION

The first step in this study was to collect representative samples from two families of equipments made by the company, out of a total of 150 families, considered by the organization to be important in terms of number of units sold every year. As a failsafe device deployment strategy, the two families of equipments were the first ones to pass through a precision weighing process in an attempt to reduce the quantity of missing pieces in the packaging sector. These families of equipments, denominated 15 and 17, served as a pilot test for the new production process.

This case study was carried out in a metallurgy company producing agricultural equipment with a portfolio of about 150 lines of various products. It also has a chain of reseller partners spread across different regions of Brazil and abroad, exporting to over 70 countries. The multilevel product engineering structure numbers between 500 and 6,000 items, depending on the model and size of each equipment. As a loading logistics strategy, the company adopted a system to not fully assemble some product lines within its industrial complex, with these final products being shipped fully disassembled to the customers. The company therefore needs to send out kits of the final product to be assembled. A regional technician from the resellers is sent to the customer for final assembly of the equipment, which needs interchangeable parts that are sent in a wooden box or plastic bag, as required for each product. Given this, it is essential that the packages sent out do not have any parts missing, otherwise it will not be possible to assemble the equipment at the final destination, causing huge losses to the company and a lot of trouble for the customers.

The company in this study had a problem in the component packaging stage for different equipments that are sent out in disassembled kits to customers where there was a relatively large number of components, of varying sizes. The packaging is done manually by operators in the packaging sector and there was a high probability that pieces would go missing. This caused frequent complaints from customers and additional re-dispatch costs, which was a serious problem for the company. Thus, following the Poka-Yoke philosophy, a client server architecture was proposed with two scales, one for the plastic bags and one for the wooden containers. This was classified as an electronic Poka-Yoke system to prevent the loss of pieces in the packaging process, while also ensuring the traceability of the order in the event of customer complaints.

In this way, it was proposed a Poka-Yoke device based on electronic balances to be used in the weighting process of the component parts that make up each equipment (packed in plastic bags or wooden boxes) to be sent to the clients.

The main goal associated with the problem in the company is related to the following question:

- How should a foolproof electronic device be applied to stop pieces from missing in the packaging process and which can also ensure order traceability?

The electronic Poka-Yoke was built in the following way: when the basket of parts reaches the measuring point (see Figure 1), the packing slip is read by an optical reader to automatically display the load order entry screen to be measured on the scales, as in Figure 2.

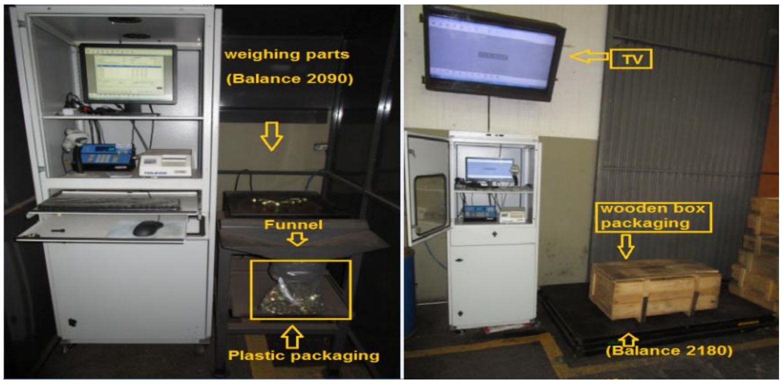

Figure1. *Use of packaging gauging points -plastic bag and wooden box*

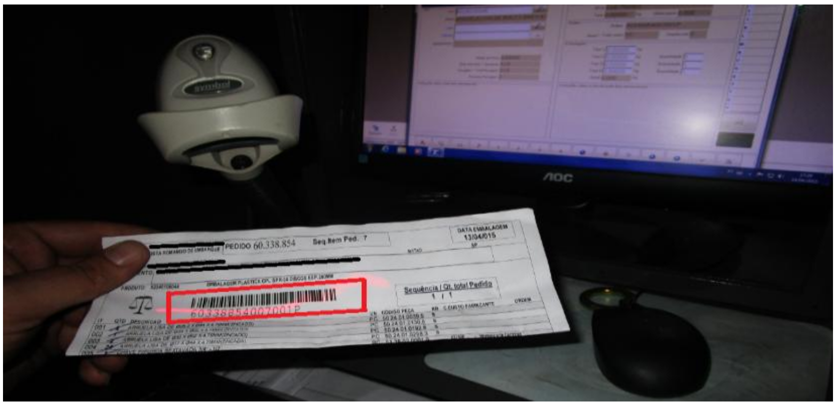

Figure2. *Optical reader to measure the load order on the scales*

On reading the packing slip bar code, the system denoted as Move Weigh System (MWS), establishes the correct sequence for the storage of parts in each type of packaging (plastic bags or wooden boxes), previously ordered in the Enterprise Resource Planning (ERP) program. This query is made in SQL-SERVER database that has each of the parts properly measured in the system (MWS). The measurement is performed in advance in this system only once for the list of component parts that make up each equipment manufactured by the industry. The interface between the ERP and MWS requires a connection between the two systems by importing and exporting data. In the exporting of data from the ERP to the MWS system, properly sorted text format tables are sent according to the loading sequence established at the time of measuring a equipment manufactured by the company. This load sequence for each piece inside the packaging is done by the dispatcher who has full knowledge of how to best store parts in each type of packaging (plastic bag or wooden box). For each piece measured in MWS there is a weighing tolerance margin around 2% to 5% to predict situations of weight differences of one piece, which can be derived from more than one supplier with unequal weights. In this way, depending on the type of component piece and the amount it is demanded to be packaged, tolerance can be changed as necessary. This system also allows every piece that goes through the scales to be identified by bar code and does not allow replacement of a specific part by another unit at the time of weighing. A preliminary procedure sequences the parts packing list within the ERP so that no pieces have approximately similar weights to each other, avoiding the erroneous replacement of a part in the automatic MWS system. In sequence at the time of weighing, with each piece weighed by the scales, the MWS system automatically advances to the next piece in the storage sequencing within each type of packaging equipment. If the expected number is not correct, the system does not allow changing of phase until the amount is corrected in the scales. The possible existence of errors is showed (see Figure 3) in the on-screen display (weights below or above) to the operator to add or remove workpieces, as appropriate. In the example, the required amount is 24 bolts, but when removing or adding one more, the system paralyzes the process with a warning sign. Once the correct amount has been obtained, the system issues an OK sign, as shown in Figure 4, and moves to the next piece automatically, and so on. Note that there is no possibility of any error in the proposed weighing process, always respecting the tolerance for each type of piece.

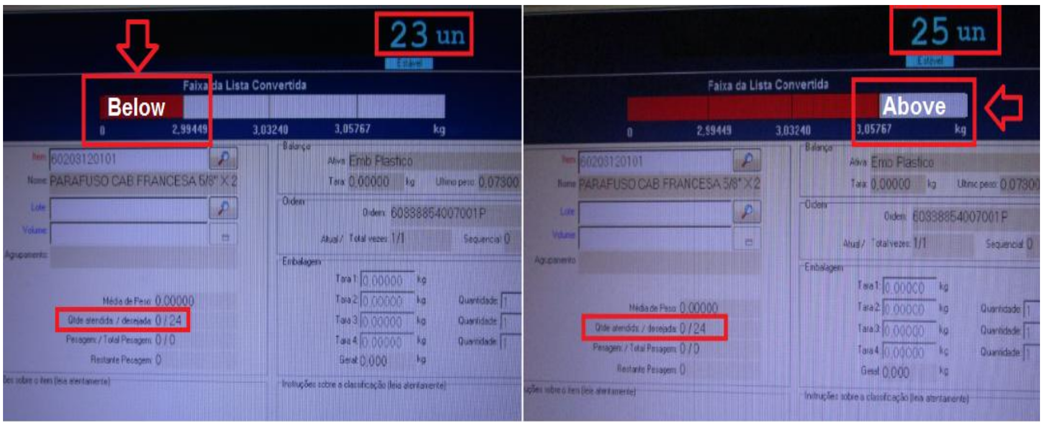

Figure3. *Digital Poka-Yoke comparing the amounts expected to the actual weighing*

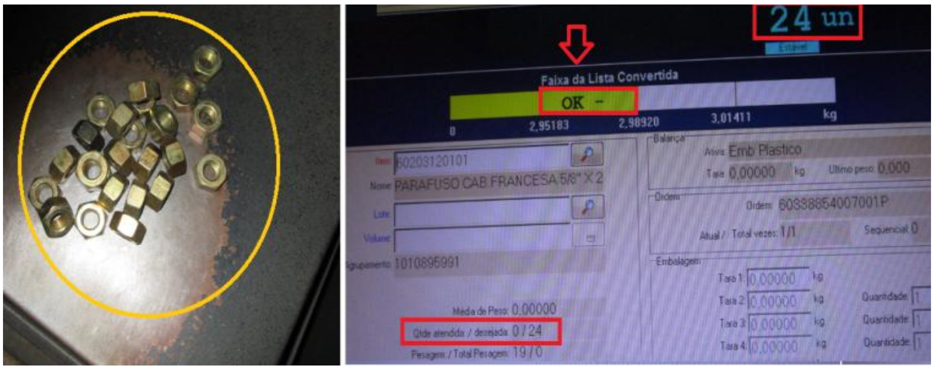

Figure4. *Digital Poka-Yoke device releasing the number of parts expected on the scales*

After the last piece has been weighted, the system automatically issues a label that traces the container measured by the precision scales, as shown in Figure 5.

DATA ANALYSIS

The dataset for this study was collected by access to the company’s report system, using specific filters to get complaints about missing parts from the two most representative families of equipment sales during the period from the year 2011 to the year 2013.

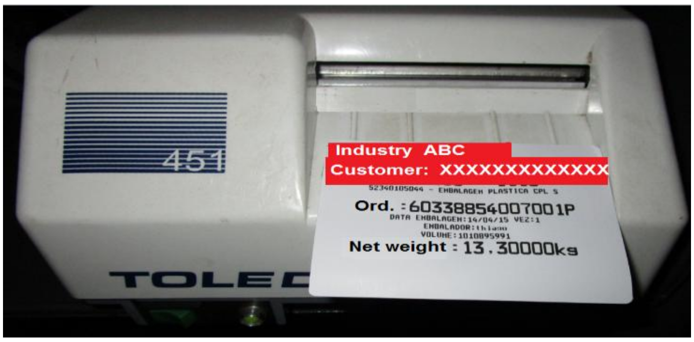

Figure5. *Label printer*

Complaints from the company’s customers about pieces missed out in the packaging process were reported between 2011 and 2013. In this three-year period, 462 units were not received by the customers. In this study, we analyzed a sample of complaints for two families of equipments produced by the company as representative of the products that were most dispatched in the period and considered to be its leading products. After 2011, some procedures were implemented under the Poka-Yoke paradigm by the company to minimize missing parts. In particular, it was proposed precision scales as an electronic Poka-Yoke device to be used in the packaging procedure for the components of each equipment before being shipped to the customer. A computer is attached to the scales and after dispatching each unit, the weight of the packaged unit is recorded as a control criterion. The data was collected for the years 2011 (before the implementation of the electronic scales), 2012 (pilot test) and 2013 (the year the electronic scales were implemented)

To observe the possible gains of using a Poka-Yoke system on the packaging line for the components of a equipment manufactured by the company, statistical analysis on several steps was carried out. There are two purposes for this statistical analysis:

- To check that the use of the Poka-Yoke system led to a decrease in the number of missing parts or no more missing parts, the final goal of the industry;
- With the collected data, to identify the factors that significantly contributed to the variability in the number of missing parts before the use of the Poka-Yoke system. Although the Poka-Yoke technique led to a satisfactory solution for the company (the main goal of this study in terms of efficiency), the statistical analysis was considered a secondary goal using regression models for detection of the most important factors affecting the variability of the number of missing parts. This result is more linked to academic interest.

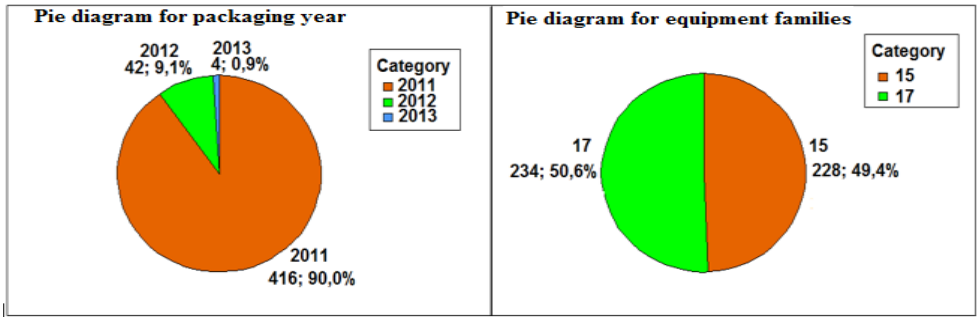

Figure6. *Pie chart for the numbers of pieces missing from each package per year and per family*

Initially a descriptive analysis of the data was carried out using standard graphical or summary descriptive measures [2,3, 4, 13].

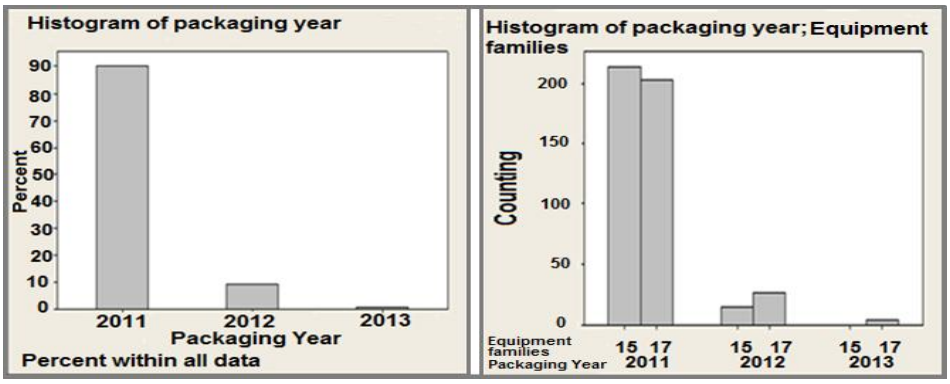

Figure7. *Histograms for the numbers of missing parts in each year and the number of missing parts in each family of equipments in each year*

Figure 6, clearly shows that after the use of the Poka-Yoke device, there was a significant decrease in the amount of missing pieces in the years 2012 and 2013 compared with 2011 (data for 2011, 2012 and 2013 given respectively by 416, 42 and 4) and that the quantities of missing parts in each family are approximately the same for families 15 and 17 (given respectively by 228 and 234). This is also observed in the histograms presented in Figure 7.

It is important to point out that the four complaints registered in 2013 (the year that Poka-Yoke system was implemented) were considered to be unfounded.

Use of ANOVA (Analysis of variance)

In this section we have used a ANOVA model with one classification for the logarithms of the counting considering the factors 'equipments' and 'equipment families. The analysis of variance was applied for the data considering the transformed count data to a logarithmic scale [log (count)] to verify some standard assumptions needed for ANOVA. With this transformation, this analysis can be very useful in checking the differences between the means for each level and for each factor (see Table 1).

Factor: equipments-log (counting)

From the results in Table 1, (use of MINITAB® software), it is observed that the means of the missing part counts in logarithmic scale for the six different equipments do not differ significantly using an ANOVA model (p-value > 0.05). Nevertheless, as the p-value is very close to 0.05 there is some indication of count mean difference in the logarithmic scale. In fact the observed sample means for the six equipment types are given, respectively by: 1.000, 6.33, 6.14, 5.20, 3.962 and 3.808 (In Table 1, DF is degrees of freedom; SS is the sum of squares; MS is the mean square; F is the Snedecor statistics; P is the p-value).

Table1. *ANOVA*

(Factor: equipments)						*(Factor: family of equipments)*					
Source	DF	SS	MS	F	P	Source	DF	SS	MS	F	P
Equipment	5	9.074	1.815	2.27	0.054	family	1	0.372	0.372	0.43	0.512
Error	92	73.667	0.801			Error	96	82.369	0.858		

Factor: family equipment-log (counting)

The results in Table 1 also show that the mean counts of missing parts in logarithmic scale for the families of products 15 and 17 are not significantly different using the ANOVA model (p-value > 0.05).

Use of Multiple Regression analysis

In this section, a multiple regression analysis for the dataset is introduced in order to study the joint relationship between the response variable (counting of missing components) with some covariates, such as packaging years, equipment families and type of equipments. A multiple linear regression with normal errors is assumed considering the response count transformed to a logarithmic scale. Figure 8 shows the plots of the response count for missing parts compared with some covariates or independent variables (factors) that may affect the response (count). As the type of equipment is a qualitative variable, some dummy variables or indicator variables are introduced, used for categorical covariates [8]. These factors or covariates are:

- X_1: packaging years: 2011, 2012 and 2013.
- X_2: equipment families: 15 or 17.
- X_3: indicator variable for XRIXTCR equipment (equal to 1 for XRIXTCR equipment and zero for other equipments). (1)
- X_4: indicator variable for XRI14DSC equipment (equal to 1 for XRI14DSC equipment and zero for other equipments).
- X5: indicator variable for XRI16DSC equipment (equal to 1 for equipment XRI16DSC and zero for other equipments).
- X6: indicator variable for XRSG equipment (equal to 1 for equipment XRSG and equal to zero for other equipments).
- X7: indicator variable for XRSG14DSC equipment (equal to 1 for equipment XRSG14DSC and zero for other equipments).

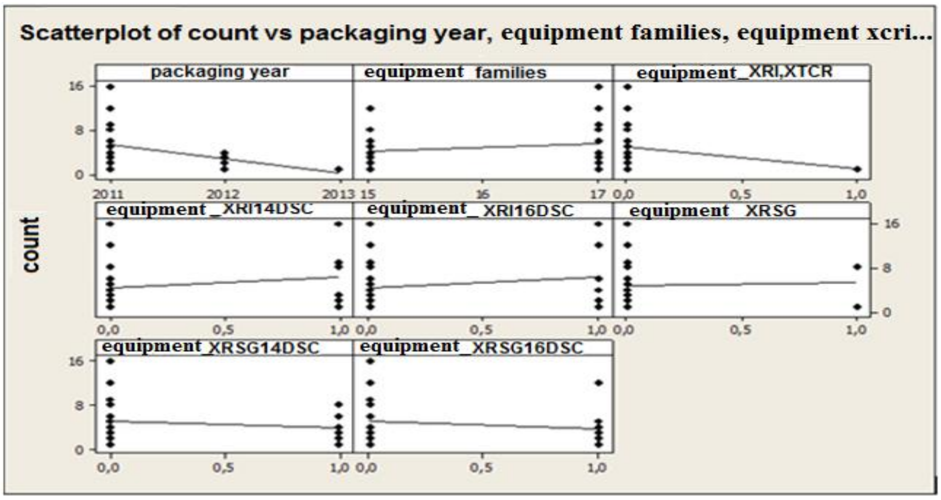

Figure8. *Response graphs for the count of missing parts against some covariates*

Equipment XRSG16DSC was taken as a reference to be compared with the other indicator variables. The graphs in Figure 8 show that all the covariates have some effect in response to the counting of missing parts in the package. To check the effects of these covariates in the response (number of missing parts) a multiple linear regression model was used.

Linear regression models are often fitted using the least squares approach. When using more than one explanatory variable to predict the behavior of a variable response, we denote it as a multiple regression model [8]. In linear regression analysis the overall effect of covariates on the response Y is verified [8, 19, 13]. To satisfy some assumptions needed for the regression model (normality of errors and constant variance) it was assumed a multiple linear regression model with the response given in the logarithmic scale was considered.

Thus, the following regression model in response y_i = log (count of missing parts) is considered:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \epsilon_i \quad (2)$$

in which, X_1, X_2, X_3, X_4, X_5, X_6 e X_7 are defined in (1); ε_i are random errors assumed to be independent, with a normal distribution with zero mean and constant variance σ^2, i=1,2,…,98.

The least squares estimators of the coefficients of the regression model (2) are obtained using the MINITAB® software, version 16, from where we get the following fitted model:

log (count) = 1743,2 - 0,865 year (pack) - 0,123 equipment. families

- 0,782 equipment (XRIXTCR) + 1,12 equipment (XRI14DSC) + 0,919 equipment (XRI16DSC) + 0,219 equipment (XRSG) + 0,379 equipment (XRSG14DSC) (3)

Table 2 presents the summary of the obtained inferences (least squares estimators and p-values to test whether the regression parameters are equal to zero) obtained for this model (In Table 2, LSE is least square estimate; SD is standard deviation of the coefficient; T is the Student statistics; P is the p-value).

Table2. *Least square estimates, Student's t statistics and p-value*

	LSE	SD Coef	T	P
Intercept	1743.2	332.3	5.25	< 0.000
Packaging Year	-0.8654	0.1654	-5.23	< 0.000
Equipment Families	-0.1229	0.2375	-0.52	0.606
Equipment XRIXTCR	-0.7824	0.6366	-1.23	0.222
Equipment XRI14DSC	1.1229	0.5111	2.20	0.031
Equipment XRI16DSC	0.9188	0.5265	1.74	0.084
Equipment XRSG	0.2194	0.3853	0.57	0.570
Equipment XRSG14DSC	0.3793	0.2283	1.66	0.100

Through the results in Table 2, the significant covariates in the amount of missing parts (p-values less than 0.05) are observed as follows: packaging year and equipment XRI14DSC. Considering a significance level of 0.10, we would also have the significance of another covariate: equipment XRI16DSC (p-value less than 0.10). The necessary assumptions for the validity of the statistical model (normality and constant variance for the errors) was verified from standard residual plots given automatically by the MINITAB® software.

CONCLUDING REMARKS

The Poka-Yoke fault-prevention device that arose from the Zero Quality Control (ZQC) philosophy could be of great interest to companies. This technique focuses on the central idea that human errors are inevitable to some extent. These preferably inexpensive devices or simple systems are included in the process to prevent errors caused by a lack of attention by workers. Using this principle in the implementation of electronic scales in the packaging area of a metallurgical company, significant gains in minimizing missing components from customer orders were achieved, as shown in the dataset in each year and from different statistical analysis of the data.

It is important to emphasize that this work, given its originality and relevance, contributes to innovation when using an electronic Poka-Yoke system to verify missing pieces in a packaging process using precision scales.

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