A Systematic Analysis of an Industrial Pick-Up & Placement Production System

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Abstract. Surface-mount technology is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of printed circuit boards. The purpose of this study was to analyze nozzle change in two production lines. Following a previous study, it was proposed that one type of nozzle would place resistors while another type of nozzle would place capacitors, contrary to what happened in the initial process, where the two placed both components. However, the change of nozzle was not done globally, but only applied to two specific types of capacitors that were more critical. Even so, the positive effect of this change was globally visible, both in the decreased number of component rejection and in the reduced number of component defects in the printed circuit boards. It was also possible to estimate the percentage saving and the expected growth from this new implementation. The data were validated using statistical analysis. Finally, the current cleaning periodicity of the nozzles was examined in order to verify if it was compromising their performance.

Keywords: Defects, Rejection, Printed Circuit Boards, Nozzles, Surface Mount Technology, Statistical Analysis.

1 Introduction

It is very important in an industrial environment to minimize all types of failures in the process of surface-mount technology (SMT) for obtaining reliable printed circuit boards (PCB) in order to make this process faster, more cost-effective and more reliable. This can only be achieved after an analysis of the problem and the subsequent implementation of possible solutions [1].

Through the analysis performed in the paper [2], it was found that 0402 components (capacitors and resistors) presented deviations of relief and shape between suppliers. These non-conformities caused vacuum losses during the insertion process. Some preliminary tests were then performed in order to perceive their behavior during placement. It was concluded, firstly, that the nozzles previously used by the company were not the most adequate and, secondly, that to achieve a better performance, both regarding component rejection and defect production in PCBs, the 925 nozzle should be used for the placement of capacitors and the 907 nozzle for resistors [2].

In the context of surface-mount technology, a nozzle change in the placement process has direct consequences on component rejection and on the product's final quality, which may have more or less defects. Therefore, it is of utmost importance to carry out comparisons and data analysis, before and after nozzle changes, in order to conclude whether it is really advantageous to make a nozzle change. Additionally, it is essential to understand the relationship between rejection and defects in order to conclude which one is more prevalent in the final product.

This study was carried out in partnership with Bosch Car Multimedia Portugal S. A, a company located in the northern city of Braga dedicated to the development and production of communication, entertainment and instrumentation systems and safety sensors for the automotive industry [3].

The objectives of this study are:

- To organize rejection and defect values before and after nozzle change;
- To compare the damage caused by defective components with that caused by those rejected;
- To analyze post-alteration productivity growth;
- To prove that preventive maintenance of the nozzles has a positive impact on rejection.

2 SMT Process

2.1 Placement of electronic components

In SMT, machines are able to pick up several components and place them sequentially on each PCB. These machines are very flexible and can place a wide range of different components at high speeds. Some physical parameters as speed, acceleration, inertia, forces, torques and other similar ones are of upmost relevance in this process. Combined with this, the configuration and the high level of automation make it easier to operate them for different productions. The automatic placement machines (Figure 1) are called pick & place machines. However, the handling of components, usually by vacuum, is not always fully effective and hence the need to know this operating procedure better. On the other hand, component size and variability make this procedure critical.

Fig. 1. Automatic placement machines.

Rejection. During automatic insertion it is normal for some components to be rejected as several of them are placed at very high speeds in a short time. Therefore, it is important to ensure minimum rejection values to achieve high productivity.

There are several reasons for a component to be rejected, the main one being vacuum loss in the case of 0402 components (as shown in Figure 2).

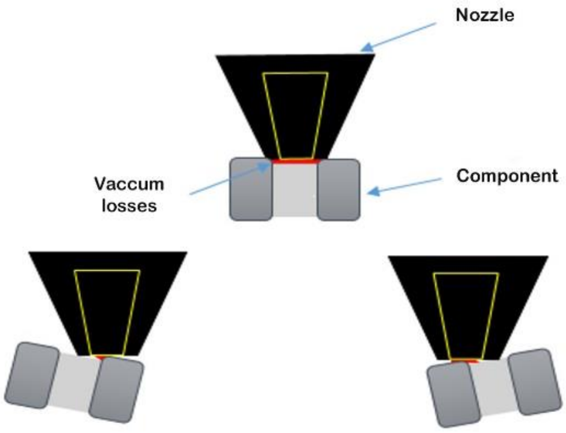


Fig. 2. Figurative example of pick-up in various positions for 0402 capacitors, in this case for a nozzle with a round cavity type.

2.2 Automated optical inspection (AOI)

This process inspects possible errors in the arrangement of components via an image analysis algorithm: the board's data file is compared with the actual board by checking the components placed on the pads. Only AOI allows a SMT line to operate at maximum capacity. In fact, without this process the operator would not be able to follow the production in the same way and the probability of error would be higher. The AOI process checks whether the solder paste deposits on the PCB are suitable and also the position of the components. An example of this process is shown in Figure 3.

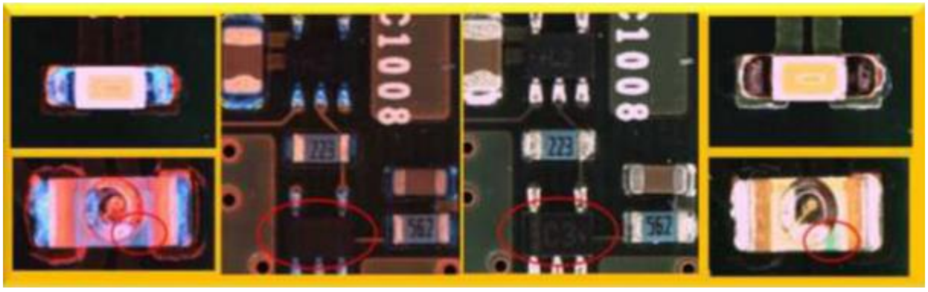
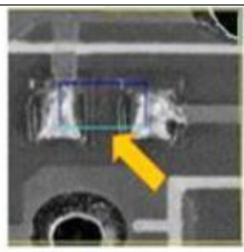
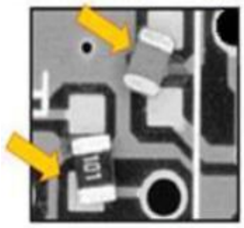
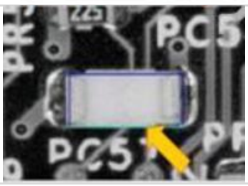
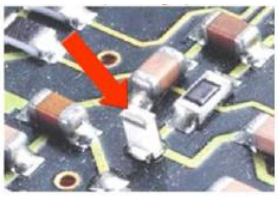
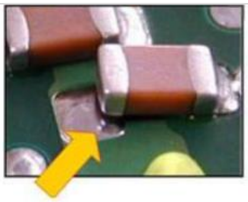
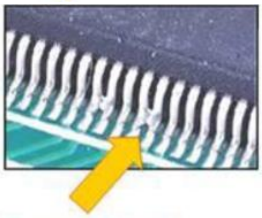
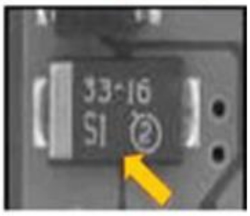
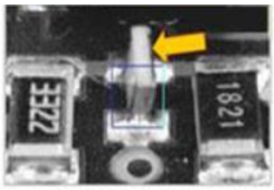


Fig. 3. Representation of the AOI check, where two welding errors and missing components are visible [4].

Defects. A number of errors can usually occur and the AOI is able to identify them. Some examples are presented in Table 1.

Table 1. – Most common types of defects detected in the AOI on PCBs [5].

Quality – Defects	
Missing component	
Component moved/misaglined	
Upside-down	

Quality – Defects	
Tombstone	
Incomplete solder joints	
Bridges or shorts	
Polarity changed on component	
Billboarding	
Components’ terminals bent	

These errors can be determined at inspection speeds of 150.000 cph (components per hour). The operator is essential to validate the presence of errors on the PCB when the remote control classifies the board as bad or possibly bad, in which case the board does not proceed to the unloader. It is up to the AOI programming team to optimize the production program in order to reduce the number of "pseudo-errors" and make the process as fast and assertive as possible [6]. These errors are critical to the company's productivity because they represent considerable costs if they are only detected after the complete manufacture of the PCBs. The competitiveness in the sector is strong, with minimal margins, requiring zero defects to achieve economic profitability.

2.3 Maintenance

According to British standard EN 13306 [7], maintenance is defined as the combination of all technical, administrative and management actions that during the life cycle of a given component are intended to maintain it or restore it to a state where it can perform the desired function, ensuring the best functions of quality, safety, cost and availability [8]. In the diagram in Figure 4 it is possible to observe the branches of maintenance.

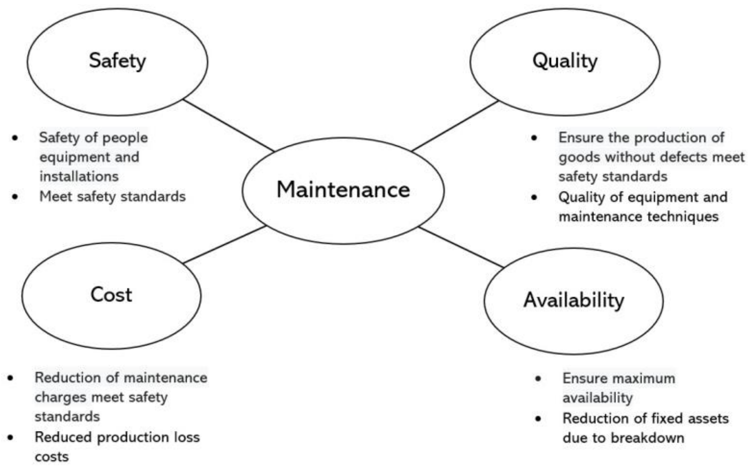


Fig. 4. List of maintenance functions, adapted from [9].

In order to maintain a well-planned organizational structure, it is necessary to differentiate some types of interventions. For this study, the most relevant two are corrective maintenance and preventive maintenance. The main difference between the two is the moment of intervention: while in corrective maintenance the order of intervention is given after the occurrence of a failure or malfunction, the preventive maintenance is done before the machine shows that same failure, because it is planned in advance [8].

2.4 Growth rate

Using formula (1), which represents the uniform growth rate [10], it is possible to estimate the uniform annual growth of a product or event. This value is obtained by calculating the difference between the present value and the past value and the respective quotient of its result by the past value divided by n, which is the period of time used.

$$\text{Growth rate} = 1/n*(\text{Present value} - \text{past value})/\text{past value}. \quad (1)$$

3 Case study

3.1 Post-test changes

According to previously obtained data, it was concluded which nozzles under study would be more suitable for the placement of 0402 components: the 907 nozzle is optimal for resistors and the 925 nozzle for capacitors [2]. The geometry of the two nozzles is visible in Figure 5.

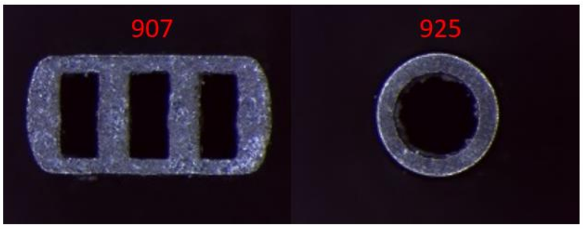


Fig. 5. Microscopic photography of nozzles 907 and 925.

Although it was not possible to make a global change, it was determined that nozzle 925, optimal for capacitors, would be guaranteed to place two critical components. As for the remaining components, as there was no restriction, they could be placed indifferently via nozzles 907 and 925.

However, with this condition defined, the system optimizer of the machine will tend to make the process as quick and simple as possible. Thus, as these components enter into most productions, both the resistors and other capacitors will tend to be placed with nozzle 925 rather than with nozzle 907, as the 925 one will have a wider range of options in the system.

3.2 Data analysis

Several statistical analysis were performed to analyse the data. The statistical package Excel 2016 was used for data entry and graphic construction, while R 3.4.0 was used for data analysis. Considering the nature of the data, non-parametric hypothesis tests were applied to verify if nozzle changes produced significant improvements in the process by comparing performance indicators for two distinct months.

Parametric tests are based on quantitative or even dichotomous measures (proportions), and the use of this type of test requires continuous variables, usually the assumptions of Normal distribution, and homogeneity of variance. In case of failure of at least one of these requirements for the application of these tests, non-parametric tests should be used [11].

In this study, due to nature of the observed variables and their respective distributions, the non-parametric Mann-Whitney-Wilcoxon hypothesis test was performed. This test is applied when comparing outcomes between two independent populations, in order to detect if the distributions are equal or to detect changes in location (median).

Statistical test results use a significance level of 5% to distinguish "statistically significant" from "statistically non-significant" changes.

Monthly analysis in production. An analysis of 0402 capacitors and resistors was performed in two different months in 2019, before and after the changes made, and quality defects, rejection in automatic insertion and the impact on the level of costs and growth with the combination of the previous factors were evaluated. The month before the changes will be designated A and the month after the changes will be designated B. The data were collected in two different production lines: line 21 and line 25.

Rejection in automatic placement. In line with the findings of [2], the graph in Figure 6 suggests that, in fact, nozzle change in the machine system led to a reduction in the percentage of capacitor rejection, both by analyzing the production lines separately and as a whole. However, at a 5% significance level of there is no statistical evidence that the location measurements for months A and B on line 21 are different (test statistic W = 42, p-value = 0.183), i.e., the nozzle change did not result in significant changes in the rejection of capacitors on that line. On the other hand, the results for line 25 show that the median of month A is higher than the median of month B (test statistic W = 620, p-value = 0.002), thus confirming the suspected improvement in the process. By looking at the two lines as a whole, there is also a significant decrease in the percentage of capacitor rejection (test statistic W = 919.5, p-value < 0.001). Besides, with this change, the rejection percentage is positioned below the target set by the company (0.114%), contrary to what happened before the change was introduced.

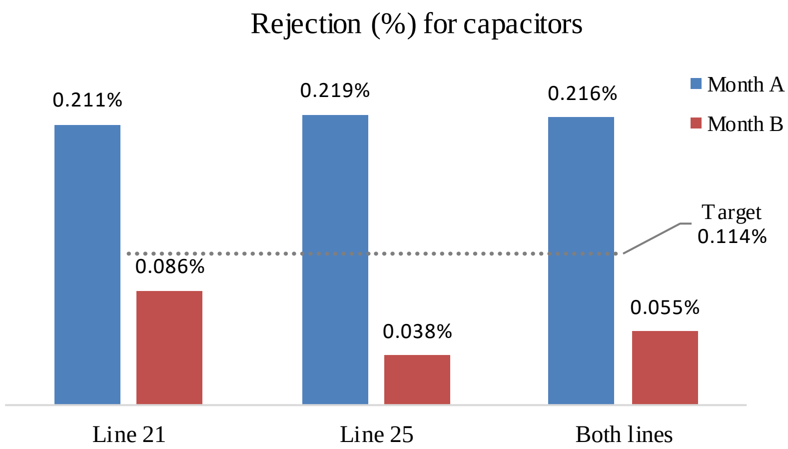


Fig. 6. Rejection (%) of 0402 capacitors depending on the line in which they were placed, for months A and B, and their respective target.

In the case of resistors, the graph in Figure 7 shows an increase in the percentage of rejection from month A to month B in the various situations under analysis. As for the capacitors in line 21, the differences in the location measurements for months A and B, regarding the rejection of resistors, are not statistically significant (test statistic W = 33, *p*-value = 0.061). For the remaining situations under study, when the rejection percentages for the two months are compared, the assumptions of rejection aggravation are corroborated by the results of the non-parametric Mann-Whitney-Wilcoxon hypothesis tests. Indeed, at a 5% significance level of there is statistical evidence that the median of rejection percentage in month A is lower than the median of rejection percentage in month B, both in line 25 (test statistic W = 583.5, *p*-value = 0.007) and in an overall analysis of the two lines under study (test statistic W = 909.5, *p*-value = 0.002), i.e., nozzle change negatively affects the placement of resistors. In fact, as mentioned in 3.1, the most suitable nozzle for the placement of resistors would be 907 and not 925, whose use has become more recurrent. With this change, the percentages of resistor rejection moved further away from the target defined by the company (0.202%).

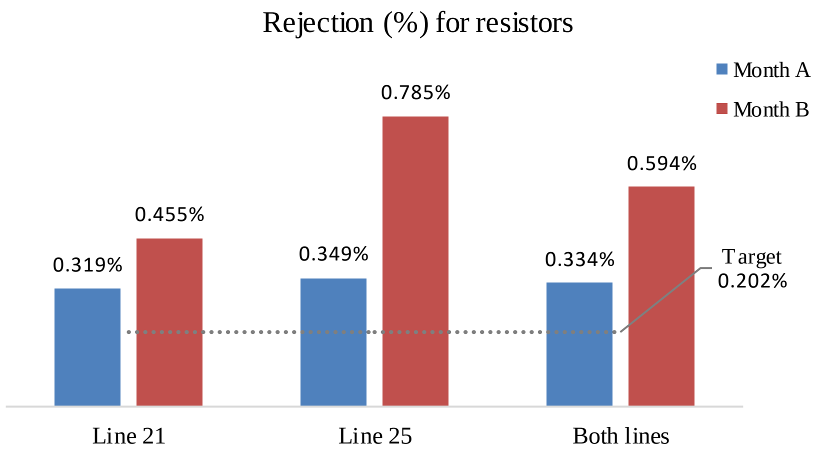


Fig. 7. Rejection (%) of 0402 resistors according to the line on which they were placed, for months A and B, and their respective target.

Product quality defects. Regarding quality, the number of defects in EDT (portion of a PCB) caused by 0402 capacitors and resistors were reduced, as suggested by the graph in Figure 8.

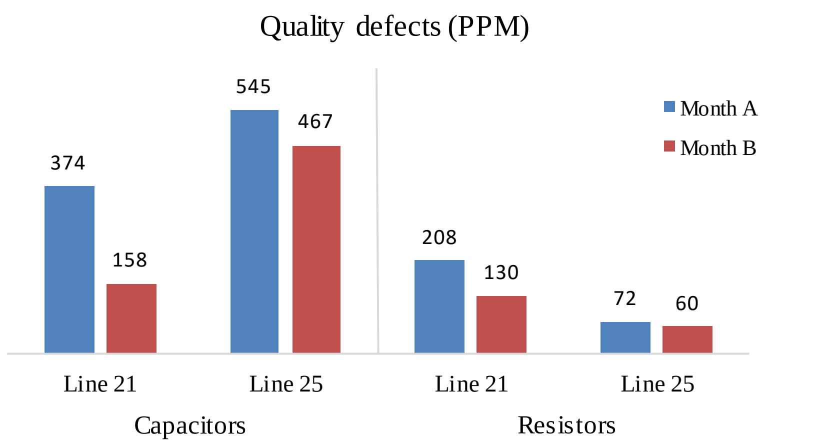


Fig. 8. Quality defects (PPM) in 0402 capacitors and resistors, depending on the line in which they were placed, for months A and B.

In the case of capacitors, the number of defects has increased from 374 PPM to 158 PPM on line 21 and from 545 PPM to 467 PPM on line 25, from month A to month B, respectively. Despite the worsening of resistance rejection, it is also possible to observe a reduction in the number of defects caused by them, from 208 PPM to 130 PPM on line 21 and from 72 PPM to 60 PPM on line 25.

Monetary impact. The monetary impact of this reduction is important and it is possible to analyze the level of rejection in placement and quality defects. The 0402 components are inexpensive components and are purchased in large quantity rolls; hence their loss in thousands of rejects is negligible.

Quality defects may refer to EDT scrap. Components with shape 0402 are repairable, except when the product is repair-free, i.e., when components poorly placed on the board cannot be repaired. This implies damage to the board itself, together with the other components making the losses more significant. In addition to these consequences, there is also a decrease in productivity, which becomes a monetary loss, since the machines have to work to compensate the loss. In this particular case, on lines 21 and 25 all products are repair-free, which makes the analysis of losses more simplistic. In order to estimate the percentage growth of productivity from one month to the next, Formula (1) was applied, listed in 2.4.

In this case, as we are working in months, we will estimate the monthly growth between month A and B, so variable n will take value 2. As the present value (month B) is lower than the last value (month A), because it translates monetary loss, the results will be transmitted in absolute value.

Through the data represented in the graph of Figure 9 it can be seen that there was an improvement from month A to month B, in both lines, for capacitors and resistors.

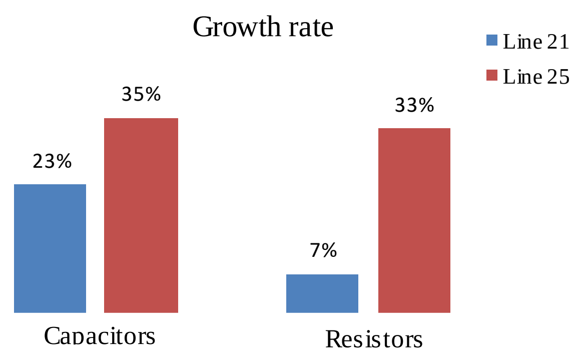


Fig. 9. Representation of growth figures (%) between months A and B according to the line and type of component.

In the case of capacitors, on lines 21 and 25 there was an improvement of 23% and 35% from A to B on the respective lines. In the case of resistors, there was an improvement of 7% and 33%. In short, in the case of resistors the savings were not as high as in capacitors, and it should be noted that much of this growth is due to the visible improvement in quality after nozzle exchange, not least because in the case of resistors there was an increase in rejection. Therefore, it is concluded that, in terms of costs, the values associated with rejection in the case of 0402 components are not as significant as those of quality.

Impact of preventive maintenance on 0402 capacitor rejection. Through the daily rejection data, the impact of maintenance on the production of 0402 capacitors was also analyzed. In this analysis, only preventive interventions, previously programmed, were considered, since the corrective ones are casual and sporadic, as previously mentioned. It should be noted that one of the interventions carried out is nozzle exchange, on a weekly basis, and hence it is possible to estimate the impact caused.

For this purpose, month C (month after all the changes) was then analyzed, taking into account all the previous assumptions.

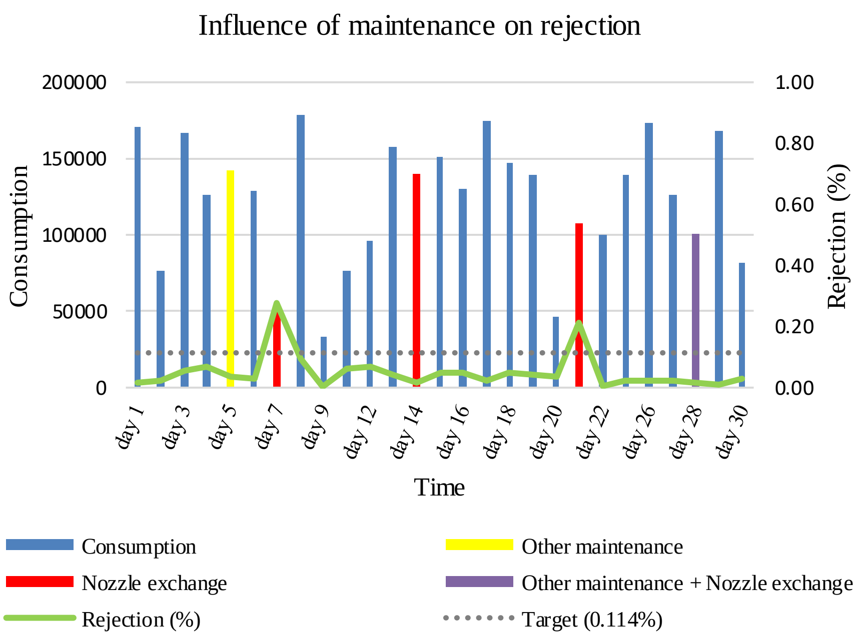


Fig. 10. Influence of maintenance on rejection in month C in relation to material consumed and rejected.

Figure 10 suggests a certain tendency to rejection decrease after maintenance, and this is most evident in the last nozzle change, where rejection remains below target. In fact, during successive productions the nozzles may accumulate dirt from dust and even slag, and fragments of the components themselves, so it is concluded that nozzle exchange, in the case of 0402 capacitors, should be performed weekly.

4 Conclusion

In short, the use of the 925 nozzle option for two critical 0402 capacitors and 907 and 925 nozzles for the remaining 0402 components was found to be positive in terms of placement costs, productivity and quality.

The monthly general analysis proved a significant improvement in the placement of capacitors, from 0.216% in month A to 0.055% in month B, and a worsening of resistor rejection, the latter explained by the high probability of using the 925 nozzle to the detriment of others. In terms of quality, there was a decrease in the number of defects, both for capacitors and resistors. Furthermore, by relating the rejection costs to the quality costs, it can be stated that the proposed changes resulted in a positive growth rate of around 23% and 35% for capacitors and 7% and 33% for resistors for lines 21 and 25, respectively.

Finally, the impact of nozzle maintenance on component rejection has been studied and was verified a reduction in rejection on the date immediately following their change, and it has been concluded that this change should be carried out weekly so as not to compromise production.

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References

1. Popkova, E. G., Ragulina, Y. V., Bogoviz, A. V.: Industry 4.0: Industrial Revolution of the 21st Century. 1st edn. Springer (2019).
2. Silva, L.: Pick-Up & placement improvement. *In Portuguese*. Master Thesis. University of Minho (2019).
3. Bosch Homepage, https://www.bosch.pt/a-nossa-empresa/bosch-em-portugal/braga/, last accessed 2019/05/13.
4. U.S.-Tech Homepage, http://www.us-tech.com/RelId/1122151/ISvars/default/MIRTEC_Europe_to_Display_the_Revolutionary_MV-9_2D_3D_AOI_Series_at_SMT_Hybrid_Packaging.htm., last accessed 2020/04/05.
5. M.I.S. Electronics Inc. Homepage, http://www.miselectronics.com/PCB-AOI-Testing.html, last accessed 2020/04/21.
6. Angel, J.: Chips – open or wrapped. Production Engineer London 68(1), 17-19 (2018).
7. Maintenance – Maintenance Terminology: EN 13306. (August 2010). EN 13306:2010. UK: British Standards Institution.
8. Ben-Daya, M., Duffuaa, S. O., Raouf, A., Knezevic, J., Ait-Kadi, D.: Handbook of Maintenance Management and Engineering. 1st edn. Springer (2009).

9. Monteiro, A.: Fiabilidade de Equipamentos na Indústria Automóvel Disponibilidade e Manutibilidade. Gestão Técnica de uma Linha de Produção. *In Portuguese*. Master Thesis. University of Porto (2000).
10. Planning Analysis: Calculating Growth Rates, https://pages.uoregon.edu/rgp/PPPM613/class8a.htm, last accessed 2020/05/03.
11. Corder, G. W., Foreman, D. I.: Nonparametric Statistics. A Step-by-Step Approach. 2nd edn. John Wiley & Sons (2014).