BUSINESS INTELLIGENCE AS AN INTEGRATION TOOL FOR FAULT DETECTION OF THE BOARD ASSEMBLY PROCESS

https://doi.org/10.56238/sevened2024.037-148

Elisete da Silva Paixão[1], Paola Souto Campos[2] and Hellen Lima Leite Alves[3].

ABSTRACT

The plate assembly process in the company in question has a stipulated goal of 2000 plates per day, and 10% of this production has failures in the process, bringing a compromise to the goals defined by management. In view of this problem, the present study aims to implement an intelligent system for identifying and correcting failures in the process of board assembly, based on Business Intelligence, aiming at the evolution of Industry 4.0 practices. The methodology was based on Process Mapping, Analysis of Requirements for Implementation of the Integrated System. The integrated system allowed communication with other systems in the production process more quickly and effectively, bringing the most assertive information possible for the performance of usability and data security. The implementation of an intelligent system for detecting and correcting failures in the board assembly process, with the support of Business Intelligence tools, represented a significant step towards the evolution of Industry 4.0 practices.

Keywords: Process improvement. Integrated system. Optimization. Industry 4.0.

[1] Bachelor of Science in Accounting
Student of the Postgraduate Course in Engineering, Process, Systems and Environmental Management at the Galileo Institute of Technology and Education of the Amazon (PPG. EGPSA/ITEGAM). Avenida Joaquim Nabuco, No. 1950. Center. Manaus-AM. ZIP CODE: 69.020-030. Brazil.
E-mail: elisetepaixao072@gmail.com
ORCID: https://orcid.org/0009-0000-2230-7386
Lattes: http://lattes.cnpq.br/4423813330383508
[2] Dr. in Biological Diversity
Professor of the Postgraduate Course in Engineering, Process, Systems and Environmental Management at the Galileo Institute of Technology and Education of the Amazon (PPG. EGPSA/ITEGAM). Avenida Joaquim Nabuco, No. 1950. Center. Manaus-AM. ZIP CODE: 69.020-030. Brazil.
E-mail: pscampos@gmail.com
ORCID: https://orcid.org/0000-0003-4827-0619
Lattes: http://lattes.cnpq.br/6414810834266975
[3] Master in Engineering, Process Management, Systems and Environmental
Professor of the Postgraduate Course in Engineering, Process, Systems and Environmental Management at the Galileo Institute of Technology and Education of the Amazon (PPG. EGPSA/ITEGAM). Avenida Joaquim Nabuco, No. 1950. Center. Manaus-AM. ZIP CODE: 69.020-030. Brazil
E-mail: jandecy.cabral@itegam.org.br
ORCID: https://orcid.org/0000-0002-9194-1628
Lattes: http://lattes.cnpq.br/3447651144220175

INTRODUCTION

Currently, there is a certain industrial competitiveness in which it requires companies to be able to produce in the most efficient way, in the shortest time, and with the highest quality (Javaid, 2022). Losses at any stage in production processes can make any production line unfeasible and waiting for failures to occur to be able to intervene, it may be too late to maintain the viability of the production process (Dos Santos et al, 2022).

The plate assembly process currently in the company in question has a stipulated goal of 2000 plates per day, and 10% of this production has failures in the process, bringing a compromise to the goals defined by management. In view of the above, the decision-making process through managers, who are challenged to make increasingly accurate and assertive decisions, of which many decisions need to be made in a short period of time.

Considering the high competitiveness scenarios to which companies are inserted, associated with the need for managers to be precise and assertive in their decisions, along with the large volume of data and the emergence of new technologies that enable the generation of information, this work aims to propose the use of Big Data and AI as a tool to support decision making.

Industry 4.0, characterized by the integration of digital technologies and advanced automation, has been revolutionizing the industrial environment and transforming the way products are manufactured and processes are managed. This new production paradigm, also known as the Fourth Industrial Revolution, is based on a set of emerging technologies, such as the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), and *Business Intelligence* (BI), which together make it possible to create intelligent and connected systems.

One of the biggest challenges faced by industries, especially those operating with complex processes, such as the assembly of electronic boards, is the identification and correction of failures. Board assembly is a delicate and precise process that involves placing and soldering electronic components onto a printed circuit board (PCB). In this context, failures can occur at various stages of the process, resulting in defective products and high costs of rework and material waste. In addition, the rapid evolution of technology demands that these industries maintain a high level of quality control, ensuring that the final products meet the standards required by the market.

Given these demands, there is a need for an integrated and intelligent monitoring system, which is capable of automatically detecting, analyzing and correcting failures, improving the quality and efficiency of the board assembly process. This system must be guided by real-time data and capable of presenting clear insights for decision-making, which is facilitated by the application of Business Intelligence tools. *Business Intelligence* offers a range of functionalities that allow continuous monitoring and analysis of data in a structured way, transforming raw information into key indicators that can be used to improve the quality of the process and reduce the number of failures.

LITERATURE REVIEW

EVOLUTION OF INDUSTRY 4.0 AND ITS IMPACTS ON MANUFACTURING

Industry 4.0 is the term that designates the transformation movements within industries that are seeking new technologies at various levels to increase the quality of their products, increasing the productivity of the entire business.

The Fourth Industrial Revolution is a milestone in history, following the other three that came before: the 1st revolution, with the steam engine and the mechanical loom, then the second revolution, with electricity and mass production. Finally, the third industrial revolution, after World War II, with the arrival of the first computers.

Industry 4.0 has come to transform business management, systems and machinery that did not exist before, allowing the creation of new business models and boosting the economy, as well as making activities more efficient and practical, based on the use of applications.

Tiwar (2021) argues that Industry 4.0 is the integration of business processes, manufacturing, and actors involved in the company's value chain. For the integration between business processes and manufacturing to occur perfectly, it is necessary to make use of manufacturing execution systems and integrated management systems, in addition to the help of cyber-physical systems, which identify, locate, track, monitor and optimize production processes through advanced connectivity collecting information in real time. In addition, companies handle a lot of raw data that needs to be analyzed and transformed into useful information to support the production process.

The automated processes in this sector of Industry 4.0 are standardized, making them safer and faster, since information can be transmitted virtually, thus also being able to customize software and systems for companies, adapting to the needs of that segment. This allows for better results and higher quality products.

According to Gentner (2016), to implement Industry 4.0, IT projects need great communication and goal setting. In addition, it is important to start by executing small things, because then the losses are smaller, but the confidence in the project is maintained.

The optimization of resources and the reduction of errors provides the organization of processes, collaborating with the reduction of waste of raw materials, resources, time and allocation of people, as well as the reduction of errors and rework is another objective of industry 4.0. Through real-time measurements and systems, there is greater predictability in case of failures, anticipating maintenance in the process of assembling electronic boards and thus reducing expenses.

The Fourth Industrial Revolution, or Industry 4.0, is based on digitalization and intelligent manufacturing with the help of physical cybernetic systems or also called cyber-physical systems (GENTNER, 2016). With this advent, production systems migrated from the classical model to the self-organizing cybernetic physical production system, allowing mass customization and flexibility in the amount of production (ROJKO, 2017).

Industry 4.0 was the consequence of what had already been started in the 3rd Industrial Revolution. With a wave of widespread digitization in the 1970s, the perfect scenario was created for the introduction of the use of smart objects today (MÜLLER, BULIGA, and VOIGT, 2018).

All the changes that have occurred since the seventeenth century with the first industrial revolution have been driven by the growing need for improvements to meet customer demands. It was necessary for industries to have a high speed of adaptation, change management and adaptability to provide the market with everything it needed (BINNER, 2014).

In this way, Industry 4.0 is directly affecting companies and the way they deal with the labor market, their employees and customers. Therefore, the next topic deals better with the nuances of this topic.

BIG DATA AND ARTIFICIAL INTELLIGENCE

The use of artificial intelligence (AI) in technical diagnostic processes is an area of great interest and relevance to the industry, as it involves the application of advanced computing techniques to detect, identify, and correct complex faults, anomalies, or deviations. industrial systems. Artificial intelligence can help professionals in the sector make more accurate, faster, and more efficient diagnoses, reducing costs, risks, and the negative impact of failures.

Artificial Intelligence (AI) allows computer applications to mimic human intelligence and can solve problems, make predictions, and present solutions.

Nascimento (2020) explains that Big Data contributes to storing the massive amount of data generated by the Internet of Things (IoT), which is produced in real time. This technology brings challenges to information technology companies such as where to store data securely and easily accessed, in addition, how to process such data so that it can be transformed into information aimed at intelligent decision-making?

Big Data can be understood in two different ways. The first identifies them as a technology that stores a massive amount of data and information. The second strand, on the other hand, understands Big Data as the amount of data present on the internet (Ribeiro, 2014).

The term BD is not new, since the 1980s some problems of large volume of data already existed, such as data from the human genome and particle physics. However, in recent years the topic has become increasingly popular in the 4.0 sector and many other sectors, as existing techniques are becoming more mature for dealing with BD and deriving value from it (LU Yang, 2021).

Applying Computer Vision in the industry can be the guarantee of more assertive and optimized results. This is one of the areas of Artificial Intelligence in greater evidence today, being a field of study that seeks to reproduce the human ability to see, that is, to see and understand what is being seen. These solutions need equipment to capture images and powerful processors that can handle the data and Artificial Intelligence algorithms. In this way, they are able to detect objects, people, facial expressions, and actions (De Andrade, et al., 2023).

Currently in Grohmann's (2021) conception, Computer Vision has been used as a basis for innovations in various areas, from games to autonomous cars. In the industrial scenario, in particular, there are many applications of these techniques that can bring high gains related to automation of production lines, repeatability, speed, precision, safety, and ergonomics in various processes. With the reduction of costs, increase in production capacity and improvement of quality, industrial productivity contributes directly to the profitability of companies. They can achieve higher profit margins, reinvest in innovation and expansion, and even lower prices to gain larger market shares.

Finally, the integration of Artificial Intelligence into engineering is only in its early stages, with the potential to completely transform the field. As we explore new applications and develop innovative technologies, AI will continue to be a driving force behind the advancement of engineering.

BUSINESS INTELLIGENCE NOT INDUSTRIAL CONTEXT

Due to the inconstancy and dynamism of information, it is verified how necessary it is for the use of BI to be closely linked to the company's strategies, after all, any poorly stipulated requirement at the beginning can lead to even greater problems in the future.

The link between intellectual capital and the efficient use of technological tools can be seen as a key component for the organization to achieve its expectations.

Through the grouping of data, it becomes possible to generate intelligent information, which in turn will be polished and transformed into knowledge.

In this way, knowledge management is an immense benefit that is intrinsic to BI, as it adds several possibilities such as: a broad notion of the market position that the organization faces, better evaluation of the competitive strategies that need to be executed, among others.

Two initial proposals that proved to be very relevant for the progress of BI as a support for business management were the decentralization of access to information and the expansion of operational autonomy for managers. In addition to not overloading the IT team, the decision-makers themselves could have greater independence and perform their metric analyses, study reports, and propose strategies without major technological mishaps.

Sampaio (2023) clarifies that when the project is well executed, if before it consumed 90% of the time preparing reports, with BI it is plausible to perform the same work 10% of the time, which causes a considerable improvement in the analysis capacity.

METHODOLOGY

RESEARCH AREA

The present research was carried out in a company located in the city of Manaus, Amazonas (Brazil), which designs and manufactures boards for notebooks. The specific location of the research was in a DIMM insertion line of components that has the printed circuit board as the final product, whose research center took place in a line of automatic insertion of components called Surface Mount Technology - SMT, where the need to create proposals so that the process always occurred in compliance were evidenced. The possible failure modes were the key piece of the study, in which, once the steps are completed, the process will reach the metrics established by the company.

METHODS

a) Mapping of the Board Assembly Process:

This observation made it possible to structure an applied methodology that analyzes the possible causes of failures. Also in the methodology, it was possible to quantify the risks of these potential failures listed and thus prioritize prevention actions.

- Identification of Steps: The process has been divided into specific phases such as solder application, SMD component positioning, reflow soldering, and quality inspection. In each of these stages, key performance indicators (KPIs) were defined that allowed monitoring quality and efficiency, such as defect rate and execution time.

- Risk Analysis: Using the Failure Modes and Effects Analysis (FMEA) method, the most common failures, possible impacts on the process, and preventive actions to mitigate them were identified.
- Definition of Monitoring Parameters: Based on the mapping and risk analysis, the parameters for continuous monitoring were defined, such as welding temperature, correct positioning of the components and uniformity of the weld. These parameters were monitored in real time to prevent deviations and automatically correct failures when possible.

b) Analysis of Requirements for Implementation of the Integrated System

Defining the requirements of an effective *Business Intelligence* (BI) system depends on a detailed analysis of the needs of the board assembly process and the objectives of Industry 4.0. This system integrated data from various sources and presented insights and reports that aided in decision-making.

- Identify key stakeholders: These include end users, customers, consumers, and other stakeholders.
- Gathering requirements from stakeholders: Gathering information about the features, limitations, and desired objectives.
- Choice of *Business Intelligence Tools*: With the requirements established, the BI tool was identified as the most suitable. Tools like Power BI that offer advanced functionality for real-time monitoring and analysis.
- System Architecture Specification: The design of this complex structure requires an engineering mindset, although it can be one of the most creative and rewarding IT architectures you can create. In a large organization, a BI solution architecture might consist of:
- Data sources
- Data ingestion
- Big Data/Data Preparation
- Data Warehouse
- BI Semantic Models

The evaluation of the effectiveness of the system was carried out through the results achieved with the implementation of Big Data and AI in fast communications and readings with more accuracy and positive results, with a reduction in failures and costs. The use of the PDCA cycle has ensured effective control and continuous improvements. These technologies are key for industries to become more competitive in the era of industry 4.0.

The implementation of an integrated *Business Intelligence* system for detecting failures in the board assembly process allows real-time control and monitoring, essential for continuous improvement and to achieve high levels of digital maturity. Based on the materials and methods described, the system will be able to transform data into valuable insights, enabling quick and accurate actions to reduce errors and optimize production.

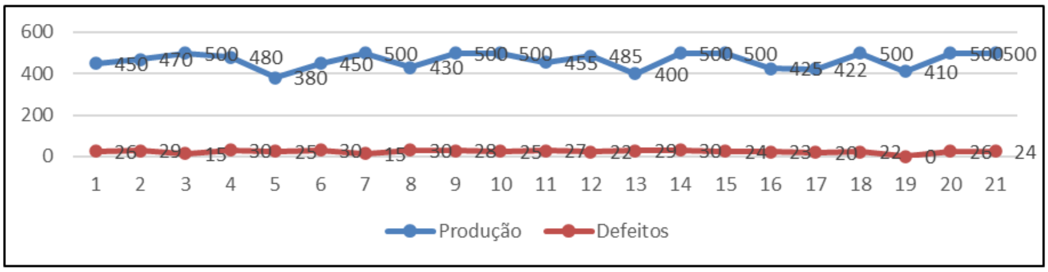
RESULTS AND DISCUSSIONS

MAP THE PRINTED CIRCUIT BOARD ASSEMBLY PROCESS

Carrying out the mapping in the process provided a comprehensive view of its entire structure, allowing the identification and analysis of critical points. This result was achieved through the execution of the mappings required during the chronoanalysis (Fig1)

Figure 1. Chronoanalysis of the process

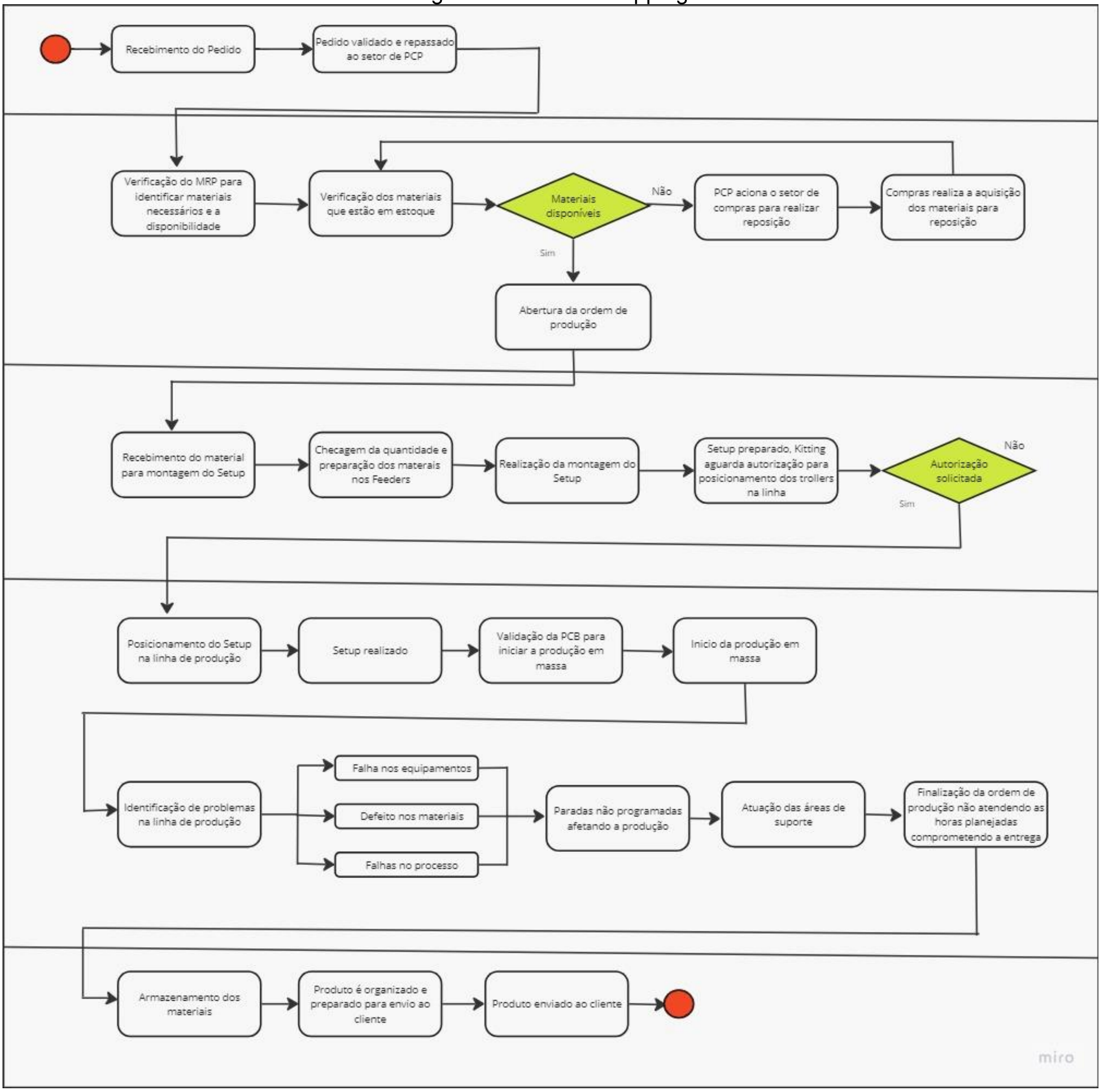
Produção mês	Planejado x Produzido											Média Eficiência		5%			Média Produção diaria			465	
10500	3	4	5	6	7	10	11	12	13	14	17	18	19	20	21	24	25	26	27	28	31
Meta Produção	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Produção	450	470	500	480	380	450	500	430	500	500	455	485	400	500	500	425	422	500	410	500	500
Defeitos	26	29	15	30	25	30	15	30	28	25	27	22	29	30	24	23	20	22	0	26	24
Eficiência	6%	6%	3%	6%	7%	7%	3%	7%	6%	5%	6%	5%	7%	6%	5%	5%	5%	4%	0%	5%	5%



Source: Authors, (2024).

With the data collected, it was defined to chronoanalyze the failures in the production process to generate improvements in productivity and efficiency of the process and allow an effective action plan.

Figure 2 - Process Mapping



Source: Authors, (2024).

ANALYZE THE REQUIREMENTS NECESSARY FOR THE IMPLEMENTATION OF AN INTEGRATED MONITORING SYSTEM

The necessary requirements that were evidenced in the mapping for the monitoring system led to the analysis of:

1. Average Time to Produce a Board
2. Number of slabs produced per hour
3. Percentage of defective plates
4. Unplanned downtime

Automated Optical Inspection (AOI) has been able to identify a wide range of defects on printed circuit boards and electronic components. Defects detected by AOI machines included:

1. Insufficient or over-solder
2. Short circuit between two solder joints
3. Component Displacement
4. Component Lifting
5. Inverted component
6. Tombed component
7. Missing Component

Ferreira (2021), recognizes that the growth of the electronics industry has led to an increased need for validation and testing methods on more efficient printed circuit boards (PCB). The author describes a prototype of a visual inspection system that made it possible to detect errors that occur during the process of solder paste deposition, and this system allowed to speed up the inspection stage in the production line.

In a production per day totaling 8 hours with a production of 500 plates, 30 faulty plates were found that were directed to repair, as shown in table 1

Table 1. Number of failures detected per hours worked

Number of hours per day	Number of boards produced per day	Number of faulty plates per day	%
8	500	30	6%

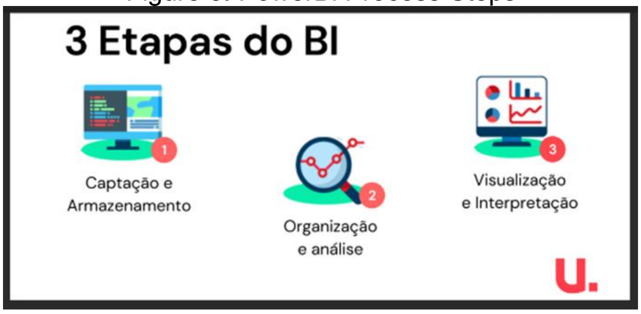
Source: Authors, (2024).

For Mendes et al, (2024), in a similar study showed that the integrated system created using vibration sensors, artificial intelligence techniques with supervised learning, and a dataset for classifying possible defects allowed the generation of alerts and recommendations for corrective actions to avoid failures and unplanned stops, contributing to the reduction of maintenance costs, increased productivity.

INTEGRATE REAL-TIME DATA COLLECTION SYSTEMS AND TOOLS TO CONTINUOUSLY MONITOR ASSEMBLY STEPS

This system allowed real-time monitoring of all process steps, from the application of the solder paste to the inspection and testing of the finished products. The main steps for implementing the process control system included: Establishing clear goals and objectives for production, as well as defining a system of continuous feedback and process improvements. (Figure 3)

Figure 3. PowerBi Process Steps



Source: Authors, (2024).

The implementation of the integrated system was essential to ensure efficiency in the production of SMT welding. Giffoni (2024) reports in his research that the integration of methodologies and systems allows for a more fluid and efficient production, with a reduction in defects, rework and waste of materials, evidencing a substantial optimization in both quality and operational efficiency.

EVALUATE THE EFFECTIVENESS OF ACTION PLANS GENERATED BY BI TOOLS, WITH A FOCUS ON ACHIEVING THE INDUSTRY 4.0 MATURITY LEVEL IN TRANSPARENCY AND PREDICTABILITY

Standardization and optimization of solder parameters are key to ensuring quality and efficiency in SMT soldering production. This included selecting the correct type of solder paste, adjusting the temperature of the reflow oven, and controlling the printing speed of the solder paste. Some tips for optimizing welding parameters include:

- Select the appropriate solder paste based on the required physical and chemical properties
- Control the printing speed of the solder paste to ensure even and consistent distribution

Quality inspection and testing are key to ensuring efficiency in SMT welding production. This involved visual and automatic inspection of the boards after each step of the process, as well as conducting functional and electrical tests of the finished products. Some tips for improving quality inspection and testing include:

- Utilize automated optical inspection (AOI) equipment to identify defects and faults

- Implement visual and manual inspection procedures to complement automated inspection
- Establish clear and strict acceptance criteria to ensure the quality of finished products

The training and qualification of operators is key to ensuring efficiency in SMT welding production. This included training in welding techniques, handling equipment, and understanding quality standards and process requirements. Some strategies to improve operator training and upskilling include:

- Establish a continuous and comprehensive training program for all operators
- Develop specific training materials for each step of the SMT soldering process
- Promote open communication and knowledge sharing among team members
- Implement an evaluation and feedback system to monitor operator performance and identify areas for improvement

Preventive and corrective maintenance of equipment is essential to ensure efficiency in SMT welding production. This included regularly inspecting equipment, making necessary adjustments and repairs, and replacing worn or damaged components. Some tips for improving equipment maintenance include:

- Establish a preventative maintenance schedule for all SMT welding equipment
- Monitor equipment performance and identify potential issues before they become critical
- Train operators to identify signs of wear or fault on equipment and report any issues

Continuous process improvement is key to ensuring efficiency in SMT welding production. This involves analyzing production data and identifying areas for improvement, as well as implementing solutions and adjustments to the process. Some strategies to promote continuous process improvement include:

- Establish a culture of continuous improvement within the organization
- Utilize data analysis and statistical tools to identify patterns and trends in production data
- Implement improvement projects focused on specific areas of the SMT welding process
- Promote collaboration among team members and encourage everyone's participation in process improvement

Process management in SMT welding is crucial to ensure efficiency in production and product quality. By implementing a process control system, standardizing and optimizing welding parameters, conducting quality inspection and testing, training operators, performing preventive and corrective maintenance of equipment, and promoting continuous process improvement, it is possible to ensure efficiency in SMT welding production and achieve high-quality results.

The integrated system allowed communication with other systems in the production process in a faster and more effective way, bringing the most assertive information possible for the performance of usability and data security. With the integration of real-time data collection tools for continuous monitoring of assembly stages and generation of management reports, it allowed to provide benefits in improved time reduction, increased productivity, and with the early detection of failures in real time.

The reports to the management will be issued more accurately and in real time for each analysis made in the process process of the plates. With the performance indicators, it was possible to identify the percentages of gains in the production process and increased productivity.

The implementation of the new integrated system allowed the increase in the capacity to identify and take actions for each failure found in the plate assembly process, it is also worth mentioning that the gains were also in quality, as the analysis and readings of the plates were 100% automatic, and no longer depended on the employee's decision to approve or disapprove the product, After the implementation of the new system, it was possible to identify the vision of the gains:

- Reduction of failures due to early identification of deviations in the process
- Increased operational efficiency by providing real-time information to managers and teams
- Better decision-making based on accurate and up-to-date reports
- Tighter standardization and control of assembly steps
- Reduced rework and non-compliance rates
- Improvement in the final quality of the products delivered to the customer (measured by VLRR indicator - Vendor Line Reject Line)
- More assertive planning, reducing the risk of delays or failures in the project
- Increased visibility into operations and their bottlenecks
- Ability to predict scenarios and propose proactive solutions

CONCLUSION

The analysis of a specific board assembly process was successfully carried out after the implementation of the integrated system in question, in the context of the industrial sector. Considering that the model was developed with a focus on the specific problems and objectives of the company, it will be relevant to evaluate its applicability in other companies in the same production segment, which may present different challenges, goals, products and manufacturing requirements.

It is suggested that the model created be applied in other areas, in order to see its applicability, which can serve as a generic guide, or if it is necessary to reformulate the model more complete. Another suggestion for future work is an analysis, promoting suggestions for an effective and dynamic relational process between Test and Production Engineering, because during the preparation of the case study, it was possible to perceive that such Engineering complements each other and makes the practice of *Business Intelligence* full, when tuned.

ACKNOWLEDGMENTS

To the Graduate Program in Engineering, Process, Systems and Environmental Management of the Galileo Institute of Technology and Education of the Amazon (PPG. EGPSA/ITEGAM), to ITEGAM and the companies Salcomp, Foxconn, Procomp/Diebold, Inventus Power, Coelmatic through Law no. 8.387/1991 on Informatics to encourage RD&I Projects with financial support PUR044/2023/CITS to the Master's project through the Coordinator of the Priority Program for Industry 4.0 and Industrial Modernization, the International Center for Software Technology (CITS)/CAPDA/SUFRAMA/MDIC.

REFERENCES

1. Binner, H. F. (2016). Industrie 4.0 bestimmt die Arbeitswelt der Zukunft. E & I Elektrotechnik und Information.

2. De Andrade, E. A., et al. (2021). Em busca da estabilização numa rede sociotécnica: A intervenção de robôs conversacionais (bots) em decisões comerciais. Available at: https://pubmed.ncbi.nlm.nih.gov/27646544/. Accessed on: November 11, 2024.

3. Dos Santos, G. G., De Souza Rodrigues, M. C., & Almeida, M. A. F. (2022). Simulação de falhas em um processo de produção de uma microempresa calçadista mineira. Engenharia, Gestão e Inovação, 3, 7.

4. Gentner, S. (2014). Industry 4.0: Reality, future or just science fiction? How to. Informação & Tecnologia, 1(1), 96-105.

5. Giffoni, S. C. (2024). Aperfeiçoamento de produtividade na área de soldagem com a aplicação do lean seis sigma.

6. Grohmann, R. (2021). Os laboratórios do trabalho digital: Entrevistas. São Paulo: Boitempo Editorial.

7. Javaid, M., et al. (2022). Artificial intelligence applications for industry 4.0: A literature-based study. Journal of Industrial Integration and Management, 7(01), 83-111.

8. Lu, Y. (2021). The current status and developing trends of industry 4.0: A review. Information Systems Frontiers, 1-20.

9. Mendes Neto, J. F., et al. (2024). Análise de vibração em máquinas industriais com inteligência artificial para previsão de falhas e classificação de defeitos.

10. Müller, J. M., Buliga, O., & Voigt, K. I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Technological Forecasting and Social Change, 132, 2-17.

11. Nascimento, M. H. da S., et al. (2020). Análise de dados coletados por dispositivos de internet das coisas aplicada a sistemas embarcados.

12. Paulo, G. B. F. (2021). Sistema de inspeção visual de pasta de solda (Master's thesis, Instituto Politécnico de Leiria, Leiria, Portugal).

13. Ribeiro, C. J. S. (2014). Big data: Os novos desafios para o profissional da informação. Informação & Tecnologia, 1(1), 96-105.

14. Rojko, A. (2017). Industry 4.0 concept: Background and overview. International Journal of Interactive Mobile Technologies, 11(5).

15. Sampaio, F. G. M. (2023). Automatização de métrica de lead time utilizando ferramenta de business intelligence: Um estudo de caso aplicado à uma indústria farmacêutica.

16. Tiwari, S. (2021). Supply chain integration and Industry 4.0: A systematic literature review. Benchmarking: An International Journal, 28(3), 990-1030.