APPLICATION OF INDUSTRY 4.0 TECHNOLOGY IN THE IMPROVEMENT OF PLASTIC INJECTION PROCESSES IN A COMPANY IN THE INDUSTRIAL HUB OF MANAUS

https://doi.org/10.56238/sevened2024.037-153

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ABSTRACT

Lead Time optimization ensures compliance with deadlines established with customers, which, in turn, promotes customer satisfaction and loyalty. In addition, the reduction of this time provides a more efficient management of resources, with direct impacts on the reduction of operating costs. This study aimed to implement Industry 4.0 technologies to improve plastic injection processes in a company in the Manaus Industrial Pole (PIM), reducing manufacturing costs, accelerating the Lead Time of device construction and optimizing time in the development of new products. In the methodology, data were collected on the new production processes and the evaluation of the impact of the technology on the reduction of manufacturing costs and the improvement of lead time was carried out, through mapping of the current flow of the process, analysis of production loss reports and production performance data. The results show a significant reduction in lead time, that is, in the time needed to create these devices, which had a period reduced from 35 (thirty-five) to 9 (nine days). 3D printing has also made it possible to create more complex and precise devices, with less material waste, directly contributing to cost reduction and an increase in product quality.

Keywords: Automation. 3D printing. Improvement. Industry 4.0.

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INTRODUCTION

In the highly competitive landscape of modern industry, operational efficiency has become an imperative necessity for companies that want to remain relevant and profitable (Serfontein, J., et al, 2013). The development of production devices, a crucial area for many industries, faces significant challenges related to lead time. High lead time not only compromises delivery times agreed with customers, but also affects the supply chain, increasing costs and reducing business agility (Chen, Chih-Jou., 2019). Investigating the root causes of delays is essential to develop practical solutions for each stage of the production process, taking into account everything from the purchase of inputs to the manufacture and testing of devices on the production line, where each phase will be thoroughly analyzed to identify opportunities for improvement. Through a systematic and integrated approach, it is expected to achieve a substantial reduction in cycle times and, consequently, increase the competitiveness of the companies involved.

Historically, development and production time has always been a critical factor in the success of manufacturing companies. From the early days of the Industrial Revolution, when production efficiency began to gain prominence, to the present day, where agility and flexibility are key, lead time has been an essential performance measure (Şen & İrge, 2020). However, with the increasing complexity of production devices and the demand for differentiated customization, lead time has become an even greater challenge. This research aims to address this contemporary challenge by exploring methods to reduce the development time of production devices. The analysis will cover the entire production chain, from the acquisition of materials to final tests, with a special focus on the practices that can be implemented to minimize delays and meet the deadlines established with customers. The intention is to offer a historical perspective that contextualizes the importance of productive efficiency and propose innovative solutions to current problems.

The success of a manufacturing company is intrinsically linked to its ability to deliver high-quality products within the established deadlines (Tortorella, L. et al. 2021). However, many companies face significant difficulties due to the high lead time in the development of production devices. This problem not only compromises customer satisfaction but can also result in lost revenue and increased operating costs. Using a combination of data analysis, project management techniques, and lean production methodologies, it is expected to develop a set of best practices that can be adopted by companies to optimize their processes and more effectively meet customer demands.

Lead time in the development of production devices is a crucial metric that directly affects the performance and competitiveness of companies (Henao, R.; Sarache, W.;

Gómez, I., 2019). A high lead time can result in delays in product delivery, customer dissatisfaction, and increased costs, which compromises the long-term viability of organizations (Mutua, M. 2015). This analytical research proposes to investigate in detail the causes of high lead time, using a systematic approach that includes the analysis of device purchasing, manufacturing and testing processes. The main barriers and bottlenecks at each stage will be examined, and solutions based on best practices addressed in the company, technological advances and innovations in process management will be proposed. The ultimate goal is to implement industry 4.0 technologies to enhance plastic injection processes in a company in the PIM.

LITERATURE REVIEW

PRODUCTION MANAGEMENT

Production is the process of creating goods or services from the combination of different resources, such as raw materials, labor, capital, technology, and has accompanied man since his origin.

Production management is an area of management that focuses on the efficient and effective management of an organization's production processes and operations, where it will ensure that goods and services are produced in an economical manner, with quality and within the established deadlines, being an important factor for the success of any organization (Paiva et al., 2009). Production management has its roots in the Industrial Revolution, when mechanization and mass production began to transform the way goods were produced. Pioneers such as Frederick Taylor and Henry Ford introduced scientific management and assembly line techniques, respectively, which revolutionized industrial production. Over time, the discipline has evolved to incorporate more sophisticated approaches, such as lean manufacturing, total quality management (TQM), and just-in-time (JIT) production (Jamba, 2024).

JUST-IN-TIME (JIT) PRODUCTION

JIT Production is based on several fundamental principles that aim to optimize production and reduce waste, eliminate waste, lean production, continuous process flow, quality at the source, and continuous improvement using Kaizen tools. (Carvalho, 2016).

JIT implementation uses several tools and techniques to achieve its goals:

- Kanban: A signaling system that controls the flow of materials and products in the production process, ensuring that items are produced and delivered only when needed.

- SMED (Single-Minute Exchange of Die): Techniques to reduce machine setup time, allowing greater flexibility and smaller production batches.
- TPM (Total Productive Maintenance): An approach to ensuring that machines and equipment are always in good working order, minimizing interruptions in production.
- Heijunka (Production Leveling): A technique for leveling the workload and avoiding peaks and valleys in production, promoting a continuous and stable flow.

JIT Production has been widely adopted in a variety of industries, including automotive, electronics, and consumer goods manufacturing, the practice offers several significant benefits such as reducing inventories by reducing storage costs and tied capital, eliminating waste and creating a continuous flow of production increases operational efficiency, emphasis on quality at the source, and continuous improvement results in higher quality products and lower defect rates, ability to produce based on actual demand allows for greater flexibility to respond quickly to changes in the market. (Ribeiro, 2017).

INDUSTRY 4.0

Known as the Fourth Industrial Revolution, it is a new phase in the organization and control of the value chain throughout the life cycle of products. This phase is characterized by the digitalization and integration of all elements of the value chain through the Internet of Things (IoT), Big Data and Analytics, Artificial Intelligence (AI) and other advanced technologies. Digitalization and the integration of value chains create significant opportunities for the optimization of production processes and innovation in business models.

Schawb (2016), says that "Industry 4.0 is characterized by the digitalization and integration of value chains, products and services, resulting in a fusion of physical, digital and biological worlds" did not emerge in isolation, but is the result of a series of technological and organizational evolutions that date back to the First Industrial Revolution. The First Industrial Revolution, which took place at the end of the eighteenth century, was marked by the mechanization of production through the use of water and steam. The Second Industrial Revolution, in the late nineteenth and early twentieth centuries, introduced electricity and mass production, while the Third Industrial Revolution, starting in the 1970s, brought automation and digitalization with the introduction of computers and information technologies.

Kagermann, Wahlster, & Helbig (2013) state that "each industrial revolution has brought significant changes in society and the economy, and Industry 4.0 is no exception, promoting automation and data exchange in manufacturing technologies." The Fourth Industrial Revolution continues this trajectory, but with a much greater focus on interconnection, artificial intelligence, and full automation of production processes, driven by a series of advanced technologies that together transform industrial processes. Among the main technologies are:

Internet of Things (IoT)

IoT allows the interconnection of devices and systems, facilitating communication between machines and optimizing production processes. Lee, Bagheri, & Kao (2015) point out that "IoT plays a crucial role in Industry 4.0, enabling real-time data collection and analysis for informed decision-making."

Artificial Intelligence (AI) and Machine Learning

AI and machine learning are essential components in Industry 4.0, providing advanced analytics and automation capabilities. "AI is revolutionizing manufacturing by enabling failure prediction, predictive maintenance, and process optimization" (Russell & Norvig, 2016).

Big Data e Analytics

The ability to collect and analyze large volumes of data is critical in Industry 4.0. "Big Data allows companies to identify patterns and trends, improving efficiency and decision-making" (Manyika et al., 2011).

Advanced Robotics

Advanced robots are increasingly being used for complex and repetitive tasks, improving accuracy and efficiency. "Robotics in Industry 4.0 is characterized by collaboration between humans and robots, creating a safer and more efficient work environment" (Bauer, Hämmerle, & Schlund, 2015).

Cloud Computing

Cloud computing allows for large-scale data storage and processing, making it easier to access and analyze information in real time. "Cloud computing is a crucial enabling technology in Industry 4.0, enabling scalability and flexibility of resources" (Armbrust et al., 2010).

Additive Manufacturing (3D Printing)

3D printing is transforming manufacturing by enabling the production of complex parts quickly and cost-effectively. "Additive manufacturing is revolutionizing production, reducing waste, and enabling mass customization" (Gibson, Rosen, & Stucker, 2010).

Augmented and Virtual Reality

Augmented and virtual reality are being utilized for training, maintenance, and design, providing interactive and immersive visualization. Azuma (1997) notes that "these technologies are improving operational efficiency by providing real-time contextual information to workers." Industry 4.0 has a profound impact on several dimensions, including economic, social, and environmental. These impacts are felt across different industries and scales, ranging from changes in the labor market to digital transformations in companies. The adoption of this revolution is increasing the productivity and efficiency of companies, resulting in significant economic benefits. "The digitalization and automation of production processes are creating new business opportunities and revenue models" (Pereira & Romero, 2017).

This revolution is transforming the job market, creating demands for digital and technological skills. Lasi et al., (2014) states that "automation and AI are replacing repetitive and manual tasks, while generating new opportunities for skilled workers". Digital transformation is a core aspect of Industry 4.0, allowing businesses to quickly adapt to changes in the market and improve their competitiveness. "Companies that adopt technologies of this model become more agile and innovative, able to respond quickly to customer demands."

The adhesion of Industry 4.0 is promoting more sustainable and energy-efficient practices. Rüßmann et al., (2015) note that "the integration of smart technologies allows the optimization of the use of resources, reducing waste and improving sustainability". Despite the numerous benefits, the implementation of Industry 4.0 faces significant challenges that need to be overcome in order for its full potential to be realized, the technological complexity of Industry 4.0 poses a significant challenge for many companies. According to Müller, Buliga, & Voigt (2018) highlight that "the integration of heterogeneous systems and the need for interoperability are important technological barriers".

With increasing digitization and interconnection, cybersecurity concerns are increasing. "Protecting against cyberattacks and ensuring data security are critical challenges in Industry 4.0" (Müller, Buliga, & Voigt (2018). Small and medium-sized enterprises (SMEs) face unique challenges in implementing Industry 4.0 due to limited resources. "Lack of access to finance and the need for investment in technology are significant barriers for SMEs" (Mittal, Khan, & Romero, 2018).

The transition to Industry 4.0 requires a highly skilled workforce, which poses a significant challenge in terms of training and education. The development of technical and digital skills is essential to make the most of the opportunities offered by the digital economy and technological innovation, as the world becomes increasingly connected and dependent on technology, these skills become fundamental for competitiveness and adaptation in the labor market.

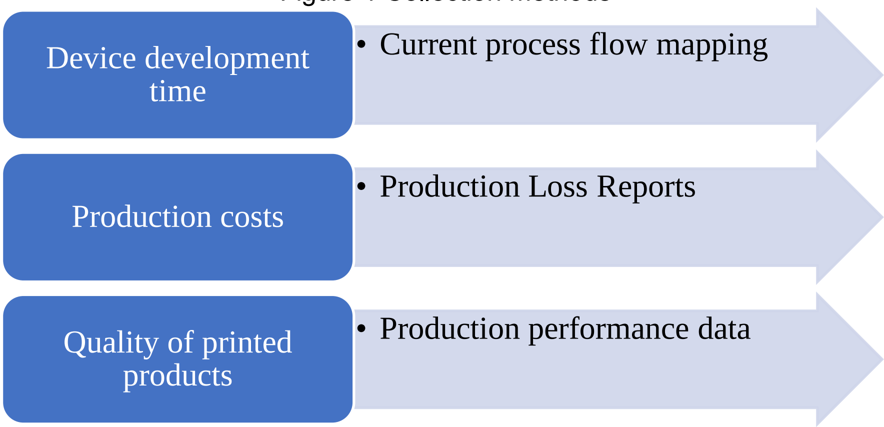
METHODOLOGY

RESEARCH AREA

The project was carried out in the plastic injection sector of a company located in the PIM. in which data on the production processes before and after the implementation of 3D printing technology was collected.

Initially, the mapping of the current process flow for the manufacture of Jigs and jigs was carried out, including the dependence on external suppliers, data collection of annual costs for new projects contemplating the delay in the development of new products, the production time, and the quality of the devices produced. These data served as a basis for comparison for the analysis of the impacts of the implementation of 3D printing. The company was accompanied during the transition process to the in-house production of the devices using 3D printing. Data was collected on the new production processes, including the development time of the devices, the production costs, and the quality of the printed products, where the analysis included the evaluation of the impact of the technology in reducing manufacturing costs and improving lead time. (Figure 1).

Figure 1 Collection methods



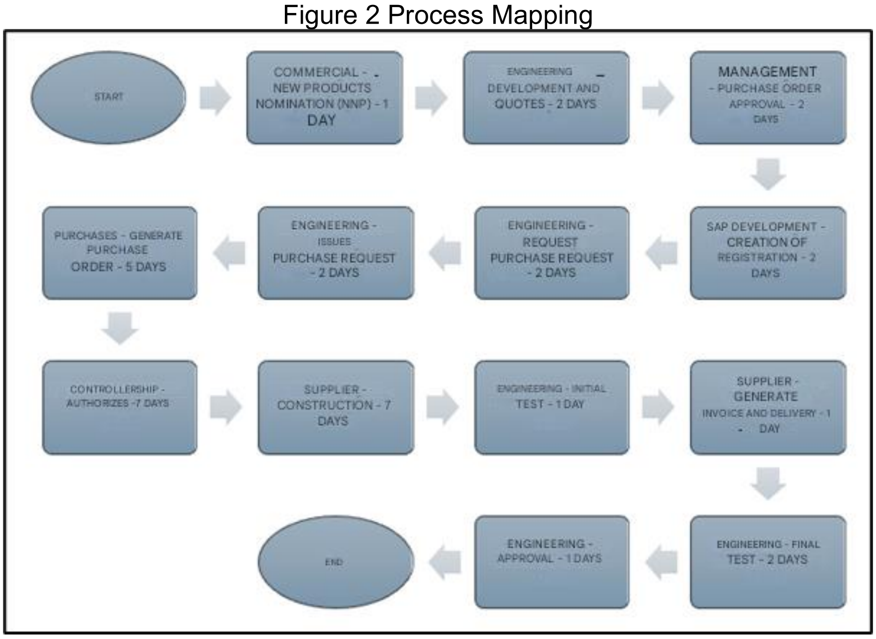
Source: Authors, (2024).

RESULTS AND DISCUSSIONS

MAP THE MAIN DEFICIENCIES IN CURRENT PLASTIC INJECTION PROCESSES

The mapping, as shown in Figure 2, consists of everything from the elaboration of the device design to the approval of the final device by the engineering team. This process, when the mapping was carried out to search for the deficiencies, in which it had a period of 35 (thirty-five) days, distributed in 13 (thirteen) stages.

Figure 2 Process Mapping



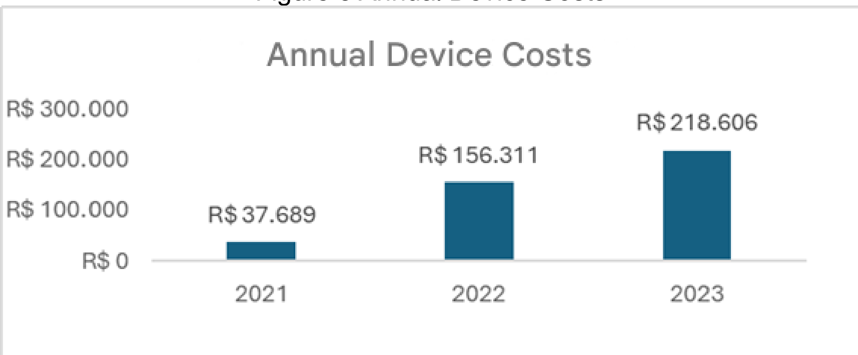
Source: Authors, (2024).

REDUCE MANUFACTURING COSTS BY ELIMINATING RELIANCE ON EXTERNAL SUPPLIERS

According to figure 3, it is observed that, in 2021, the production demand with the use of devices (Jigs) in the process was relatively low, this scenario reflected a limited use of this resource. However, in 2022, the situation underwent a significant change, with a considerable increase in the use of Jigs, which led to an improvement in the company's processes and productivity. This growth, while contributing to an increase in production, also brought with it an increase in operating costs.

In 2023, the company received new processes, including more pad printing and assembly engraving, which generated a substantial increase in production costs. These processes, although they added value to the operation and allowed the diversification of production capacities, also resulted in a higher cost compared to previous years. The increase in costs is related to the complexity of the new processes and the need for greater investment in technology.

Figure 3 Annual Device Costs

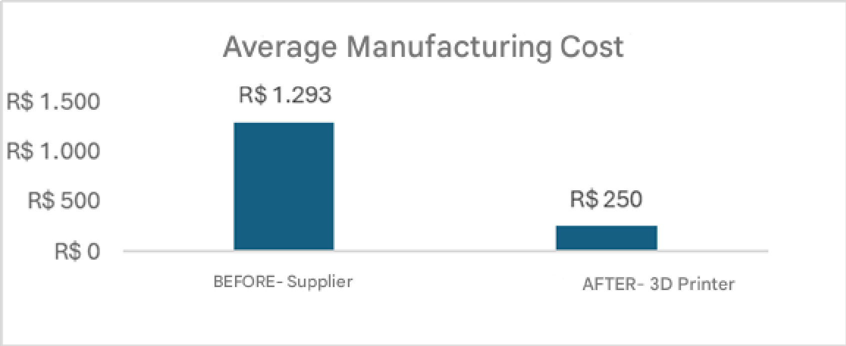


Source: Authors, (2024).

In the traditional manufacturing scenario, production processes often involve the use of machining processes, in addition, there is the cost of materials and the high production time of 240 hours as shown in Figure 5, which include steps such as design design, preparation, molding and finishing by the supplier.

With 3D printing, these costs can be drastically reduced. 3D printing allows the direct manufacture of the part from a digital model, without the need for additional molds or tools, eliminating preparation costs and considerably reducing material waste, the production time is significantly reduced to 6 hours as shown in figure 5, since 3D printing can create a part in hours, while traditional methods can take days, especially for small productions or prototypes. Recent research conducted by Gartner (2023) highlights that 3D printing has the potential to reduce manufacturing costs by up to 25% for companies adopting the technology for mass production, especially in high-personalization, low-print industries.

Figure 4 Average manufacturing costs

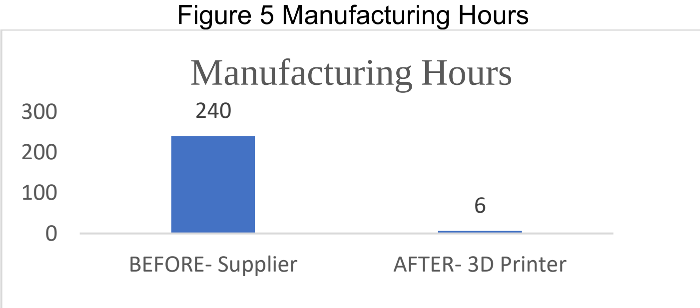


Source: Authors, (2024).

ACCELERATE THE LEAD TIME OF DEVICE CONSTRUCTION, IMPROVING AGILITY IN THE IMPLEMENTATION OF NEW PROJECTS

The implementation of strategies such as process automation, the integration of advanced technologies such as 3D printing has made it possible to significantly reduce device development time. Before the adoption of these improvements, the average lead time for building devices was 240 hours. After the implementation of the changes, this time was reduced to just 6 hours. This enhancement not only accelerates the launch of new products for customers but also strengthens the company's competitiveness in the market, allowing for a more agile response to consumer demands and innovation requirements (Kuczynski et al., 2023).

Figure 5 Manufacturing Hours

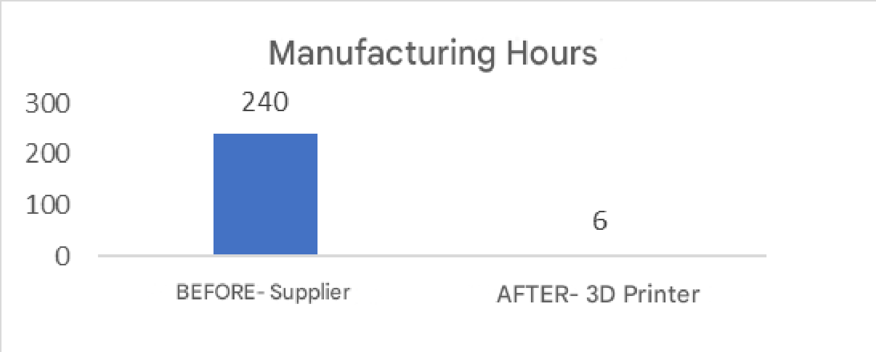


Source: Authors, (2024).

OPTIMIZE TIME IN NEW PRODUCT DEVELOPMENT BY UTILIZING 3D PRINTING TECHNOLOGY

This process, when the mapping was carried out after implementation, had a reduced period from 35 (thirty-five) to 9 (nine days) distributed in 9 (nine) stages, a 74% reduction in the time with the manufacture of the part itself, which eliminated the purchase by suppliers.

Figure 6 Flowchart after implementation



Source: Authors, (2024).

Steps of the 3D printing process

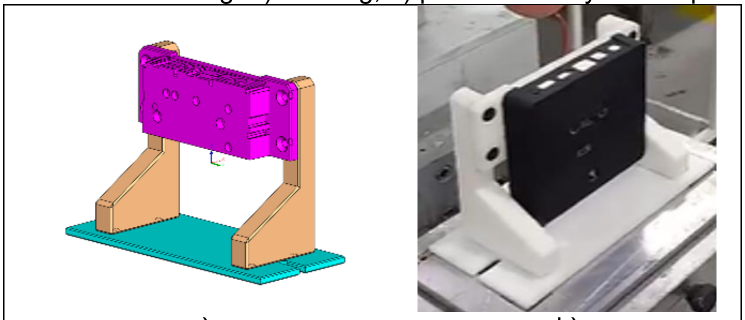
The 3D printing process has been broken down into a few key steps:

- Creation of the 3D Model: The first step consisted of creating or obtaining a digital 3D model of the object to be printed carried out in the 3D modeling software.
- Slicing: The 3D model was converted into thin layers (slices) through slicing software, this software generated the G-code that the printer used to determine how the object would be printed layer by layer.
- Printer Preparation: Before starting printing, it was necessary to verify that the printer was set up correctly, with the filament inserted and the print bed level.
- Loading the G-Code into the Printer: The G-code generated by the slicing software has been loaded into the printer, usually via SD card, USB, or direct connection to the computer.
- Start of Printing: The printer begins to heat the necessary components (such as the extruder nozzle and heated bed) and then begins printing layer by layer according to the instructions in the G-code.
- Print Monitoring: During the printing process, the monitoring process was important to ensure that the material was deposited correctly and that the model was being printed flawlessly.
- Object Finalization and Removal: After printing is finished, the object must be carefully removed from the printing platform.

Implementation of the improvement

These steps are quite common and apply to many 3D printers. Figure 7 shows the modeling of a "Jig" type device used to mount the Top Cover. This device has the function of facilitating the positioning and fixation of the piece during the pad printing process. Figure 7 shows the projected part, which was 3D printed, allowing a more detailed and accurate visualization of the design.

Figure 7 Top Cover device modeling. a) drawing; b) part created by the 3D printer, implemented.



a) b)

Source: Authors, (2024).

The evolution of production demands in recent years has driven a constant search for the optimization of industrial processes, in this scenario, 3D printing stands out as a transformative technology, bringing significant advances both in terms of cost and efficiency. The ability to produce parts on demand and with high customization makes 3D printing an essential tool to reduce waste and improve agility in processes. In industries, 3D printing allows the manufacture of rapid prototypes, which accelerates the development of new products. In addition, it makes it possible to create complex components, which would be difficult or impossible to produce with traditional methods. This flexibility in design results in a significant reduction in raw material costs and decreases the need for expensive tooling and tooling equipment.

Another crucial benefit of 3D printing is the decrease in production lead times. The ability to produce parts directly from digital models eliminates the need for additional steps, such as adjustments to tooling machinery. This not only speeds up the delivery of products, but also allows for better use of human and material resources.

Therefore, 3D printing not only improves operational efficiency but also offers practical and innovative solutions to the challenges of modern industry, effectively balancing costs and product quality. This technological advancement is an important step in meeting the growing demand for faster and more personalized production.

Figure 8 Future situation of the process with the Kings 3d Printer with its characteristics

Source: KINGS 800PRO industrial 3D printer, based on SLA (Stereolithography Apparatus) technology, (2024).

Table 1: Materials and Characteristics.

Material	Characteristics
Standard Resin	•Smooth surface finish. -Brittle.
High Detail Resin	- Increased dimensional accuracy. - Hig
Transparent Resin	- Transparent material. - Requires post-processing.
Moldable Resin	- Used to create mold parts. - Low percentage of ash after burning.
Resin Resistant or Durable	- Mechanical property similar to ABS. - Low thermal resistance.
High Temperature Resin	- Temperature resistance. - Used for injection molding and tooling.
Dental Resin	- Biocompatible. - High abrasion resistance.
Flexible Resin	- Rubber-like material. - Dimensional accuracy.

Source: KINGS 800PRO industrial 3D printer, based on SLA (Stereolithography Apparatus) technology, (2024).

Figure 8 shows a KINGS 800PRO industrial 3D printer, based on SLA (Stereolithography Apparatus) technology. The content is organized into three main sections: equipment, materials, and their characteristics. At the bottom of the figure, the following benefits are highlighted: Print Quality; Speed and Efficiency; Precision and Consistency and Variety of Materials. Figure 8 shows that the KINGS 800PRO 3D printer has high versatility, being able to use a wide range of resins, with specific characteristics that meet various industrial and technical applications (Table 1). Figure 9 shows the results according to a comparative analysis before and after the implementation of a 3D printer, highlighting the gains in cost reduction, manufacturing time and economic viability. Below is the detailed description:

Comparative Table:

1. Before Implementation (Supplier A): Manufacturing Hours: 240 hours; Unit Cost of Manufacturing: R$ 1,293.00.

2. After Implementation (KINGS 3D): Manufacturing Hours: 6 hours (97% reduction); Unit Cost of Manufacturing: R$ 250.00 (81% reduction).

The comparison shows a significant decrease in manufacturing times and costs with the use of the KINGS 3D printer.

3. Problems Identified: Location: 3D Printer.

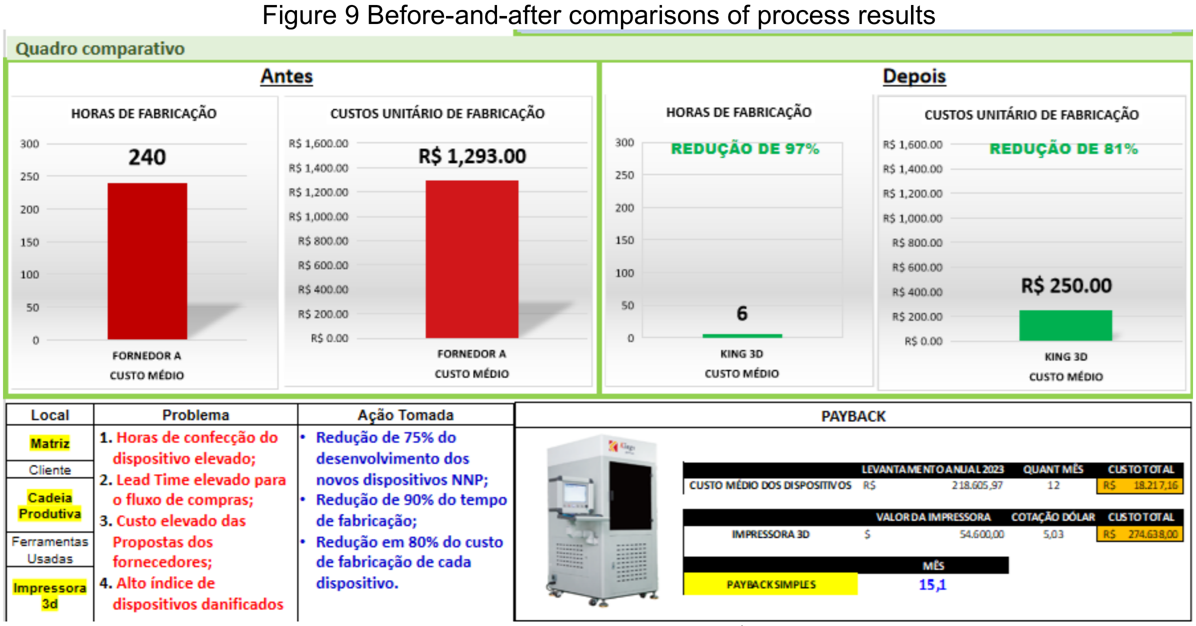
Problems: High device manufacturing hours; 2. High lead time for the purchase flow; 3. Suppliers and 4. Assessed high cost High rate of damaged devices.

4. Action Taken: a) 75% reduction in the development of new NNP devices; b) 90% reduction in manufacturing time and c) 80% reduction in the manufacturing cost of each device.

5. Payback (Return on Investment): The Payback section presents: a) Average Device Cost: R$ 1,293.00 before → R$ 250.00 after; b) Number of devices: 50 units; c) Total Cost (before): R$ 64,650.00; d) Total Cost (with 3D printer): R$ 12,500.00; e) Total Savings: R$ 52,150.00 and Simple Payback: 15.1 months.

The implementation of the KINGS 3D printer generated great advantages in the process: 1. Drastic reduction in manufacturing time (from 240 hours to 6 hours); 2. Significant reduction in unit costs (from R$ 1,293.00 to R$ 250.00); 3. Savings of R$ 52,150.00 on 50 devices and 4. Economic viability confirmed with a payback of 15.1 months. The action brought greater operational efficiency, cost reduction and agility in the production process.

Figure 9 Before-and-after comparisons of process results



1. 1-year saving estimates profit of R$ 156,145.00.
2. 5-year savings estimate profit of R$ 782,250.00.
Source: Authors, (2024).

CONCLUSION

Specifically Jigs, and as this technology positively impacted the development process, the main advantage highlighted is the significant reduction in lead time, that is, in the time needed to create these devices, in which there was a reduced period from 35 (thirty-five) to 9 (nine days) distributed in 9 (nine) steps in time with manufacturing, which provided greater agility in responding to customer demands. 3D printing has made it possible to speed up the stages of creating and adjusting devices, which were previously time-consuming and dependent on traditional methods such as manual machining. In addition, the adoption of printing technology has resulted in an increase in operational efficiency. The replacement of traditional methods with more modern industry 4.0 solutions has reduced production costs, improving the company's competitiveness in the market.

3D printing has also made it possible to create more complex and precise devices, with less material waste, directly contributing to cost reduction and an increase in product quality. Integrating 3D printing into jig development and production not only optimizes time and costs, but also offers benefits in terms of flexibility and customization, making companies more adaptable to specific customer needs. The adoption of 3D printing brings a significant transformation in the production process, providing continuous improvement in delivery times, cost reduction, and product quality, as well as boosting the company's competitiveness in the market.

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.

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