Manufacturing Processes in the Era of Industry 4.0. Case Study: Analysis of a System Architecture in Automotive Industry

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Abstract: In the context of Industry 4.0, intelligent manufacturing systems are the key to creating higher value-added processes and services that enable product customization. This is made possible by dynamically reconfiguring manufacturing systems based on customer needs. Robotic Process Automation (RPA) in manufacturing should only be implemented after correctly identifying those processes that can be automated. Management support for the implementation of RPA is required at all stages. RPA must be integrated into the company in convergence with the Enterprise Resource Planning (ERP) system in place. The study presents an applied research, the aim of which is a project to integrate advanced technologies for automated manufacturing of three-dimensional (3D) digital model objects into the production process management system of a factory in the automotive industry. The automotive sector needs to enable the use of artificial intelligence in terms of open innovation in both manufacturing and management. Research results show that robotic process automation is a key factor in transforming the business process in an automotive factory. The implementation of RPA in the automotive industry is a decision with a major impact on the efficiency of business processes in the Industry 4.0 era.

Keywords: Automotive sector, Design of Industry 4.0 architecture, ERP, Additive manufacturing, Artificial intelligence, 3D printer, SAP.

1. Introduction

Over the past four years, the global economy has undergone a reset induced by the crisis caused by the COVID-19 pandemic, which has affected production and supply chains, causing a lot of disruptions to economic processes. In this context, factories have reconsidered their business strategies, by innovating business processes and implementing new technologies to optimize operational flows.

According to a report by the Romanian Association of Automobile Manufacturers, the Romanian automotive industry is expected to return in 2022 to the level of 2019, i.e., to the size of activity before the markets were affected by the medical crisis, the war crisis and the raw material crisis that affected the industry. The analysis shows that, at the level of 2020, the turnover of the automotive sector decreased to 26.4 billion euros, compared to 2019, with an insignificant increase in 2021, when it reached 27.5 billion euros. In 2022, the turnover reached a level of almost 31 billion euros, setting a production record in the automotive industry with more than 507,000 units manufactured nationwide.

Considering both the potential of the automotive industry and its significant contribution to the growth of the national economy, and the disruptive influence of the current economic context, strategies for the development of this sector must take into account the use of Industry 4.0 and, more recently, of Industry 5.0. technologies, as solutions.

The use of artificial intelligence (AI) in terms of open innovation (Armstrong, 2023), targeting both manufacturing and business management (Kuzior, Sira & Brożek, 2023), is imperative for ensuring business competitiveness today. A study by Stanford University shows that, globally, the corporate investment in artificial intelligence has skyrocketed over the past decade (Stanford University, 2024). Compared to 14.6 billion dollars in 2013, the total investment in 2021 was 276.1 billion dollars. The study was conducted

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by analyzing investment data from over 8 million public and private global companies over the period 2013-2022, with investments totaling 934.2 billion dollars.

The article was structured in 5 sections. In the introduction section, the effect of the COVID-19 pandemic on the automotive industry and the need to innovate business processes and implement new technologies based on artificial intelligence were presented. Section 2 is a literature review on the implementation of new manufacturing process technologies in the Industry 4.0 era. Section 3 presents the system architecture for launching special orders using AI, iRPA, and AM and is structured into 3 subsections, workflow solution, steps used for implementing workflow solution using BPM, and integrated architecture. Section 4 is dedicated to results and discussions and Section 5 to conclusions.

2. Literature Review

The embracing of new technologies such as AI, Robotic Process Automation (RPA), and, more recently, intelligent RPA (iRPA), has been made possible by the need for business process improvement that has arisen over the years and the desire to increase the productivity of the use of information systems, Systems, Applications and Products (SAP) being one of the core systems used in the business environment (Reddi, 2023). The aim of implementing new technologies was largely driven by ensuring the efficiency of business processes through automation, but also by improving already automated processes, where possible, by integrating new facilities enabled by the advent of smart technologies.

A company's digital transformation must take a strategic approach (Banciu, Vevera & Popa, 2023), with success achieved by continuously integrating new features and functionality into specific business operations to improve product performance and customer experience. A company's investment in information technology is one of the critical success factors of business process management systems (BPMs) (Ubaid & Dweiri, 2020). The emergence of smart technologies specific to Industry 4.0 is relevant from a customer perspective insofar as it enables product customization, made possible by dynamically reconfiguring production systems based on demand (Da & Duan, 2019).

In Industry 4.0, the specific architecture design becomes complex, as it incorporates manufacturer and customer requirements, and cyber-physical systems (CPSs) are the core components of Industry 4.0, in addition to cloud computing, additive manufacturing, big data analytics, and others (Aguirre & Rodriguez, 2017), as a mechanism through which physical and cyber technology combine, enabling interaction between different components of the manufacturing system (Zong et al., 2017). An intelligent manufacturing system uses a service-oriented architecture (SOA) over the Internet that facilitates human-machine integration by providing customized customer services, flexibility, and reconfigurability of manufacturing processes.

They define the new concept of smart factory, which integrates the communication process, computation process and control process to meet industrial requirements (Chen et al., 2018). Smart manufacturing relies on a mix of technologies such as CyberPhysical Production Systems (CPPS) (Dumitrache et al., 2017), IoT, robotics/automation, cloud computing or big data analytics to facilitate data connectivity (Do & Jeong, 2022; Mihai et al., 2023). In the context of Industry 4.0, smart manufacturing systems are fundamental to create higher value-added processes and services (Zong et al., 2017).

To build a cyber-physical system (CPS) for smart factories, the 8C system architecture has been proposed (Jiang, 2018), which complements the 5C architecture previously proposed by Lee, Bagheri and Kao (2015). The 5C system architecture consists of five levels – connection, conversion, cyber, cognition, and configuration.

Jiang (2018) conceptually improved the 5C architecture by adding 3 levels: the coalition, considering the integration of the value and production chain to ensure the processuality of production; the content, a level related to the retrieval, storage, and query of all product-related data (design, manufacturing parameter, product traceability record, and after-sales service); and the customer, the facet considered with the most important role in the production process. The use of an 8C architecture ensures a fast response to various customer orders through automatic material preparation, flexible planning of production processes, dynamic reconfiguration of production lines, and automatic arrangement of product storage and delivery, making possible both the product customization and the series production. Research shows that the design of CPS architecture must ensure that products and services primarily conform to customer needs (Sony, 2020).

An emerging type of business process automation technology in various industries is RPA (Madakam, Holmukhe & Jaiswal, 2019), based on software robots that incorporate artificial intelligence in their various forms. Several studies have confirmed that the application of RPA increases the speed of processing certain workloads in a business and of productivity (Aguirre & Rodriguez, 2017; Filip, 2021). An RPA-based system architecture is different from company to company and at the same time industry-specific with a uniqueness, as some researchers conclude (Madakam, Holmukhe & Jaiswal, 2019). Industry 4.0 prefigures the development of an industrial configuration in which systems are autonomous and interconnected and production adopts unconventional processes, such as additive manufacturing (AM) (Jandyal et al., 2022). Computer software attached to the 3D printer creates the desired design, then generates a special type of file to be sent to the printer, which reads the data and creates the product. 3D printing is an effective tool for product development in the automotive industry, speeding up design. Design improvements can be made relatively quickly and at no additional cost, and automakers can increase the efficiency of their research and development processes (Sarvankar & Yewale, 2019). The benefits of 3D printing include digital data transfer, remote access, and the ability to develop complex products and prototypes (Jandyal et al., 2022), which offers the possibility to customize the product offer according to the needs of customers. Studies show that the adoption of AM has a positive effect on the supply chain, giving it flexibility (Delic & Eyers, 2020).

Process architects have multiple responsibilities, from understanding the operational flow, to managing tasks or system efficiency, so that a production system based on RPA or iRPA generates, as some authors have concluded, added value for the company (Roblek, Meško & Krapež, 2016). Certain industries or business operations, such as purchasing, customer service, manufacturing processes, are more amenable to automation than others (Anagnoste, 2018). Considered one of the building blocks of Industry 4.0, robotic process automation should only be implemented after properly identifying those processes that can be automated (Siderska, 2020). Management support for the implementation of RPA is needed at all stages, by providing sufficient resources during the development of software robots or later, during operation using RPA (Plattfaut et al., 2022). Moreover, Siderska (2020) points out that RPA should be integrated into a company in convergence with the implemented BPM system.

Some researchers believe that, in terms of the implementation of Industry 4.0 technologies, a concern for the future should be the decentralization of the control service, so that each smart technology component in a system can make self-adaptive decisions to enable seamless operation at each stage of an assembly line or cooperation with other production lines to ensure synchronization, for example (Zhong et al., 2017). Other studies highlight the need to further explore RPA-based functionalities and system architectures to increase their capabilities across multiple domains and applications, considering robotic process automation as a key driver of digital transformation (Syed et al., 2020).

Considering the issues outlined above, this study represents an applied research of an interventionist nature (Lukka & Wouters, 2022), developing a case study based on ideas drawn from the authors' practical experience using empirical data.

The authors carried out an applied research aimed at improving the existing business process in a factory producing automotive sub-assemblies. As a subsidiary of a large global manufacturer, the effects of implementing new technological facilities in the plant's production processes are beneficial both to the business and to the entire value chain. Also, the purpose of this research is represented by automatic production planning, such as car seats, steering wheels, doors, headrests, front panels, etc. All these products are made in the Romanian factory and delivered for export on special orders.

To achieve the research goal, the authors set out to develop a project which would integrate a system architecture that would ensures the most efficient automation of the work process. The project aims at drawing up the delivery list, on the one hand, and the production plan for certain products, on the other hand, these being necessary in a sales order created for a certain range of products.

3. System Architecture for Release Special Orders Using AI, iRPA, AM

The authors of this paper propose a system architecture that involves modeling the order release process in the production of 3D printed plastic ornaments.

3.1 Workflow Solution to Release Production Orders for Plastic Ornaments Through AM

The present research is an Enterprise Resource Planning (ERP) - iRPA - Production Planning (PP) - applying AM using 3D printing integration project, i.e., the relationship between front-office (ticketing) - back-office (ERP - SAP) - non-SAP applications. It is focused on the need to create a production process (workflow) in which the order from a customer is taken, then sent to production in the shortest possible time, using software robots, either from the same software manufacturer (SAP-iRPA) or from another company, such as UiPath. This workflow is shown in Figure 1.

The process shown in Figure 1 uses several closely related technologies: ServiceNow, SAP, iRPA, RPA, AutodeskFusion, with integration being achieved through dedicated Application Programming Interface (API). The model responds to a need to increase the turnaround time of the production process specific to the production of sub-assemblies needed in the automotive industry, such as car seats, steering wheels, doors, headrests, front panels, etc. The need to automate the business processes of the automotive company for which the authors conducted this case study is a topical one. Business processes such as those required for sales, procurement, production, integration between them, as well as the link with other IT systems within the company need to be redesigned, if the business entity is to be competitive in a market where customers can choose from a range of products with similar characteristics.

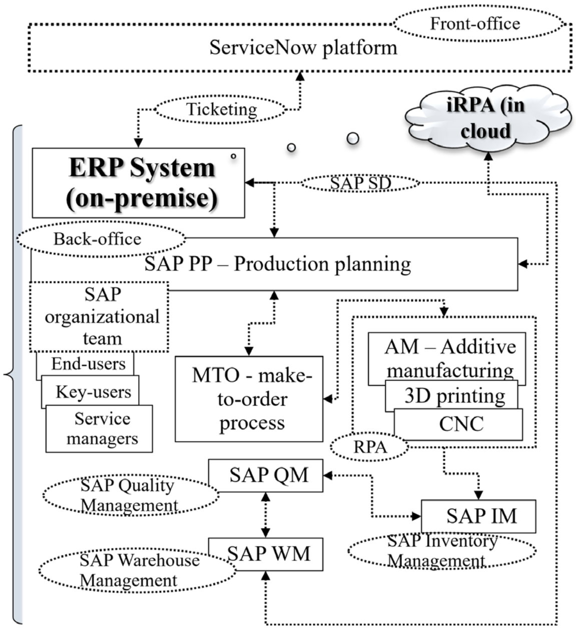

Figure 1. PP – make-to-order – AM – process implemented workflow

3.2 Steps Used for Implementing Workflow Solution Using BPM

The promptness with which the supply of a service, product or information is confirmed makes the manufacturing plant competitive. The automation and modelling of business processes was carried out using the model of a business process management (BPM) system as a strategic and structured method to manage and improve operational processes in a company. Its goal is to create value, improve efficiency and enhance the competitiveness of the organisation by optimising and effectively managing production flows and business operations. Figure 2 highlights the main actors of this modelling process, considering a BPM system, in order to have a proper approach to manage and optimize the specific operational processes of the automotive company for which this research was conducted.

Aligning the SAP ERP integrated system, which has implemented the existing business processes,

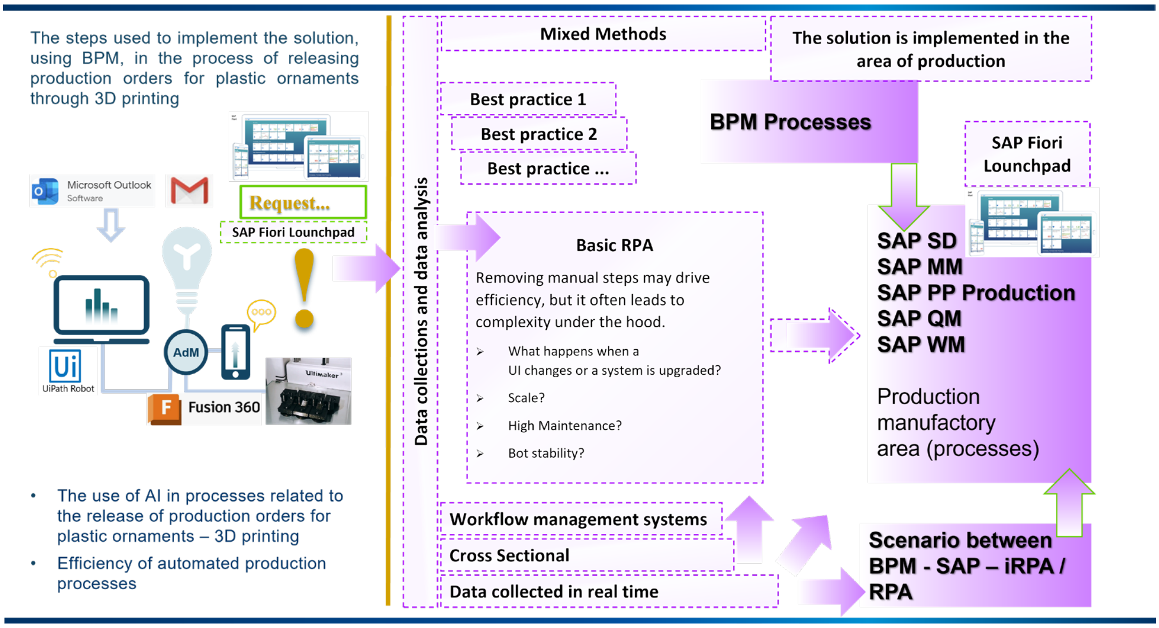

Figure 2. End-to-end BPM process used for implementing the solution
Source: authors' contribution

from sales and distribution - O2C - Order to Cash, procurement - P2P - Procure to Pay, SAP PP production process, additive manufacturing process (3D printing), to SAP QM including the storage in SAP WM of the resulting products, as the core system, with all non-SAP applications, took into account the reliability of system integration.

The components of the BPM system that were considered in the design are: process modeling, analysis and optimization of automated processes, identification of weaknesses, inefficiencies and opportunities for improvement. The final aim is to propose changes to improve and optimise the business processes in question, in order to maximise their efficiency and effectiveness.

An additional aspect addressed was the automation and management of business processes through the use of intelligent workflow management systems.

Another component of the BPM system used in the design of the production process modeling was that of monitoring and control in all aspects of performance tracking. The modelling covered the flows of sales, purchasing, production, quality management, as well as warehouse management serving the business for which this automation and interfacing was done in terms of the smart technologies used. The configuration of the ticketing platform-ERP system process and its implementation are shown in Figure 3. It contains all the steps, from receiving and creating a ticket in the platform assigned to this type of activity (ServiceNow), to transforming and transferring the requirement to the ERP-SAP system (sales order).

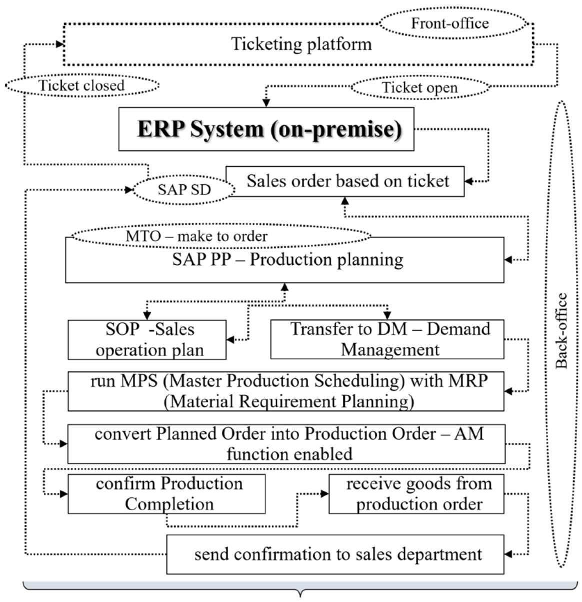

Figure 3. Implemented workflow ticketing platform – ERP system

The entire production process, up to receiving the finished product in stock, sending it to the customer, then closing the ticket created, constitutes the entire circuit.

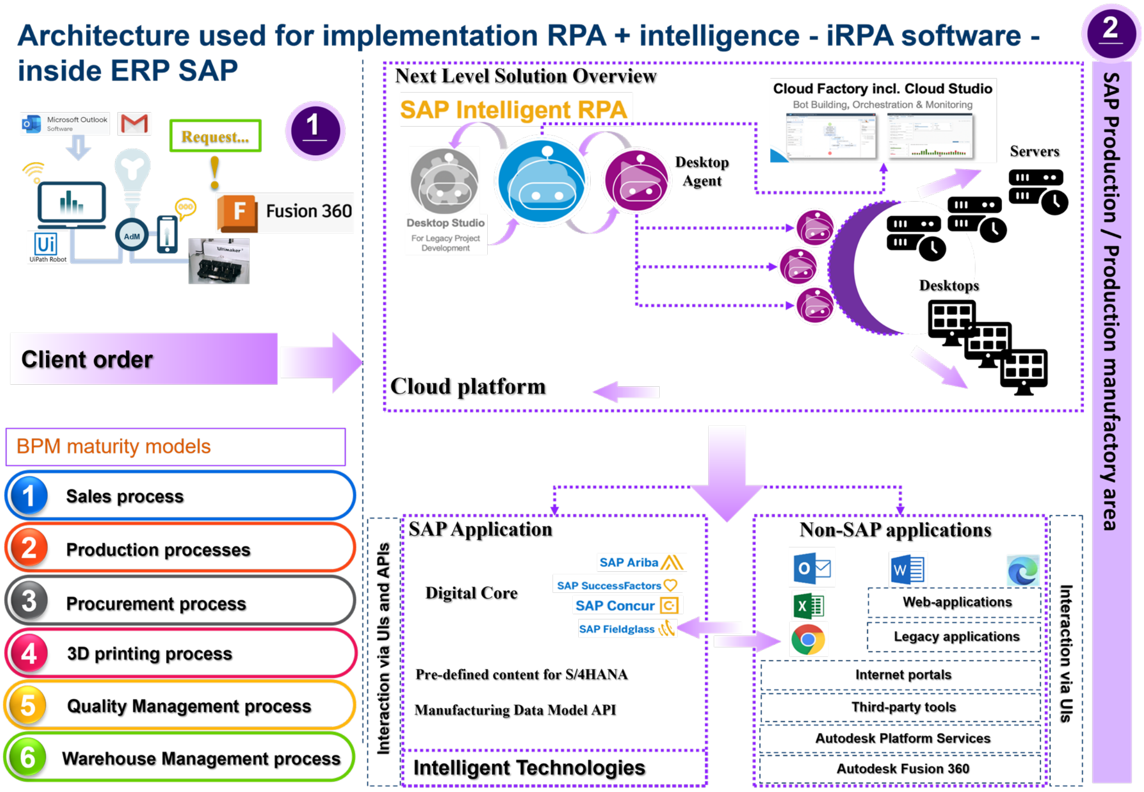

Figure 4. Sistem architecture with iRPA – RPA + intelligence used for implementing the solution

3.3 Integrated Architecture Using iRPA –RPA + Intelligence Inside ERP SAP

The need for company management is to improve the automation of the closely interlinked business process flows, from sales, where the initial demand for the product to be produced is recorded, to production, which is closely linked to supply. If a shortage of raw material is identified, it will be automatically ordered, by using a software robot that will create supply orders based on stock level analysis.

Figure 4 shows a system architecture that integrates operational workflows using iRPA - RPA + intelligence inside SAP ERP.

After the products have been produced, the quality management process is triggered, i.e., the inspection necessary to see if the product meets all the manufacturing standards, as it can be seen in Figure 5. If everything goes according to normal parameters, the warehouse management process is automatically triggered, which represents the way to store the created product.

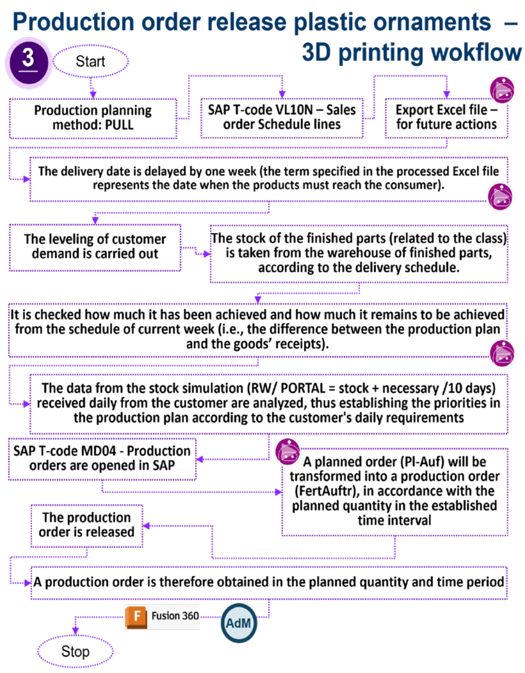

Figure 5. Implemented workflow ticketing platform – ERP system

4. Results and Discussions

The implementation of the system architecture facilitates the attachment within the SAP integrated system of the file containing the data

(G-code) required for 3D printing or sending the information from the G-code file to the Computer Numerical Control (CNC). The CNC can send data to various machine tools, which are used to process and manufacture components using subtractive methods (Ryan & Theis, 2001) such as cutting or milling materials, as opposed to additive 3D printing methods, which build objects layer by layer.

The set up of existing business processes in the car company uses a number of BPM system components, thus aiming at a uniform modeling in terms of adaptation and adoption of smart technologies, in order to integrate them into the existing steps of the operational flow.

In the business process related to the SAP PP production area - Production order release plastic ornaments - 3D printing (PORPO3D) - software robots have intervened, with the task of taking over repetitive tasks and reducing response times for certain requirements.

The design of the SAP PP - PORPO3D process, integrated with AM, involved the creation and adaptation of an interface that would be able to transmit the information necessary for the subsequent production of the finished product, i.e. design using fusion 360, 3D slicer: bambulab, PETG (polyethylene terephthalate glycol - raw material) printing material. OLC45 steel (heat-treatable quality steel for machine building) was used in the CNC, as shown in Figure 5. The idea of linking the SAP ERP system with non-SAP applications, such as Autodesk Fusion 360 software, was intended to make it possible to store the information required for the execution of the desired finished products in the SAP system as a file attached to the material registered in the SAP MM (material management) module of the integrated system.

The described correlation offers the possibility that the system, by means of a software robot using AI, can automatically correlate the incoming requirement (from the sales order) with the existing G-code needed to produce the finished product, either for 3D printing or using CNC. As shown in Figure 6, it is possible to create a series of materials/products, maintaining several characteristics in the material master maintained in the SAP ERP system as the core system, including technical details related to the raw materials used, i.e., steel, plastic, etc., depending on the requirements for 3D printing or CNC use.

The implementation of the solution required an extended timeframe and a mixed team of specialists. The integration of iRPA into SAP software has had positive implications on the functionality of the ERP-SAP system and has been well accepted by the company, as the cost

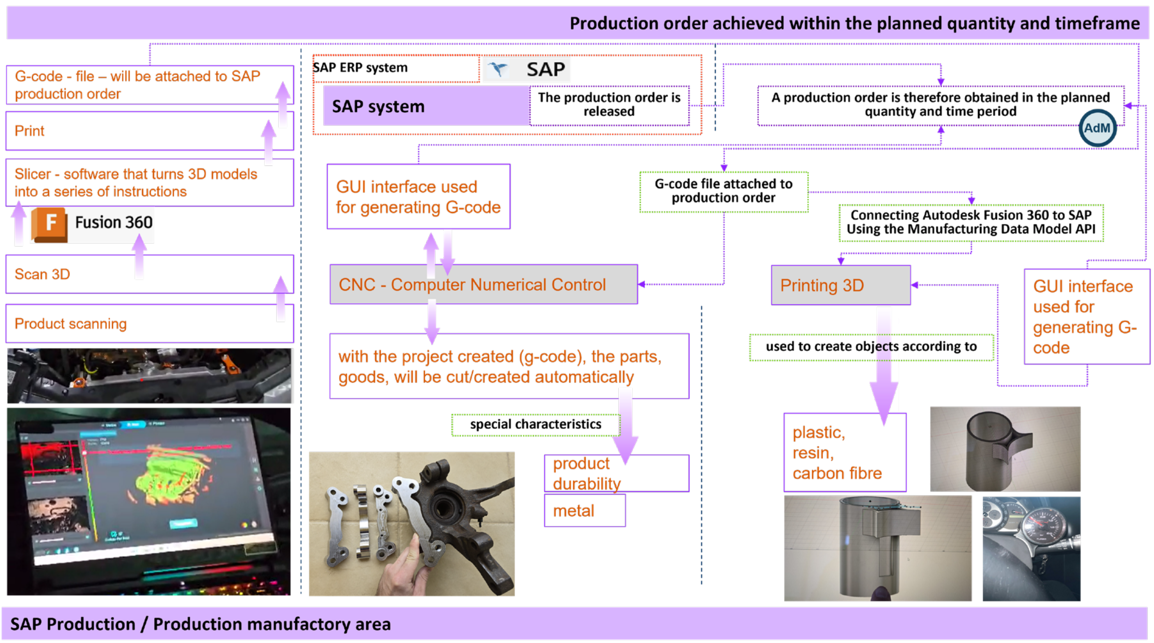

Figure 6. End-to-end non-SAP process including additive manufacturing
Source: authors' contribution

of the full SAP service package is lower than the cost of individual services. In contrast, during the implementation phase of UiPath's RPA solution, there were several runtime errors due to frequent updates of the supplied software, and it was more difficult to integrate.

In conclusion, the integration of software solutions from the same vendor is much more feasible.

In addition to the specific technical issues mentioned above, the implementation of the new system architecture in the production process has created challenges related to the responsiveness of the company's staff to the changes brought about by the integration of smart technologies, a critical issue being the training of employees and their ability to adapt to change. The causes were related to a significant proportion of staff with secondary education and the age of employees, with slow adaptation to change and negative consequences on staff turnover.

However, the implementation of the new system architecture has generated several positive effects on the company's business processes, both qualitative and quantitative.

Thus, from the operating errors (order processing delays, repeat the operation of wrong orders, etc.) generated before the integration of iRPA and RPA into the ERP-SAP system, the transmission of customer orders has been optimized and, now, it is carried out automatically, non-stop by the software robots, which helps the company to better link sales-supply-production-warehousing activities.

The quality of products produced by integrating additive manufacturing (3D printing) has improved, resulting in a growing customer base, although the company operates in an increasingly competitive market.

A benefit in business efficiency is reflected in the significant increase in labor productivity, quantified as the average sales value per employee. If before the new system architecture implementation, the average annual labor productivity rate was between +11% and +15%, after it became operational, the annual productivity increased from 22-25% to 31%, after 4 years of operation, as shown in Figure 7.

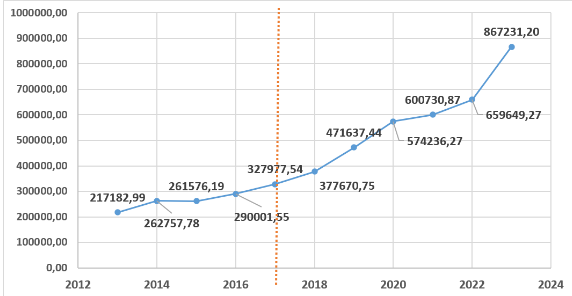

Figure 7. Productivity growth before and after implementing the intelligent solutions

It can be stated that the performances obtained are the effect of ensuring scalability in the integration of the new components (iRPA, RPA and AM in ERP-SAP). Both in the design and implementation phases, repeated changes were made to the integration of new software components, memory, and storage, although this involved higher costs, which improved the working capacity of the servers used for the software solution. Involving software bots, working with a single user required for interfacing, has streamlined operational activity (which also involves higher licensing costs) by integrating system components, an essential attribute of ensuring the performance of the newly created system.

Due to changes in customer perception, customers increasingly want to obtain individualized products and the life cycles of goods (products, materials, etc.) are becoming shorter. For a company to remain competitive, time to market needs to be much faster, which is essential to achieving economic and financial performance. Customer demand for products to be customized will lead to more complex product variants, forcing companies to be agile and more responsive to market needs.

5. Conclusion

The researchers set out to develop and implement a project in a company, in the automotive industry, that could automate as many workflows as possible, such as the preparation of the delivery list, on the one hand, and the production plan for certain products, on the other, which come together in a sales order created for a certain range of products, to respond to a customized request.

The integrated design of this architecture using BPM ensures the automation of several steps performed in either SAP ERP or non-SAP applications.

The SAP ERP system, using the iRPA solution, facilitates the optimization and automation of most of the work tasks encountered in the specific business processes of the targeted automotive company. However, there are certain limitations related to the used non-SAP applications (Fusion360, CNC, etc.), and the iRPA solution provided by SAP cannot be useful. Therefore, the solutions provided by UiPath were used, and UiPath performed several activities related to non-SAP applications.

Considering what has been presented in this project, the implementation of advanced technologies using AI, iRPA/RPA and the integration of three-dimensional (3D) digital model object manufacturing into the production processes of the automotive company are pertinent decisions to adopt in the development strategies needed to ensure competitiveness in the Industry 4.0 era.

Today's manufacturing companies are challenged to produce not only mass-produced, but also customized products in an environment of variable, ever-changing customer demand, in a highly volatile market. Robotic process automation is a key driver of digital transformation and a response to the industry's staff shortage. The automotive industry needs to enable the use of artificial intelligence in terms of open innovation, both for manufacturing and business management.

The generalization of the proposed system architecture to other business sectors can be done by considering the particularities of the existing infrastructure, the production processes, and the version of the ERP system used (CORE system). Thus, it can be stated that firms belonging to the circular economy could benefit from the system architecture presented in this article.

The study solves practical problems and also contributes to the theoretical development of innovative design of new system architectures that streamline business process management systems.

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