Analysis of the Impact of Advanced Technologies on Business Processes

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This study examines how advanced manufacturing technologies influence the performance of business processes through a Business Process Management approach. A basic product manufacturing process was selected as a case study and modelled in its current (AS-IS) and redesigned (TO-BE) states using the EPC method in the ARIS tool. The redesigned process integrates 3D scanning, CAD modelling, additive manufacturing, and collaborative robotic assembly while removing manual fabrication, paper documentation, and repetitive handling activities. Both process models were compared using performance indicators, including the number of activities, documents, and the share of IT-supported tasks. A comparative analysis shows that technology integration allows mass customization and increases digital support and automation. The findings suggest that although advanced technologies enable long-term process standardization and data transparency, organizations may experience short-term structural complexity and implementation challenges. The study contributes empirical insight into how advanced technologies reshape process structure and performance measurement.

DOI
https://doi.org/10.18690/um.fov.4.2026.42

ISBN
978-961-299-152-4

Keywords:
business process management,
advanced technologies,
process modelling,
digital transformation,
manufacturing process

University of Maribor Press

1 Introduction

Modern organizations face unprecedented pressure to improve process efficiency in response to dynamic market demands and shorter product lifecycles. Industry 4.0 and 5.0 paradigms emphasize aligning production processes with advanced technologies to meet customer needs quickly and flexibly (Sachdeva et al., 2023). This article explores the impact of these technologies on key process performance indicators. In the following, we first define business process management and key performance indicators. This is followed by a chapter that discusses various modern technologies and their impact on business process execution.

However, existing studies often discuss advanced technologies such as additive manufacturing, 3D scanning, CAD/CAM, and collaborative robots separately, with less attention given to how their combined implementation changes the structure and measurable indicators of a concrete business process. In particular, there is limited process-level evidence showing how such technologies affect process models, documentation flows, role allocation, and IT-supported activities. This study addresses this gap by comparing a real badge manufacturing process before and after the integration of selected advanced technologies.

1.1 Business process management

Business Process Management (BPM) is a structured, holistic approach that enhances organizational performance by systematically managing and continuously improving business processes (Lahajnar & Rožanec, 2015). It encompasses the identification, modelling, execution, monitoring, and optimization of processes, aligning operational activities with strategic objectives (Dumas et al., 2013). The BPM life cycle is typically divided into six core phases: preparation for improvement, process mapping, analysis, improvement, solution implementation, and process monitoring (Dumas et al., 2018). Among these, the most critical phases for achieving sustainable process enhancement are analysis, improvement, and monitoring.

The analysis phase forms the cornerstone of informed decision-making in BPM. It entails a thorough examination of existing processes to identify inefficiencies, redundancies, bottlenecks, and deviations from expected performance levels. Analytical activities are typically divided into two key dimensions: operational and structural analysis of process indicators (Krhač Andrašec, 2022). Operational analysis focuses on dynamic performance indicators, including time, cost, quality, and flexibility (Franz et al., 2012; van der Aalst, 2013; Urh et al., 2018). Structural analysis, on the other hand, examines the underlying architecture of processes, including task sequencing, role allocation, communication flows, and interdependencies among process elements (Sarnikar & Deokar, 2017). Both dimensions are essential for uncovering the root causes of performance issues and developing data-driven strategies for process improvement.

The improvement phase aims to modify and optimize business processes based on insights gained during analysis. A wide range of measures, methods, and techniques (Krhač Andrašec, 2022) may be employed, depending on the specific context and identified performance gaps. Common approaches include Lean Management (Sari et al., 2017), Six Sigma (Tosuner et al., 2016), Total Quality Management (Rusev & Salonitis, 2016), and Business Process Reengineering (Botha et al., 2012), each offering distinct methods and techniques for process optimization. Methods and techniques such as root cause analysis (Pinney et al., 2015), simulation (Dumas et al., 2018), and benchmarking (Boutros & Cardella, 2017) further support the systematic development and evaluation of improvement scenarios. Interventions may target changes in workflows, information systems, or organizational roles.

The monitoring phase involves continuously tracking key performance indicators (KPIs) to assess the effectiveness of implemented improvements and ensure long-term alignment with organizational objectives (Dumas et al., 2018). This phase not only verifies the success of transformation initiatives but also facilitates early detection of emerging issues, thereby sustaining a cycle of continuous improvement. Feedback obtained during monitoring is typically reintegrated into the BPM life cycle, promoting adaptability and responsiveness in dynamic business environments.

In summary, BPM provides a comprehensive framework for managing and improving organizational processes. The integration of operational and structural analyses, targeted improvement methods and techniques, and rigorous performance monitoring enables organizations to achieve higher levels of efficiency, quality, and agility.

1.2 Advanced technologies and their impacts

In the context of Industry 4.0 and 5.0, several advanced technologies (especially collaborative robots, 3D scanning, and additive manufacturing) are changing how business processes are executed. We examine how these technologies are impacting different key process performance indicators. These technologies also serve as key enablers that make new process designs and performance improvements possible.

Collaborative robots (cobots) are designed to work safely alongside humans and support repetitive, strenuous, or precise tasks. By automating repetitive assembly work, cobots can increase production rates and allow workers to focus on more complex activities (Borboni et al., 2023). Wang et al. (2019) also report productivity gains from cobot integration in a real assembly process, while human-robot collaboration can improve efficiency, quality, and safety (Gualtieri et al., 2020). Cobots also provide ergonomic benefits by reducing exposure to unfavourable postures and repetitive strain (Realyvásquez-Vargas et al., 2019). In addition, they improve consistency, reduce human error, and increase flexibility, as they can be reprogrammed for new tasks more easily than conventional stationary automation. This makes small-batch and customized production more cost-efficient by reducing the need for retooling or specialized equipment (Ford & Despeisse, 2016; Vranić, 2017).

Three-dimensional scanning improves process efficiency, especially in design, prototyping, and quality control. It captures physical objects as high-resolution digital data, which can then support CAD modelling and reduce the need for manual measurement. Modern 3D scanning can speed up product development in design, testing, and production, while reducing development time, costs, and design errors (Haleem et al., 2022; Javaid et al., 2021). In some cases, accurate scan data has reduced design cycle costs by up to 75% compared with traditional methods (Muminović et al., 2024). 3D scanning also supports quality control by enabling fast comparison of manufactured parts with CAD specifications, helping to detect defects or deviations more quickly than traditional inspection methods (Yao, 2005). This can reduce reject rates and rework, improve cost efficiency, and support consistent quality (Klemenčić & Skala, 2013), while also enabling greater flexibility in engineering changes and mass customization.

Additive manufacturing (AM), commonly referred to as 3D printing, streamlines prototyping and production by building products layer by layer from digital models. This reduces the need for specialized tools and enables greater design freedom. AM can shorten development cycles and reduce manufacturing time, leading to faster time-to-market for new designs (Attaran, 2017). It also improves cost efficiency because no hard tooling or moulding is required, making small production runs and customized parts more economically viable. In addition, AM uses only the material needed for production, which reduces waste, costs, and environmental impact compared with traditional cutting processes (Duraković, 2018). Companies can also print spare parts or customized products on demand, reducing inventory needs and the risk of overproduction (Shivananda Devi & Nilanjana, 2022).

Computer-aided design and manufacturing (CAD/CAM) systems support modern product and process development by linking digital design with production. The introduction of 3D CAD modelling can shorten development time from concept to production while also reducing costs (Vranić et al., 2017), as potential problems can be identified virtually and the need for physical mock-ups is reduced. CAD-based rapid prototyping also enables complex product geometries with minimal additional costs or delays (Jorgić et al., 2025). Once the design is finalized, CAM software can optimize manufacturing by creating efficient toolpaths, reducing machining time and scrap, and supporting consistent quality through automation (Iwata, 2003). CAD/CAM integration also embeds specifications and tolerances into manufacturing instructions, reducing interpretation errors and improving consistency across production runs (Sivakumar & Dhanalakshmi, 2013; Sun, Xia, & Mao, 2010). Finally, customizable CAD models support product customization and quick engineering changes (Shin & Kwak, 2003), enabling mass customization when combined with additive manufacturing or high-speed CNC (Shui-liang, 2007; Barros, Duarte, & Chaparro, 2014).

The reviewed literature shows that each technology can improve specific aspects of process performance, such as speed, quality, flexibility, ergonomics, or cost efficiency. Nevertheless, most studies focus on individual technologies or general implementation benefits. Fewer studies examine how several advanced technologies interact within one redesigned business process and how this affects structural process indicators. This paper focuses on the combined process impact of 3D scanning, CAD modelling, additive manufacturing, and cobot-assisted assembly.

2 Methods

This study analyses the impact of advanced manufacturing technologies on business process performance indicators through process modelling and comparison. We selected a badge manufacturing process as an example case study. A single-case design was selected because it enables a detailed comparison of process structure, roles, documents, and system support before and after redesign. The analysed process represents a real small-batch badge production workflow used as a case study for modelling and redesign. This current process (AS-IS) was modelled using the EPC method in the ARIS tool based on documented workflow steps, roles, and information flows. The model captured all activities, involved employee roles, documents, and system support.

Next, a redesigned process (TO-BE) was developed by introducing selected Industry 4.0 and 5.0 technologies, namely 3D scanning, CAD modelling, AM, and cobot assembly. Manual fabrication steps, paper documentation, and repetitive handling activities were mostly removed or automated. Both process models were analysed using process indicators defined by Krhač Andrašec (2022).

Finally, a SWOT analysis was performed to evaluate the TO-BE model and assess the overall impact of technology implementation. The study addresses the following research question: "How does the integration of advanced manufacturing technologies affect performance indicators of a production process?".

The contribution of the study is twofold. First, it provides a process-level comparison of the same manufacturing workflow in its AS-IS and TO-BE states, rather than discussing technology impacts only at a general organizational level. Second, it shows how the integration of multiple technologies changes structural indicators such as the number of activities, documents, and IT-supported tasks. In this way, the study links the theoretical discussion of Industry 4.0/5.0 technologies with concrete BPM-based process redesign evidence.

3 Results

3.1 Current badge-making process

The current (AS-IS) process of badge manufacturing begins when, upon receiving a customer order, the availability of products in stock is checked, the data is entered, and planning changes are monitored. This is followed by the calculation of material requirements, after which it is determined that either:

- the sticker with the logo is not available,
- the sticker carrier is not available,
- the materials or components are available.

In the first case, material requirements for the first semi-finished product are calculated. If the production material is unavailable, the process proceeds with procurement; if it is available, the material issue process follows. After the material and components are issued from the warehouse, the 2D printer operator prints the labels, and the warehouse worker and production worker transfer the components to stock.

In the second case, material requirements for the second semi-finished product are calculated. Depending on material availability, the process continues with procurement or material issue. After the material and components are issued from the warehouse, the production worker cuts and shapes the base material, performs surface finishing and cleaning, and glues the clip to the carrier. The warehouse worker and production worker then transfer the components to stock.

Once all materials and components are available, capacity planning follows. If capacity is unavailable, the process is repeated. Otherwise, the planner prepares the working documentation, and the material issue process is carried out. The warehouse worker prints the product labels, after which the production worker manually affixes the labels to the carriers and packages the products in bags. Finally, product transfer to the warehouse and production reporting are carried out simultaneously. The process ends when the products are in stock and ready for shipment.

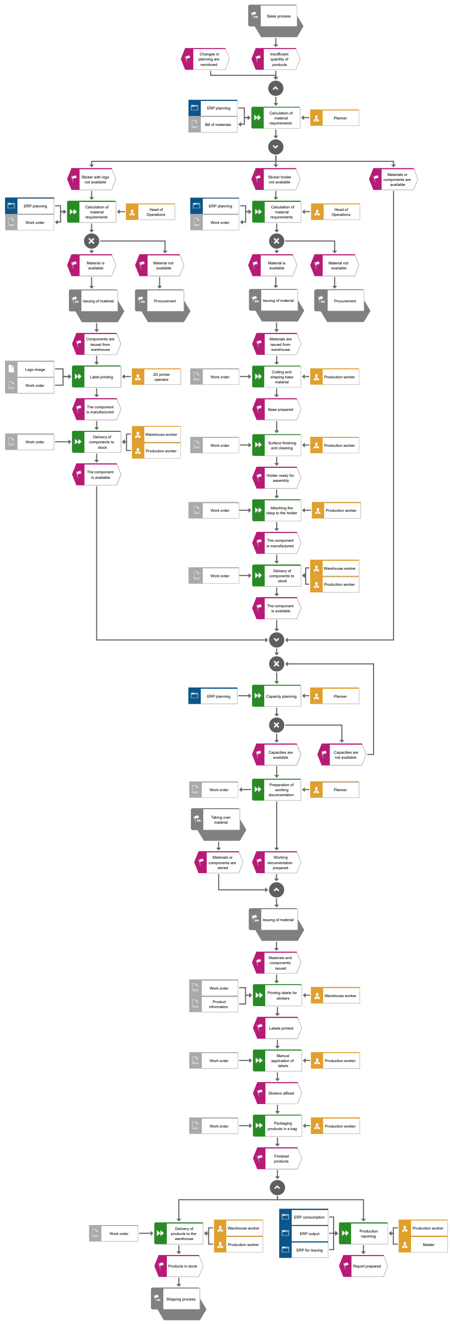

Figure 1: Process model in initial (AS-IS) state

Source: Own

The ARIS tool was used to prepare the current state of the selected business process. The model of the selected process execution is shown in Figure 1.

3.2 Redesigned badge-making process

In the TO-BE process, to introduce mass customization, the production flow is redesigned to integrate digital technologies and eliminate manual, low-value activities. When the product is not in stock, the new process introduces 3D scanning of customer samples and 3D CAD modelling. These activities run in parallel with a simplified material availability check to ensure that printing materials are ready for use. The 3D scan and CAD model together form a digital job packet that includes the CAD file, 3D printer settings, and label design. This replaces the paper-based drawings and work instructions used in the AS-IS process and provides a single, standardized input for production.

In the manufacturing phase, manual activities such as cutting, shaping, and surface finishing are removed entirely. The 3D printer now fabricates the badge holder or semi-finished component directly from the digital model. Because of on-demand AM, there is no longer a need to plan or issue semi-finished holders from stock. Only the filament or resin used for printing must be monitored and replenished. This reduces waiting times and eliminates delays caused by workshop availability or external suppliers. The result is a shorter and more flexible production cycle that can efficiently handle both standard and custom orders.

During assembly and packaging, a cobot replaces several manual, repetitive tasks. The cobot applies the label with vision guidance, performs an automatic visual inspection to verify label position and quality, and helps attach the clasp to the holder and package the finished component. These changes enhance process precision, minimize human error, and substantially reduce the physical strain on workers. The cobot cell ensures a more stable and predictable cycle time while freeing operators to focus on supervision and quality monitoring.

Finally, the information flow is fully digitalized. The paperwork, orders, and manual confirmations in the AS-IS process are replaced by automatic data exchange with the ERP. The system now records printing status, inspection results, and completion confirmations directly from the cobot cell. This enables real-time visibility of work in progress and quality data, removing late or missing postings.

The changes are marked with red circles in Figure 2 below.

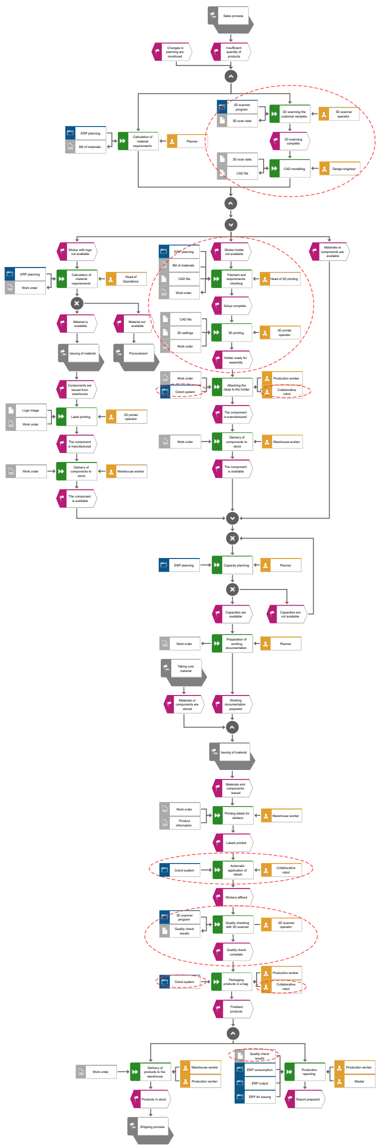

Figure 2: Process model in redesigned (TO-BE) state

Source: Own

4 Discussion

4.1 Analysis and comparison of process models

The TO-BE process introduces 3D scanning, CAD modelling, 3D printing, and robotic assistance, while removing manual fabrication, paper documentation, and repetitive handling. One of the main benefits is mass customization, which combines the high-volume efficiency of mass production with the individualized tailoring of custom-made products (Meglič & Jeraj, 2004). The expected results include shorter lead times, reduced rework, higher first-pass yields, improved ergonomics, lower inventory levels, and simplified planning that focuses solely on printing materials (Attaran, 2017; Realyvásquez-Vargas et al., 2019; Shivananda Devi & Nilanjana, 2022).

In accordance with the established research purpose, an analysis of the processes in both their current and redesigned states has been conducted. The analysis encompasses the fundamental indicators identified by Krhač Andrašec (2022). The number of activities increases (from 16 to 18) due to introduction of machine vision quality control integrated with the help of cobot, which increases the quality of products. The number of documents rises, but they are mainly replaced by electronic forms that are now stored within the system. At the same time, the share of IT-supported activities grows from 31.25% to 55.56%, reflecting the integration of digital modelling, AM and robotic assistance.

The comparison shows that technology integration initially increases structural complexity despite higher automation levels. Therefore, it is possible to conclude that the process after the implementation of advanced technologies initially deteriorates primarily in terms of time (e.g. due to adaptation to a new method of execution) and cost (e.g. due to a significant initial investment). Given the initially poorer understanding of the process and of advanced technologies, it is expected that at least a temporary deterioration in process execution quality will occur. Overall, despite short-term structural challenges, the redesigned process is expected to support long-term improvements through more IT-supported activities, greater use of electronic documentation, more stable execution, and a gradual shift of employees from repetitive manual work toward supervision, quality monitoring, and exception handling.

4.2 SWOT analysis of the integrated digital production workflow

The SWOT analysis in Figure 3 summarizes the main operational factors linked to the integrated 3D scan–CAD–AM–cobot workflow. It highlights key internal strengths (Bhuiyan, 2011; Liu et al., 2022) and weaknesses (Quanjin et al., 2020; Jonuzakov, 2023) together with external opportunities (Gruska and Cherry, 2005; Walter and Marcham, 2020) and threats that may affect implementation, performance, and long-term sustainability.

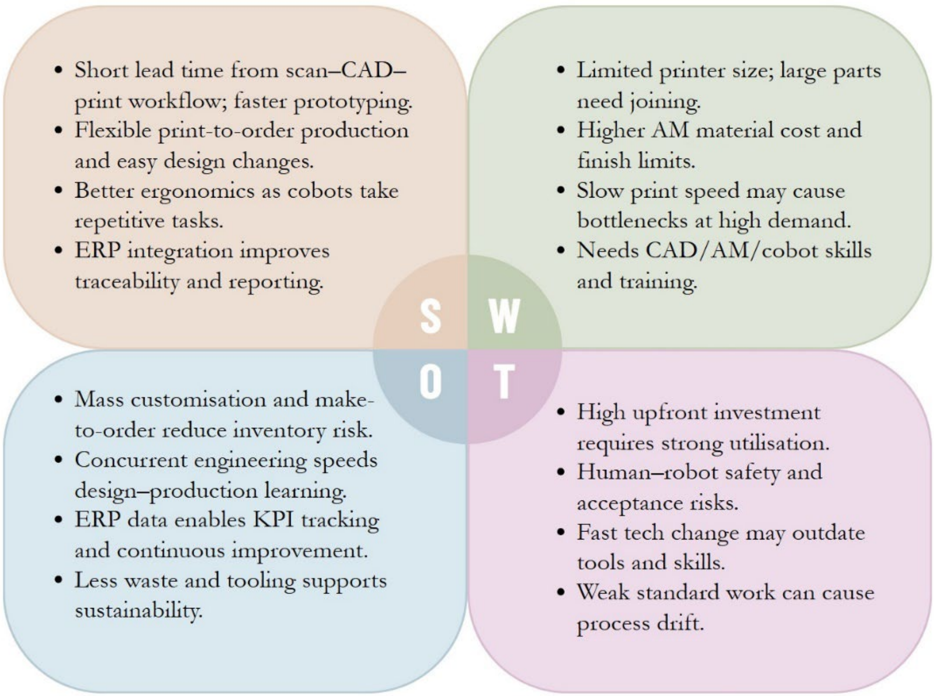

Figure 3: SWOT analysis of the redesigned process
Source: Adapted from Jorgić et al. (2025)

Overall, the redesigned process replaces manual and paper-based steps with a digital workflow integrating 3D scanning, CAD modelling, AM, and robotic assistance linked to the ERP system. The comparison shows higher digital integration, automated handling, and consolidated information flows through a unified digital job packet. These effects align with established findings that AM shortens development cycles and reduces setup effort (Attaran, 2017; Vranić et al., 2017;

Wong & Hernandez, 2012), CAD-based workflows reduce design errors and iteration time, 3D scanning supports faster modelling and inspection (Ebrahim, 2015; Haleem et al., 2022), and cobots stabilize execution while reducing manual strain (Liu et al., 2022; Pearce et al., 2018; Villani et al., 2018). Consistent with product-development research, the results suggest that digital technologies improve process consistency and flexibility, although implementation may initially increase structural complexity and require organizational adaptation (Agrawal & Bhuiyan, 2014; Guzik, 2023).

Despite these benefits, several practical limits must be considered. Printer size, material constraints, and high production volumes may limit the suitability of the redesigned process, while investments in equipment, training, and safety require careful planning. These factors should be included in capacity planning, workforce preparation, and operational control.

This study also has limitations. First, it is based on a single case process, which limits the generalizability of the findings. Second, the TO-BE process is a redesigned model rather than a fully implemented and measured process. Therefore, the expected effects on time, costs, quality, and learning curves should be validated in practice. Third, the analysis does not include detailed investment costs, training costs, equipment utilization, or organizational readiness, all of which may affect whether the redesigned process delivers the expected benefits.

To support long-term improvement, organizations should monitor key performance indicators such as lead time, first-pass yield, and labour time per unit. Regular KPI review links process analysis, improvement, and monitoring. Overall, Industry 4.0 and 5.0 technologies can stabilize execution, improve transparency, and reduce manual strain, while supporting future optimization and scaling. The main novelty of this study is not the analysis of one technology, but the BPM-based demonstration of how several technologies jointly reshape the structure, documentation, automation level, and control logic of a concrete manufacturing process. Future work could extend the EPC-based information flow model with material flow analysis to better assess inventory movement, resource utilization, and the efficiency of mass customization processes.

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