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# The Impact of Process Management on Productivity and Flexibility in Digitalized Production Systems Within the Context of Advanced Manufacturing Techniques

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**Abstract.** Digitalization and the Industry 4.0 approach have brought about not only a technological transformation in production systems but also a radical change in the way processes are managed. The aim of this study is to examine the effects of process management on production efficiency and flexibility in digitalized production systems within the context of advanced manufacturing techniques. The study is designed as a qualitative research based on a literature review; the concepts of process management, digitalization, efficiency, and production flexibility are addressed within a holistic framework. The findings show that digital technologies (IIoT, data analytics, process mining, digital twin) provide a high amount of data and automation in production processes; however, this potential needs to be integrated with process management principles to translate into efficiency and flexibility. It is concluded that process management plays a critical role in monitoring performance indicators and reducing losses in terms of efficiency, and in developing alternative process designs and rapid adaptation mechanisms in terms of flexibility. The study reveals that digitalization and process management must be considered together to achieve a sustainable competitive advantage in advanced manufacturing techniques.
**Keywords**: *Advanced manufacturing techniques, process management, digitalization, production efficiency, production flexibility.*

## 1. Introduction

Today, production systems are undergoing a major transformation due to the increasing pressures of global competition, the shortening of product lifecycles, and the constantly changing customer demands. In this transformation, companies are expected not only to achieve high production capacity but also to successfully manage performance elements such as efficiency, flexibility, rapid adaptation, and process effectiveness. Within this context, digitalization and the Industry 4.0 concept stand out as a significant paradigm shift in reshaping production systems (Şener et al., 2020).

Industry 4.0 describes the digitalization of production processes through cyber-physical systems, the Internet of Things (IoT), big data analytics, and intelligent automation technologies. This method enables real-time data flow in production systems and makes decision-making processes faster, more accurate, and more flexible (Buri, 2025). This structure of digitalization requires a reassessment of production processes not only from a technological perspective but also from a managerial and process-oriented point of view.

Process management is a management strategy based on defining, measuring, monitoring, and continuously improving the input and output relationships of business organizations. In production systems, process management plays a crucial role in the efficient use of resources, reducing errors within the process, and improving performance indicators. In digitized production areas, process management replaces manual monitoring and control methods with data-based and automated process monitoring systems; this makes process performance more transparent and measurable (Bilgin Sarı, Özveri & Şenyay, 2019).

The impact of digital transformation on productivity is frequently discussed in the literature. Digital technologies reduce downtime in production stages, make processes more efficient, and significantly prevent resource waste (Adem, 2020). In particular, smart sensors and big data analytics applications enable real-time performance monitoring on the production line, helping to achieve more effective process management (Buri, 2025).

On the other hand, it is observed that digitized production systems have a significant impact not only on efficiency but also on production flexibility. Production flexibility is defined as the ability to adapt to product variety, respond quickly to demand fluctuations, and reorganize production systems. Industry 4.0 technologies offer businesses a competitive advantage by increasing this flexibility through modular production structures and digital process design (Höse et al., 2023; Castiglione, 2024).

The aim of this research is to comprehensively examine the effects of process management on productivity and flexibility in digitized production systems within the context of advanced manufacturing techniques. In this framework, the study evaluates the relationship between digitalization and process management; considering productivity and flexibility, the two main dimensions of production performance, it aims to highlight the strategic importance of process management.

**2. Advanced Manufacturing Techniques and Digitalized Production Systems**

Advanced manufacturing methods represent modern production approaches and go beyond traditional methods; they are based on the integration of technology, information, and processes. These methods include automation, flexible manufacturing systems, computer-aided manufacturing, robotics, and data-driven decision-making processes. The main goal of advanced manufacturing methods is to increase efficiency in production processes, improve quality, and establish flexible structures that adapt to changing market conditions (Şener et al., 2020).

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Digitized production systems enable data generation at every stage of the production process and real-time analysis of this data. Thanks to Internet of Things (IoT) based sensors, critical indicators such as machine performance, production speeds, error rates, and energy consumption can be monitored in real time. This allows for early detection of deviations in production processes and more effective process management (Adem, 2020).

The integration of advanced production techniques with digitalization has paved the way for the emergence of the concept of smart factories in production systems. Smart factories are defined as production systems that can monitor themselves, learn, and make decisions to a certain extent. In these systems, production processes are automated to reduce human intervention; coordination between processes is ensured through digital platforms (Bilgin Sarı, Özveri & Şenyay, 2019).

Another significant contribution of digitalization to advanced production techniques is its ability to reconfigure production systems. While process changes in traditional production systems require high costs and time, in digitized production structures, processes can be redesigned based on software. This provides businesses with a significant advantage in increasing product variety and responding quickly to demand fluctuations (Höse et al., 2023).

The literature emphasizes that the success of digital manufacturing systems depends not only on the technologies used, but also on the extent to which these technologies are integrated with process management principles. Integrating digital technologies into production processes randomly or haphazardly will not deliver the expected performance increase; on the contrary, it may increase the complexity of the processes. Therefore, the effectiveness of advanced manufacturing techniques requires a process management approach where processes are managed end-to-end and continuously monitored using performance indicators (Castiglione, 2024).

In this context, digitized production systems increase the applicability of advanced manufacturing techniques and make process management a central component of these systems. Without process management, it seems impossible to transform the data and automation opportunities offered by digital production systems into sustainable competitive advantages. Therefore, advanced manufacturing techniques, digitalization, and process management are considered the cornerstones of modern production systems.

**3. The Concept of Process Management and its Application in Production Systems**

Business Process Management (BPM) is an approach that treats business activities not as fragmented structures like "department tasks," but as end-to-end processes that transform inputs into outputs. It manages processes through a cycle of defining, modeling, executing, monitoring, and continuous improvement (Dumas, La Rosa, Mendling & Reijers, 2018). In a manufacturing environment, the value of BPM emerges by making the production flow (material-information-decision) visible and its performance measurable: indicators such as cycle times, workstation load balance, waiting times, rework/defects, and energy consumption can more clearly show "where losses are occurring" from a process perspective. Therefore, when considered together with advanced manufacturing techniques (automation, flexible lines, robotics, data collection infrastructures), process management manages not only technological capacity but also the transformation of the output produced by technology into process performance.

In terms of quality and management systems, the process approach forms the basis of ISO 9001:2015 and emphasizes the need to plan processes along with their interactions and to regularly monitor process performance using the PDCA cycle and risk-based thinking (ISO, 2015). This approach becomes even more functional in digitized production systems, as sensors, MES/ERP, and production automation systems generate much more frequent, detailed, and reliable data about processes. Thus, process management ceases to be a "process defined on paper" and transforms into a dynamic management system that can be continuously verified with data and allows for rapid action when deviations occur.

Process mining is one of the fundamental tools that strengthens process management in digital manufacturing; it allows for the revelation of process flow, identification of bottlenecks, and quantitative analysis of deviations through event logs generated by information systems. Systematic reviews conducted within the context of Industry 4.0 show that as the level of real-time data sharing and automation in production increases, process mining becomes more critical in terms of monitoring, compliance control, and continuous improvement activities (Akhramovich, Serral Asensio & Cetina, 2024). Especially in the dynamic and frequently changing nature of smart manufacturing systems, maintaining the currency of digital twin and simulation-based decision support tools is gaining importance; in this context, studies aimed at dynamically creating production models using process mining provide a roadmap for implementation by concretizing data requirements and model updating approaches (Friederich, Lugaresi, Lazarova-Molnar & Matta, 2022). Furthermore, current applications demonstrating that process discovery can be performed via industrial communication data (e.g., IIoT/OPC UA network data) show that data collected from the field can be directly recovered as operational insights for process management (Hornsteiner et al., 2024).

BPM literature states that using technology to change the way a business operates is better if the business also possesses the skills and habits to do so well (Huy, 2025). This implies that some research on how IoT and BPM work together shows that using sensors and smart products can help people better see what is happening in a process; however, it also suggests that it can complicate the process, and this complication needs to be addressed through effective process management methods (Janiesch et al., 2020). Other studies on AI-powered BPM systems show that models that learn from process data can aid in process monitoring and decision support. However, it is also important to consider reliability, constraints, and governance principles.

**4. The Impact of Process Management on Production Efficiency**

How well a production system uses its resources to produce output depends on how much and how well that output is. - Digitalized production systems can do more work faster and better. But that's not enough. They need to avoid problems that prevent them from working and show how much they lose when they do work. They also need to ensure they produce the right things the first time and deal with potential losses. - Process management makes work faster and better by frequently checking and changing tasks. - Process management uses numbers and facts to see and solve problems, rather than guessing and hoping for better results (ISO, 2014).

The first critical step in process management that contributes to efficiency is monitoring process performance using KPIs as a common language. The ISO 22400-2 standard frames the definition, formulas, and usage contexts of KPIs used for manufacturing operations management, thus helping businesses create a consistent and comparable framework for "what each indicator measures" (ISO, 2014). However, since designing KPIs in a "neutral" way across sectors does not always fully meet the needs of the process industry, there are also studies discussing the gaps between the specific performance needs of the process industry and the ISO 22400 KPI set (Zhu, Johnsson, Varisco, et al., 2018). At this point, process management requires the creation of a measurement architecture tailored to the company's manufacturing characteristics, rather than blindly applying the KPI set.

One of the most common indicators for monitoring efficiency and analyzing losses is Overall Equipment Efficiency (OEE). OEE shows how efficiently equipment uses its planned production time by evaluating availability, performance, and quality components together (IBM, undated). The practical value of OEE lies in revealing losses in the process from different perspectives through these three key components; for example, availability losses are mostly due to downtime, performance losses are due to speed reductions and minor stoppages, and quality losses are due to errors/defects and start-up losses (Leroux, undated). This "loss reading" logic of OEE facilitates the accurate prioritization of improvement in process management (OEE.com, n.d.).

Digitalization significantly enhances the capacity of process management to create efficiency because losses can be measured more frequently and in greater detail thanks to sensors, MES/ERP logs, and IoT-based data collection systems. This transforms indicators like OEE from a "monthly report" into a management tool that can be monitored in real time and enables action. For example, a case study using real-time OEE data reported that monitoring supported by Industry 4.0 technologies (IoT, big data, cloud) reduced unplanned downtime in the studied work centers and led to a significant increase in average productivity (Novochadlo & Paladini, 2024). The critical point from a process management perspective is not just collecting data, but also linking that data to process discipline in terms of which decisions it triggers at which thresholds (outage analysis, root cause, maintenance/adjustment plan, standard job update, etc.).

Finally, one of the current trends in increasing efficiency is the combined use of lean manufacturing tools and process mining. Process mining can more objectively reveal bottlenecks and deviations by extracting the actual flow of the process from event logs generated in information systems. When combined with a lean perspective, this approach has the potential to identify waste in the value stream in a "data-verified" way and detect real-time deviations at an early stage (Khakpour, Ebrahimi, and Seyed-Hosseini, 2024). Thus, process management shifts efficiency gains from one-off projects to a continuous measurement-analysis-improvement cycle (continuous improvement).

**5. The Impact of Process Management on Production Flexibility**

In today's rapidly digitalizing manufacturing environment, "flexibility" is not only the capacity to produce different products, but also the ability to adapt the system from the design stage to the face of demand uncertainty, product variety, and changing constraints. Therefore, flexibility is systematically addressed in the literature by categorizing it into different types such as capacity, product/product mix, routing, volume, and trigger time, and determining which types of flexibility become critical under which manufacturing paradigm (Weckenborg et al., 2024). It is particularly emphasized that in high-mix, low-volume (HMLV) production structures, flexibility has transformed from an "operational preference" into a necessary capability for competitiveness due to on-demand production, short product lifecycles, and frequently changing workflows (Gan et al., 2023).

At this point, process management provides a framework that transforms flexibility from “scattered improvement initiatives” into an end-to-end measurable and manageable system capability. The process approach makes it possible to monitor both efficiency and adaptability simultaneously by defining value streams, process ownership, standard work, and data-driven performance indicators (e.g., cycle time, delivery reliability, rework rate). When choosing between different types of flexibility, decision-making models and evaluation approaches should be used to determine which level of flexibility is meaningful in terms of “necessary” and “available” flexibility (Höse et al., 2023; Weckenborg et al., 2024). Thus, process management transforms the abundance of data brought about by digitalization not only into reporting but also into an operating logic that produces a rapid and controlled response to change.

When Industry 4.0 components (IIoT, cyber-physical systems, data analytics, etc.) are integrated with process management, flexibility shifts from “reactive adjustment” to “proactive adaptation.” In the literature, this relationship is explained as technologies sometimes increasing existing flexibility, while in other cases, they reduce “necessary flexibility” by providing better information and coordination (Höse et al., 2023). For example, real-time monitoring and predictive analytics make variable demand and capacity constraints visible earlier, allowing process owners to manage them before bottlenecks occur. This logic is particularly important in the reconfigurable manufacturing systems (RMS) approach: designing systems according to the principles of modularity, scalability, and adaptability supports the implementation of process changes at a lower cost and in a shorter time (Koren, 2018; Yelles-Chaouche et al., 2021).

Digital twin applications elevate process management to the level of “simulation-validated decision-making” because process changes (planning rules, resource allocations, checkpoints, etc.) can first be tested in a virtual environment and then implemented in the field with lower risk. Experimental reports show that digital twin-based control in flexible manufacturing systems can provide significant improvements in productivity, energy consumption, and quality indicators (Ullah & Younas, 2024). Similarly, approaches that combine digital twins with artificial intelligence components aim to accelerate "dynamic reconfiguration" decisions regarding layout, parameters, and operating times at the production cell/line level (Mo et al., 2023). In this context, process management links insights obtained from digital twins to KPIs (e.g., OEE, lead time, transition time), connecting flexibility to a measurable, comparable, and sustainable improvement cycle.

**6. Literature Review and Discussion**

Literature examining the relationship between advanced manufacturing techniques, digitalization, and process management shows that these three components, when considered together, create significant and sustainable impacts on production performance. Studies conducted within the framework of Industry 4.0, in particular, emphasize that digital technologies (IIoT, big data analytics, cyber-physical systems) increase the traceability and controllability of processes, thereby enhancing the effectiveness of process management (Höse et al., 2023). This demonstrates that process management has gone beyond being merely a management tool and has become a central component of digital manufacturing systems.

When productivity-focused studies are examined, it is seen that digitalization initiatives not supported by a measurement and continuous improvement cycle fail to deliver the expected performance increases. Indicators such as KPIs and OEE, defined within the framework of ISO 22400, allow for the systematic identification of productivity losses in digital production environments; however, these indicators often remain tools used only for reporting purposes when they are not integrated with process ownership, shared responsibility, and a culture of continuous improvement (Zhu et al., 2018). In this context, the literature reveals that process management, as a governance mechanism that makes sense of digital data, interprets it, and transforms it into concrete improvement actions, plays a critical role in increasing productivity (Novochadlo & Paladini, 2024).

In terms of production flexibility, research shows that digitalization alone does not guarantee flexibility; flexibility must be structured from the design phase of processes through modularity, alternative routing, and decision rules (Weckenborg et al., 2024). Studies focusing on high-complexity, low-volume production environments highlight that process management reduces flexibility costs and shortens response times by ensuring coordination in these complex structures (Gan et al., 2023). These findings support the view that flexibility is as much about "process design and management" as it is about "technological capacity".

The current literature addressing process mining, digital twins, and AI-powered BPM approaches demonstrates that they elevate data-driven decision-making capabilities in process management to a higher level. Process mining enables the visualization of real process flows, allowing for the objective identification of bottlenecks affecting efficiency and flexibility (Khakpour et al., 2024). Similarly, digital twin-based approaches reduce the risk of flexibility decisions by allowing process changes to be tested before implementation in the field (Mo et al., 2023; Ullah & Younas, 2024).

When these findings are considered together, the key point emphasized in the literature is that the impact of digitalization on production performance is meaningful only insofar as it is integrated with process management. Digital technologies increase data without process management; however, process management lacks speed and agility without digitalization. Therefore, in the context of advanced manufacturing techniques, these two dimensions need to be addressed simultaneously and in a coordinated manner to sustainably increase productivity and flexibility.

**7. Conclusion and Recommendations**

This study comprehensively examines the effects of process management on productivity and flexibility in digitized production systems within the context of advanced manufacturing techniques. When the literature findings are considered together, it is seen that the contribution of digitalization to production performance becomes meaningful and sustainable when supported by a process management approach in which processes are systematically defined, measured, and continuously improved (Höse et al., 2023; Weckenborg et al., 2024). In other words, digital technologies alone do not increase productivity and flexibility; their integration with process management principles plays a decisive role.

The findings regarding efficiency show that process management stands out, particularly through its measurement and visibility functions. Systematically monitoring production losses through KPIs defined within the framework of OEE and ISO 22400 enables early detection of unplanned downtime, speed losses, and quality-related waste in digital production environments (ISO, 2014; Novochadlo & Paladini, 2024). This demonstrates that with digitalization, process management has moved beyond being merely a "reporting" tool and has become an action-oriented performance management tool.

In terms of production flexibility, process management addresses flexibility not only as a temporary capability based on operational interventions, but also at the design and governance levels. The literature emphasizes that flexibility should be considered in different dimensions such as product mix, volume, and orientation, and that these dimensions are directly related to process design (Gan et al., 2023; Weckenborg et al., 2024). While digitalization enables faster evaluation of alternative process scenarios, process management transforms flexibility into a controlled and sustainable capability by defining under what conditions and how these scenarios will be implemented (Höse et al., 2023).

Additionally, contemporary approaches such as process mining and digital twins take the data-driven decision-making capabilities of process management to a higher level. Process mining enables objective analysis of real process flows, facilitating a more accurate detection of bottlenecks affecting efficiency and flexibility (Khakpour et al., 2024). On the other hand, digital twin-based applications reduce decision risk, especially in flexible production systems, by enabling process changes to be tested before implementation in the field (Mo et al., 2023; Ullah & Younas, 2024). These tools turn process management into a strategic decision support mechanism in digitalized production systems.

From a practitioner's perspective, the study's key emphasis is that digital transformation projects should not be viewed solely as technology investments. It is crucial that such projects are considered in conjunction with process ownership, performance indicators, and a continuous improvement approach. It is recommended that businesses transitioning to advanced production techniques first clearly define their existing processes, identify critical points of variation within those processes, and develop data-driven decision rules for these points (ISO, 2015). This holistic approach enables businesses to manage their production processes more effectively and adapt to changing conditions in a more controlled manner.

Finally, some suggestions can be made for future studies. First, there is a need for application studies that examine the relationship between process management, digitalization, and performance at the sector and enterprise levels based on empirical data. Second, a comparative evaluation of the effects of integrated approaches that consider process mining and digital twin applications on productivity and flexibility will contribute to the literature. Lastly, the inclusion of dimensions such as sustainability, energy efficiency, and human-machine interaction within the framework of process management is important for understanding the future directions of studies in the field of advanced manufacturing techniques.

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