

DIGITAL TRANSFORMATION AND KEY PERFORMANCE INDICATORS IN MANUFACTURING: A COMPREHENSIVE LITERATURE REVIEW

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Abstract: *Digitalization presents a revolution in the manufacturing sector that refers to the transition from traditional to digital technologies forming an integral part of Industry 4.0. The purpose of the article is to present the relevant literature dealing with Digital Key Performance Indicators and Digital Transformation Key Performance Indicators and their application in the manufacturing industry. The aim of the article is to improve the comprehension of digitalization in production processes and their optimization, where these key performance indicators are of high importance. The intention of the article is to highlight the importance of the application of digitalization in manufacturing companies, identifying key challenges, by presenting the results of the literature review using the bibliographic databases Scopus and Web of Science. The results presented in this article can help manufacturing companies improve the planning of their resources and direct them towards digital transformation, tending to gain a competitive advantage in the market.*

Keywords: *digitalization, Industry 4.0, manufacturing, digital KPIs, digital transformation KPIs*

1. INTRODUCTION

Digitalization presents a key process of transition from traditional work methods to digital technologies. In modern business, huge progress has been made in the fields of information technology, automation and robotics. All these technological achievements are a prerequisite for the development of Industry 4.0, that presents “the current trend of digitalization, automation and data exchange in production” (Thun et al., 2019). Industry 4.0 is a new industrial era that digitally transforms all processes across industries, from manufacturing to logistics, through innovative technologies (Rajković et al., 2023). The first step in digital transformation is “to assess the digital maturity and readiness of the company” (Machado et al., 2019). In practice, companies often encounter challenges in the process of digitalization, such as lack of skills and employees, finding the appropriate technology, balance between strategic, operational and financial KPIs, and others (Kane et al., 2018). Concerning all mentioned, digitalization has transformed the way companies do business, communicate and manage resources and processes. It has profound implications for every industrial branch, especially manufacturing. To achieve company objectives, it is essential to continuously monitor and measure performance, making adjustments as needed to align with desired outcomes (Radjenović et al. 2023). To measure performance effectively, it is crucial to establish specific performance indicators, along with the methods and benchmark values needed for comparing the results of these indicators (Lečić-Cvetković et al., 2024). With the emergence of digitalization, the need to monitor and measure performance through Digital Key Performance Indicators (DKPIs) and Digital Transformation Key Performance Indicators (DTKPIs) has appeared. “Digital transformation is characterized by the fusion of advanced technologies and the integration of physical and digital systems, enabling innovative business models and new production processes to prevail” (Almeida et al., 2020). Digitalization has impacted DKPIs and digital transformation in several ways. It enabled companies the need for KPIs measurement and analysis to collect a greater amount of data using technologies such as the Internet of Things (IoT), Data Analytics (DA) and Artificial Intelligence (AI), to extend the set of KPIs that companies use and measure, as well as to provide a deeper understanding of the company's processes (Siedler et al., 2020). It has also empowered incremental innovations in the way how companies operate, requiring new KPIs to measure the efficiency of business models and processes. This provides a reduction in production costs and increase flexibility. Digitalization presents a key driver of changes enabling performance measurement in the fast and more dynamic business environment. This article introduces the concepts of DKPIs and DTKPIs in the manufacturing industry by reviewing the relevant literature in this field.

This article consists of five chapters. The first chapter is the introductory chapter. The second chapter presents theoretical concepts of digitalization in the manufacturing industry. The third chapter presents the research methodology and summarized results of the literature review of articles from the Scopus and the Web of Science (WoS) bibliographic databases. The fourth chapter presents the findings from the literature review pointing out the significance of DKPIs and DTKPIs in assessing digital performance and transformation strategies. The conclusion of the article is presented in the fifth chapter.

2. DIGITALIZATION IN PRODUCTION MANAGEMENT

In 2011, when the term Industry 4.0 was introduced, digitalization has received increasing attention, aiming at a digitalized industry that has become more dynamic. In this regard, digitalization affects not only production processes, but also business models, and for this reason in practice is also referred to as digital transformation (Jeske et al., 2021). The main goal of digitalization in the manufacturing industry is primarily to increase productivity, efficiency and support human-robot cooperation. Digitalization in the manufacturing industry provides new opportunities for process optimization that can directly affect the improvement of product quality and cost reduction. Digital transformation is defined as “the use of new digital technologies (devices, social media) to enable major business improvements, such as improving user experience, simplifying manufacturing operations or even creating new business models” (Liere-Netheler et al., 2018). In this regard, it encompasses the change of business model, monitoring and processes in production using digital technologies such as IoT, AI, DA, robots and others. It presents “one of the most important keys to competitiveness in the era of Industry 4.0, guaranteeing high performance in production indicators through linking productivity and flexibility, eliminating costs and improving product quality” (Bitsanis & Ponis, 2022). “The ultimate goal of digital transformation is to increase sales, sustainability and customer satisfaction” (Libert et al., 2016). DTKPIs are used to determine how far a company has progressed in its digital strategy and in improving its results in the digital market, while DKPIs present measurable indicators that are necessary to manage and monitor the production process performances, enabling companies to analyze the impact of the digitalization process in all business processes. DKPIs should support operational objectives and include parameters such as production efficiency, overall equipment effectiveness (OEE), downtime, product quality and other indicators to assess the success of the application of digital technologies (Miqueo et al., 2020). The DTKPIs and the DKPIs present an important part of the management strategy, as they allow companies to quantitatively analyze what impact digitalization has on the business. Understanding the process of digitalization and its benefits in manufacturing environments, both theoretically and practically, it allows companies to better plan and strategically direct their resources towards digital transformation, indicating the great importance of this topic for the manufacturing industry.

3. RESEARCH METHODOLOGY

The aim of this article is to explore the utilization of DKPIs and DTKPIs within the manufacturing industry. Specifically, this research endeavours to analyze the implementation and efficacy of these KPIs in optimizing various facets of manufacturing processes. For this research, a systematic literature review of articles based on the application of DKPIs and DTKPIs in companies was done. The authors of this article have applied the following research methodology (Tomašević & Slović, 2022; Tranfield et al., 2003): formulation of research questions, sourcing of articles, screening of articles and analysis of articles, as presented in Figure 1.

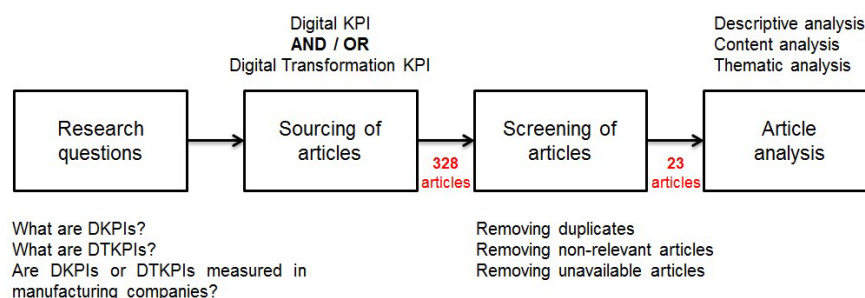


Figure 1: Research methodology

The first phase of the research methodology was to define three research questions that reflected the purpose of this article: What are DKPIs?; What are DTKPIs? and Are DKPIs or DTKPIs measured in manufacturing companies? The second phase of the research methodology was the sourcing of articles. To comprehensively explore the landscape of DKPIs and DTKPIs and their role in digital transformation, a systematic research strategy was utilized. Two keywords were selected to search bibliographic databases: “digital kpi” and “digital transformation kpi”. These terms were chosen to encompass various aspects of performance measurement in the context of digital initiatives. These terms were combined using the “AND” association to refine the search results (e.g. “digital kpi” AND “digital transformation kpi”). The search was confined to article titles, abstracts and keywords, focusing on peer-reviewed journals and articles written in

the English language from 2014 to 2024. The search was conducted using bibliographic databases such as Scopus and WoS. Using both databases ensures comprehensive coverage across publishers without excluding any, with Scopus offering wider coverage and WoS providing access to older sources, aiding thorough research (Thürer et al., 2019). Authors chose to search only journals as Source type to ensure the inclusion of peer-reviewed literature and reviews, prioritizing recent and scholarly information pertinent to their research. The search resulted in a total of 328 articles, all included in the original sample. The third phase of the research methodology was a screening of articles. By removing duplicates, the original sample was reduced to 325 articles. By reviewing the references cited in the selected article, the authors have discovered an additional 8 articles that aligned with search terms and research questions. Despite not being retrieved from the Scopus and WoS databases, these articles were deemed relevant and were included in the analysis. Upon examining the titles, abstracts and keywords of the articles identified in the search results, six out of eight articles from the WoS database, 293 out of 317 articles from the Scopus database and six out of eight additionally included articles were excluded. This resulted in a total of 28 articles remaining for the subsequent stage of analysis. Figure 2 and Table 1 summarize the basic characteristics of the 28 articles sample. Figure 2 illustrates a progressive increase in published articles over the years, particularly notable in 2022 and 2023, indicating a heightened level of engagement or focus within the field during those two years.

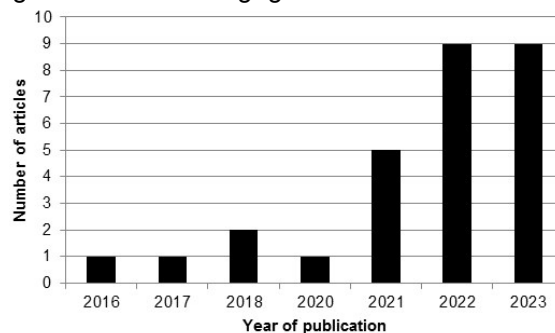


Figure 2: Distribution of articles per publication year

Table 1 presents the most common journals that have published selected articles.

Table 1: Journals where selected articles were published

Journal	No. of articles
International Journal of Computer Integrated Manufacturing	3 (10,71%)
IEEE Access	3 (10,71%)
Sustainability	3 (10,71%)
Applied Sciences	2 (7,14%)
Machines	2 (7,14%)
Other (one article per journal)	15 (53,57%)

For five out of 28 articles, authors did not have access, so the original sample was finally reduced to 23 articles. The remaining 23 articles underwent a detailed analysis, as presented in the fourth chapter.

4. RESEARCH FINDINGS

To facilitate analysis, an Microsoft Excel spreadsheet was created as a two-dimensional matrix to collect relevant research information. During the detailed literature review analysis, six out of 23 articles did not provide essential information regarding the results of DKPIs and DTKPIs application and KPIs, so they were excluded from the detailed analysis, leaving 17 articles to be in detail analyzed. The following details were extracted from each article and presented in Table 2: identification of the industry sector where the company from the analyzed article operates; identification of DKPIs or DTKPIs in the article; concise clarification of how and why the specified KPIs are employed within the observed industry; enumeration of the KPIs specified per article, with a focus on the most significant ones; specification of the outcomes ensuing from the implementation and measurement of the identified KPIs. The noticeable focus on DKPIs and DTKPIs within manufacturing is exemplified by the nine articles, highlighting their critical role in directly evaluating digital strategies associated with manufacturing, five articles demonstrate indirect connections, while three show no connections. Various definitions are available to address the initial research question. The response to the first research question (*What are DKPIs?*) is presented in the following. DKPIs are essential metrics used to evaluate various aspects of a company's performance in the digital era, providing quantitative insights into the company's digital activities, such as online presence, customer engagement, operational efficiency and sustainability efforts (Engel et al., 2022; Joo et al., 2022). These KPIs are quantifiable metrics derived from real-time data processing, essential for evaluating and optimizing industrial performance across various levels, particularly within the context of Industry 4.0 (Ferrer et al., 2018). Within the specific industry, DKPIs are strategically used for different purposes. These include enhancing workplace design to foster

productivity and employee satisfaction, tackling environmental concerns by reducing carbon emissions and optimizing production processes to improve cycle time (Joo et al., 2022; Kanan et al., 2023). The response on the second research question (*What are DTKPIs?*) is that DTKPIs are quantifiable parameters used to evaluate the progress and success of a company's efforts to adapt, innovate and leverage digital technologies across its operations, processes and strategies (Sanchez-Gonzalez et al., 2022). These KPIs have a crucial role in facilitating a company's improvement and innovation across various sectors, including minimizing customer complaints, optimizing operational efficiency and enhancing product quality (Ng Corrales et al., 2022; Salwin et al., 2023). By tracking DTKPIs related to minimizing customer complaints, companies can assess the effectiveness of their digital initiatives in addressing customer needs and resolving issues promptly, leading to higher satisfaction and loyalty (Salwin et al., 2023). DTKPIs focus on optimizing operational efficiency and product quality, enabling organizations to identify areas for improvement, streamline processes and deliver better products and services to customers (Fortoul-Diaz et al., 2023; Sarabia-Jácome et al., 2020). Additionally, by developing evaluation systems encompassing financial, logistics, customer and improvement perspectives, companies can assess the holistic impact of digital transformation efforts, guiding strategic decision-making and ensuring alignment with overall business objectives (Xiao-Ping et al., 2021). The answer to the third research question (*Are DKPIs or DTKPIs measured in manufacturing companies?*) is that DKPIs and DTKPIs are certainly measured in manufacturing companies. Based on the results presented in Table 2, it can be concluded that DKPIs focus on measuring the performance of specific digital activities or channels, while DTKPIs assess the broader impact of digital initiatives on the company's overall transformation path and strategic objectives.

Table 2. DKPIs and DTKPIs in different industry branches

Article	Industry	DKPIs / DTKPIs	Application	KPIs	Results
(Aiello et al., 2020)	Manufacturing	DTKPIs	Assisting decision makers in decision-making; KPIs for monitoring preventive maintenance effectiveness	Component efficiency; Equipment reliability; Number of interventions; Number of alarms	A secure maintenance management approach using blockchain and mathematical models showcased through pump monitoring
(Demko-Rihter et al., 2023)	Manufacturing	DKPIs	Improving ability for material reusability; Decreasing material losses; Increasing the share of recycled materials in new products	Proportion of material losses; Quantity of production material compared to GDP; Recycling rates for wastes	Not stated
(Engel et al., 2022)	Service	DKPIs	Formalizing customer expectations; Ensure accountability for service quality	Service availability; Service up-time; Incident resolution time;	Not stated
(Facchinetti & Citterio, 2022)	Telecom	DKPIs	Monitoring performance and resource optimization	Overall equipment productivity	Defined measures of the service-providing efficiency factors
(Ferrer et al., 2018)	Manufacturing	DKPIs	Illustrating and implementing a set of KPIs as outlined in the ISO 22400 standard	Allocation efficiency; Utilization efficiency; Availability; Quality ratio; Scrap ratio	Defined KPIs improved monitoring performance and enhanced the management of production activities (scheduling, resource allocation...)
(Fortoul-Diaz et al., 2023)	Manufacturing	DTKPIs	Improving the efficiency of the asset in performing repetitive tasks	On-time delivery; Average task completion time; Time activity	Achieved on-time delivery; More precise architecture in competition time; Assets perform a task close to half of the total time
(Joo et al., 2022)	Manufacturing	DKPIs	Improving the effectiveness of energy-intensive manufacturing methods to attain carbon neutrality	Specific energy consumption; Total production; Pouring temperature (quality facet)	Reducing process loss without altering product quality or existing facilities resulted in a 12.6% decrease in energy consumption
(Kanan et al., 2023)	Manufacturing	DKPIs	Improving workplace design; Reducing carbon emissions produced from direct use of electricity; Improving cycle time	Job satisfaction; Carbon emission by material wastage; Cycle time; Lead time	Improvements in work design reduced stress; Carbon emissions reduced by 19.2%; Reduction in cycle time by 15.5%
(Lange et al., 2021)	Service	DTKPIs	Maximize aerodynamic performance, resource efficiency and competitiveness in Formula Student racing projects	Drag; Downforce	Major design improvements led to performance upgrade
(Marziala et al., 2022)	Transportation	DKPIs	Problems with the outsourced logistic systems; Trucks failed to provide services on time; Order fulfillment issues	Punctuality of trucks; Order picking errors	Developed KPIs enhance operational oversight and foster real-time decision-making
(NG Corrales et al., 2022)	Logistics	DTKPIs	Increasing the overall efficiency in the production support activities	Availability; Performance; Quality; Punctuality	Guiding framework, enhanced data collection; Data-driven management transition; Optimized truck arrival planning
(Salwin et al., 2023)	Manufacturing	DTKPIs	Minimizing customer complaints; Optimizing operational efficiency and product quality	Employee performance; Quantitative production indicator; Level of complaints; Level of scrap	Employee performance and production performance nearly 10% higher; Scrap level decreased by 47% (plastic) and 22.6% (steel)
(Sanchez-Gonzalez et al., 2022)	Transportation	DTKPIs	Aiming to facilitate the industry's digital transformation	Improvement on ratio cost using old process; Decrease in human errors; Decrease in annual maintenance hours	Implementing given KPIs allows maritime container shipping companies to identify quick wins, optimize processes, align strategies, mitigate risks and measure success

Table 3. (continued)

Article	Industry	DKPIs / DTKPIs	Application	KPI	Results
(Sarabia-Jácome et al., 2020)	Transportation	DTKPIs	Monitoring and enhancing the efficiency of the operation leveraging Industry 4.0 technologies	Vessels average time occupancy; Container terminal occupancy weekly; Average time waiting for a free terminal	Streamlined seaport systems through integrated Big Data architecture, enhancing operations planning, decision-making and coordination
(Verhaelen et al., 2021)	Manufacturing	DKPIs	Defining indicators from three dimensions (costs, flexibility, innovations) and two levels (site and supply network)	Material stock; On-time delivery date; Throughput time; Batch size	Performance improvement, in supply network (access to new customers and markets) and site level (efficiency, quality, flexibility)
(Watanabe et al., 2018)	Manufacturing	DKPIs	Evaluating the performance indicators for dispersed productive systems related to sustainability	Wastewater discharged; Packaging materials reused; Energy costs; Labor accident rate	The framework tracks sustainability in developing countries but may need adjustments for cases where sustainability is a top priority
(Xiao-Ping et al., 2021)	Logistics	DTKPIs	Developing evaluation system through financial, logistics, customer and improvement perspective	Sales revenue; Warehouse cost; Average delivery time interval; IT penetration	The utilization of IT and digitalization significantly enhances the efficiency, accuracy and coverage of information transfer

5. CONCLUSION

Digitalization in industry, including the manufacturing industry, is changing the company's environment by enabling companies to face challenges in the environment and make better progress. It also enables changing the way performance is measured, that allows improving the efficiency of production processes, productivity and product quality. Digitalization is related to Industry 4.0 and its technologies. It often happens that technologies are implemented, but the company is not ready to fully exploit their potential, that depends on the degree of the company's development. This article identifies important aspects of the application of DKPIs and DTKPIs in production through systematic research of the relevant literature. Their importance in production was highlighted, allowing for quantitative analysis of the impact of digitalization on processes and business as a whole. DKPIs provide measurable indicators for evaluating manufacturing processes, such as equipment efficiency, downtime, product quality, and others, while DTKPIs present indicators of the success of the business model transformation. Together, they give an overall picture of the company's business performance, enabling the company's management to make timely and adequate decisions, following a strategy with predefined digitalization goals. The direction of future research of the authors of this article is to examine the effectiveness of applying the DKPIs and DTKPIs in companies around the world from various industries and to identify opportunities for further improvement of business processes.

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