

The Development of Digitalization Management in the Automotive Industry: Processes and Challenges

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Abstract. Digitalization represents one of the most significant transformations with a direct impact on the competitiveness, sustainability, and adaptability of modern organizations. The adoption of digital technologies is no longer an option, but an essential condition for survival and adaptation, particularly in the economic and technological context shaped by Industry 4.0 and the transition towards Industry 5.0. The topic is highly relevant given the accelerated transformation of market requests, the speed of technological change, as well as increasing pressures related to sustainability and competitiveness. The paper contributes to the topic by analyzing the current stage of digitalization management in the automotive industry, by structuring the processes and stages specific to digital transformation. This analysis provides a clear understanding of how organizations can approach digitalization in a systematic manner, with illustrative examples from the automotive sector, thereby reducing risks and maximizing benefits. Taking into consideration that the world is changing constant, digitalization stands as a transformative driver of the economic and technological environment, enabling companies to adapt swiftly, foster innovation, and maintain competitiveness.

Keywords: Digitalization, Management, Automotive Industry, Innovation, Competitiveness.

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Introduction

Digitalization can be defined as the process through which organizations integrate digital technologies into operational, managerial, and production processes in order to achieve greater efficiency, flexibility, and capacity of innovation [1]. In the automotive industry, digitalization plays a crucial role due to major internal and external pressures: strict sustainability regulations, the need to reduce carbon emissions, growing international competition, and the necessity to adapt to changing consumer requests. This is reflected in connected vehicles, the use of Artificial Intelligence (AI) in design, the optimization of supply chains through Big Data, the development of smart electric vehicles, and the use of digital platforms for customer relations [2].

This study provides a structured analysis of the stages and processes required for the effective implementation of digital technologies, highlights the challenges and opportunities associated with the transition toward Industry 5.0 – where sustainability and personalization become priorities – and offers a critical perspective on current transformations and future challenges. The aim is to enable organizations to better understand their level of digital maturity, identify existing gaps, and develop feasible strategies for the future [3].

The research establishes a comprehensive theoretical framework that deepens the conceptual understanding of digital transformation within the automotive industry, thereby supporting the development of evidence-based strategies and informed policy recommendations

Literature review

The evolution of the concept

The concept of Industry 4.0 marked the beginning of integrated digitalization throughout the product life cycle [4]. In the automotive industry, this change translated into the transition from rigid production lines to smart and flexible factories capable of responding quickly to market demands [5]. However, prior to Industry 4.0, earlier stages of industrial development included Industry 1.0, focused on technical drawings, computers measurements, and interchangeable parts; Industry 2.0, focused on mass production; and Industry 3.0, centered on automation. All of them contributed gradually to the current stage.

The evolution continues with Industry 5.0, which emphasizes the interaction between humans and technology by unlocking human potential [2]. Consequently, automotive digitalization emerges as a combination of automation, personalization, and social responsibility. Figure 1 illustrates the timeline of each industrial stage.

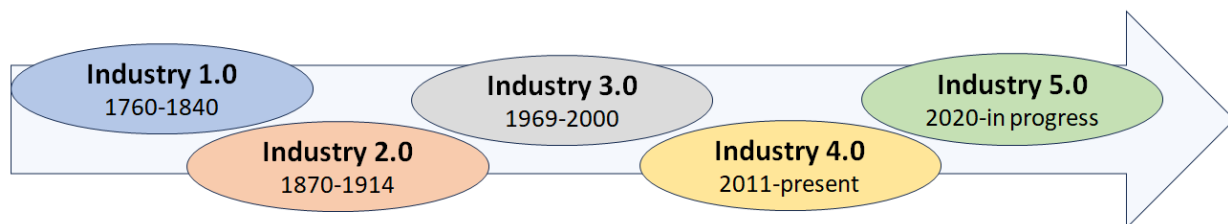


Figure 1: Emergence of industries

Source: Author's own contribution

Key technologies

The literature highlights several technologies supporting the digitalization process, such as:

- *Internet of Things (IoT)* that connects vehicles to digital infrastructures for monitoring, such as equipment tracking and real-time data collection in production, or real-time delivery tracking in logistics [6].
- *Blockchain* that ensures transparency and security in both logistics and production by protecting data integrity and preventing manipulation [7], [8].
- *Artificial Intelligence (AI) and Big Data* that enable the collection and analysis of large volumes of information on consumer behavior and preferences, while supporting component design [9], [10].
- *3D Printing* is applied in prototyping and spare parts manufacturing [11].

Digitalization represents the transformation of activities, processes, and analog information into digital formats. This process enhances efficiency, accessibility and data analysis capacity through the effective use of digital technologies. Beyond converting physical data (e.g. paper documents) into digital formats, digitalization reshapes organizational activity by fostering the adoption of new technologies and digital strategies [12].

Naturally, several constraints exist within the digitalization process, such as financial resources and technological infrastructure, which may serve as both barriers and catalysts. While the costs of adopting digital technologies are substantial, small and medium-sized enterprises (SMEs) face significant challenges in securing financial resources. Moreover, outdated technological infrastructure often requires costly upgrades to ensure compatibility with new digital solutions [13], [14].

Stages of Digitalization

The digitalization process requires several stages to be followed for successful implementation:

- *Analysis and planning* represent the first steps in the digitalization process, achieved through the evaluation of the company's current state [15] and the identification of strategic objectives [16]. These involve a detailed analysis of internal processes, IT infrastructure, and employee competencies. It is also essential for companies to clearly define which aspects of their business they intend to digitalize whether production, logistics, or after-sales services [17] and, crucially, to identify the drivers behind this transition, such as competitive pressure, market regulations, and customer expectations. Recognizing these factors determines the necessity of initiating the digitalization process [18].

- *Technology implementation* involves selecting and deploying the most appropriate digital technologies [19]. These may include IoT, AI, Big Data, Cloud Computing, and process automation [20]. When considering technology adoption, attention must be paid to organizational culture and resistance to change, as these may significantly slow down or even halt the implementation process [21].
- *Monitoring and optimization* represent the final stage of digitalization, consisting of continuous performance monitoring and the adjustment of strategies based on obtained feedback [22]. The analysis of data collected from diverse sources enables companies to identify opportunities for improvement and drive constant innovation [23]. Additionally, the integration of AI solutions with human expertise can enhance human performance while supporting the anticipation of market trends and the rapid adaptation to shifts in consumer preferences.

Once internal processes have been digitalized, companies can shift their focus to improving customer experience. The use of digital platforms for sales, technical support, and after-sales services allows for more efficient and personalized interactions with clients.

Digital Business Models

Whereas in the past the focus was primarily on selling vehicles as finished products, today the emphasis is increasingly shifting toward integrated digital services, data-driven platforms, and continuous use engagement. By analyzing the literature, there were identified several directions, including the connected smart product model, in which the product constantly generates data on usage, technical condition, and environment data that can be monetized through additional services. For instance, Tesla remotely updates its vehicles' software, adding functionalities such as Autopilot through over-the-air (OTA) updates, while customers can later purchase additional software options. This creates a continuous revenue stream [24]. Similarly, BMW and Mercedes-Benz have introduced subscription-based services for features such as heated seats and advanced driver assistance systems.

Another prominent model is *Mobility as Service (MaaS)*, which shifts the focus from ownership to usership. In this model, users no longer own a vehicle but access personalized mobility services via digital platforms. Companies such as Uber, Lyft, and Free2Move (Stellantis) are the key players, offering integrated mobility services that combine ride-hailing, car-sharing, and public transport within a single application.

A further significant model is *flexible production and mass customization*. Automotive manufacturers can now adjust production lines in near real-time, enabling large-scale customization without cost increases by leveraging IoT and AI integration. For example, Volkswagen employs its "Industrial Cloud", developed in partnership with Amazon Web Services, to connect factories and suppliers in a global digital network, thereby enhancing both flexibility and production efficiency.

Identified Challenges

Although the opportunities presented by digitalization are clear, the literature emphasizes a complex set of challenges that may slow down or even compromise the process.

A major challenge relates to *high costs and financial barriers*, as digitalization requires significant investments in technologies (AI, IoT, Cloud Computing), security infrastructure, and software development. While such costs are manageable for large corporations, they represent a substantial obstacle for SMEs, which often cannot sustain the transition to digitalized production without government support or partnerships [11], [27].

Another significant challenge concerns the *digital skills gap*, as digital transformation requires advanced competencies in data analytics, AI, and cybersecurity. At present, one of the most pressing global challenges is the shortage of software engineers and cybersecurity specialists. For example, Volkswagen and BMW have established internal digital training academies, although this remains a long-term process.

Cybersecurity and privacy issues also constitute critical challenges given that connected vehicles are vulnerable to cyberattacks. It is essential that cybersecurity be integrated into vehicle design from the outset, rather than treated as an add-on [8].

Moreover, digitalization involves not only the adoption of technologies but also the transformation of organizational processes and mindsets. The challenge lies in breaking down cultural barriers and overcoming resistance to change. Traditional companies often display internal resistance among both employees and managers, who may fear the implications of transformation [5].

Standardization gaps further complicate the process. For connected and autonomous vehicles to operate seamlessly within the digital mobility ecosystem, common standards are required [2]. In the European Union, initiatives concerning autonomous vehicle standards and smart city infrastructure are still under development.

Sustainability concerns are becoming increasingly relevant. Digitalization requires considerable energy consumption through data centers, servers, and cloud computing. For digitalization to be sustainable, it must be integrated with renewable energy sources and accompanied by policies for recycling electronic components [1].

Methodology

The methodological approach employed in this study is based on an exploratory and qualitative analysis of the specialized literature, designed to identify and synthesize the main trends, technologies, and strategic directions of the digital transformation in the automotive industry. This review aimed to outline the theoretical framework and to understand how digitalization reshapes production processes, business models, and organizational strategies in the automotive sector, with a particular emphasis on differences between large corporations and SMEs. Relevant sources were collected from specialized sites, using keywords as “*digital transformation*”, “*automotive industry*” and “*Industry 4.0/5.0*”. Only peer-reviewed articles, international reports, and market studies published between 2013 and 2025 were included.

A thematic content analysis was applied, structured along three dimensions: technological – identification of key digital technologies; business – emerging models and digital value creation; and organizational – barriers and readiness levels. The comparative synthesis of findings between large corporations and SMEs allowed the identification of asymmetries in adoption capacity and diverse pathways toward *Industry 5.0*.

Through this structured methodological process, the study constructs a coherent theoretical framework for understanding digital transformation in the automotive sector, providing a foundation for the formulation of practical strategies and policy recommendations.

Results and further discussions

Within the context of the automotive industry, the literature review revealed multiple findings regarding the development of digitalization management for the integration of digital technologies, the evolution of business models, and the digital transformation of production.

The results regarding the integration of digital technologies show a non-uniform adoption across companies. Large manufacturers as Toyota, Tesla, Volkswagen, have made significant progress in implementing IoT, AI, and blockchain solutions, while small and medium-sized enterprises (SMEs) continue to face financial and technological barriers.

Regarding new digital business models, the findings highlight the success of software-driven approaches, such as Tesla’s remote software updates and the monetization of additional functionalities. Similarly, Toyota’s transition toward Mobility as a Service (MaaS) through its Kinto platform demonstrates that digital business models are diversifying rapidly [25].

In terms of digitalized production, the adoption of technologies such as predictive analytics and IoT monitoring has led the measurable efficiency gains. For example, Volkswagen’s Industrial Cloud achieved a 20% reduction in downtime through IoT based monitoring and predictive analytics [1], [26].

The main challenges identified include high implementation costs, a shortage of digital skills, cybersecurity vulnerabilities, and the lack of global technological standardization. In addition, organizational and cultural resistance remain significant barriers, while sustainability concerns particularly the high energy consumption of data centers further complicate the digitalization process.

The analysis also revealed a set of critical dilemmas, such as:

- *Innovation vs. Security*: while digital innovation generates immediate benefits, it simultaneously exposes companies and users to increased cybersecurity risks, thus requiring a careful balance between innovation speed and data protection.
- *Customization vs. Standardization*: mass customization offers competitive advantages, yet the lack of global technological standards limits interoperability.
- *Competitiveness vs. Sustainability*: digitalization enhances competitiveness but raises ecological concerns, underlining the need for renewable energy integration and sustainable digital infrastructures.
- *Concentration vs. Collaboration*: digital platforms tend to concentrate economic power in the hands of a few global corporations (Tesla, Google, Amazon), potentially limiting ecosystem diversity. As an alternative, collaborative partnerships and shared platforms are suggested.

The critical assessment highlights and *adaptive model of digitalization management* based on three interdependent dimensions:

1. *Technological dimension* to adopt gradually the digital technologies key (IoT, AI, Blockchain, 3D printing).

2. *Organizational dimension* to transform the business models through connected vehicles, MaaS, and digital platforms.
3. *Strategic dimension* to establish a systematic and collaborative management of risks, including cybersecurity, financial, and organizational challenges.

This adaptive model enables automotive companies to balance the benefits of digitalization with its associated risks, thus facilitating a sustainable and competitive transition toward Industry 5.0.

Conclusion

This study has analyzed the development of digitalization management within the automotive industry, with the objective of identifying the stages, business models, and challenges associated with the digitalization process. It provides a comprehensive perspective on the management of digital transformation in the automotive sector, while acknowledging the limitation of not being able to fully capture the real-time dynamics of implementation, given the accelerated pace of technological advancement.

The analysis highlights a complex framework shaped by the interdependence of technology, organizational structures, and strategic approaches. The integration of digital technologies ranging from IoT and AI to Blockchain and 3D printing, generates significant opportunities for innovation, efficiency, and personalization. At the same time, it poses challenges related to costs, skills shortages, cybersecurity, and sustainability. The results show that while large automotive manufacturers have made substantial progress in adopting digital solutions and developing innovative business models, SMEs remain constrained by financial and technological barriers.

Nevertheless, the study has certain limitations. It relies primarily on secondary and qualitative analysis, which constrains the ability to measure the real-time impact of digital initiatives. Additionally, the rapid pace of technological evolution may render some findings time-sensitive. Future research should apply case studies and quantitative approaches to test and refine the proposed framework.

Overall, the findings reaffirm that digitalization is not only a technological upgrade but a systemic reconfiguration essential for competitiveness, sustainability, and resilience in the era of Industry 5.0.

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