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THE CUSTOMIZATION AND PERSONALIZATION OF PRODUCT IN INDUSTRY 4.0

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Purpose: The purpose of this publication is to present the benefits and challenges of customization and personalization in Industry 4.0 era.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: The advent of Industry 4.0 has brought about a profound revolution in customization and personalization within the manufacturing landscape. This evolution traces its roots from traditional craftsmanship through mass production to the forefront of Industry 4.0, characterized by data-driven personalization. This article explores the substantial advantages of customization and personalization in this era, including enhanced customer experiences, increased revenue, improved efficiency, and a competitive edge. Furthermore, customization aligns seamlessly with sustainability objectives, reducing waste and expanding market reach. Nonetheless, these advantages are accompanied by a set of challenges that businesses must navigate. Issues such as data privacy, complexity in data management, implementation costs, and skill shortages must be addressed. Achieving the delicate balance between personalization and customer preferences, handling ethical concerns, and ensuring regulatory compliance can prove intricate. Scaling operations, maintaining data quality, adapting to change, and delivering a consistent personalized experience across various channels are additional complexities. In the dynamic Industry 4.0 landscape, customization and personalization are indispensable tools for business survival and success. To harness their full potential, organizations must confront these challenges with meticulous planning, investment, and an unwavering commitment to ethical and regulatory standards. By doing so, they can unlock the remarkable benefits offered by customization and personalization, charting a path towards a more customer-centric and sustainable future in manufacturing.

Keywords: Industry 4.0, digitalization, artificial intelligence, customer; customization, personalization.

Category of the paper: literature review.

1. Introduction

The fourth industrial revolution, often referred to as Industry 4.0, has ushered in a new era of manufacturing characterized by automation, data exchange, and the integration of cutting-edge technologies. One of the most transformative aspects of Industry 4.0 is the ability to offer customization and personalization of products on a scale previously unimaginable. This shift represents a fundamental change in the way we conceive, design, and produce goods, catering to the diverse and evolving needs of consumers.

The purpose of this publication is to present the benefits and challenges of customization and personalization in Industry 4.0 era.

2. The Evolution of Customization and Personalization

In traditional manufacturing, mass production was the norm. Factories churned out identical products in large quantities, leading to economies of scale but limited variety. Consumers had limited choices, and products were often designed to meet the average needs of a broad market segment. In the table 1 there is a historical description of following stages of customization and personalization of product evolution.

The concept of product customization has undergone a remarkable transformation over the years, driven by advancements in technology, changes in consumer preferences, and the evolving dynamics of the business world. This evolution can be categorized into several distinct stages, each reflecting the progression of customization from its early beginnings to its current state in the digital age. The earliest form of product customization can be traced back to the craftsmanship era. During this period, skilled artisans and craftsmen would create unique, made-to-order products for individual customers. Each item was meticulously crafted by hand, tailored to the customer's specific requests. While highly personalized, this level of customization was limited by the artisan's expertise and available resources (Castro et al., 2024).

With the advent of the Industrial Revolution, mass production became the dominant mode of manufacturing. Customization took a backseat as products were standardized to achieve economies of scale. Mass-produced goods were more affordable and accessible to the general population, but customization was largely sacrificed for efficiency and cost-effectiveness. In the late 20th century, businesses began to explore the concept of mass customization. This marked a significant shift, as companies sought to combine the efficiency of mass production with the personalization of craftsmanship. Emerging technologies, such as computer-aided design and manufacturing (CAD/CAM), allowed for limited customization

within predefined parameters. Products like personalized sneakers or custom-configured computers became available to consumers (Du et al., 2023).

The digital revolution and the rise of Industry 4.0 have transformed product customization as we know it (Wolniak, 2016; Czerwińska-Lubszczyk et al., 2022; Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018, 2023; Grabowska et al., 2019, 2020, 2021; Wolniak et al., 2023; Wolniak, Grebski, 2023; Wolniak, Skotnicka-Zasadzień, 2023; Jonek-Kowalska, Wolniak, 2023). With the integration of advanced technologies like artificial intelligence, data analytics, and the Internet of Things (IoT), businesses can now offer highly personalized products and experiences on a massive scale. E-commerce platforms, for instance, use algorithms to recommend products based on a customer's browsing and purchase history manufacturing (Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021; 2022). In manufacturing, 3D printing and CNC machining enable the creation of one-of-a-kind, custom-designed items with precision and efficiency. Today, we are witnessing a shift towards co-creation and user-driven customization. Customers are actively involved in the design and personalization of products and services. Companies engage their customers in the creation process, allowing them to select features, colors, materials, and even contribute to product ideation. Crowdsourcing and collaborative design platforms have become integral to this stage, allowing businesses to tap into the collective creativity of their customer base (Damma, 2023).

Looking ahead, customization is likely to continue evolving, with a growing emphasis on sustainability and ethical considerations. Consumers are increasingly conscious of the environmental and ethical implications of their purchasing decisions. Customization will play a role in reducing waste and overproduction, aligning products more closely with individual needs while promoting responsible consumption (Du et al., 2023).

Table 1.
The stage of evolution of customization of product

Stage of Evolution	Description
Pre-Industrial Era	Craftsmen produce goods individually.
	Limited customization due to manual labor.
	High cost and time-consuming.
Industrial Era	Mass production with standardized goods.
	Limited customization, if any.
	Economies of scale but lack of variety.
Digitalization Era	Introduction of computer-aided design.
	Some customization possible in design.
	Limited personalization, mainly in sizing.
Industry 4.0	Advanced technologies like IoT and AI.
	Data-driven customization and personalization.
	Efficient, automated, and agile production.
	Highly tailored products for consumers.

Source: Own analysis on basis: (Fjellström, Osarenkhoe, 2023; Castro et al., 2024; Du et al., 2023; Pech, Vrchota, 2022; Wand, Ma, 2023).

With the advent of Industry 4.0, customization and personalization have become central to manufacturing processes. Industry 4.0 leverages technologies such as the Internet of Things (IoT), artificial intelligence (AI), 3D printing, and robotics. These technologies enable the creation of highly customized products by automating and optimizing production processes. The vast amount of data generated by smart manufacturing processes is used to gain insights into consumer preferences, behavior, and market trends. This data-driven approach allows manufacturers to tailor products to individual or niche demands (Jonek-Kowalska, Wolniak, 2021, 2022; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021; Orzeł, Wolniak, 2021, 2022, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Steculа, Wolniak, 2022; Olkiewicz et al., 2021).

Digital twin technology creates virtual replicas of physical products, allowing manufacturers to simulate and optimize designs and performance. This enables more precise customization without the need for costly physical prototypes (Wang et al., 2023).

3. Benefits and challenges of customization and personalization of product

Customization and personalization create a more personalized and engaging experience for customers. When products or services align closely with their desires and expectations, it leads to higher satisfaction and loyalty. This, in turn, can result in repeat business and positive word-of-mouth marketing. When businesses offer personalized recommendations, product configurations, or pricing based on individual preferences, it can significantly boost sales. Customers are more likely to make purchases when they perceive the value and relevance of the offerings (Jiang, 2023).

Industry 4.0 technologies, such as IoT (Internet of Things), automation, and data analytics, enable more efficient and streamlined production processes (Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Wolniak, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022; Gajdzik, Wolniak, 2023; Wolniak, 2013, 2016; Hys, Wolniak, 2018). This reduces waste, lowers production costs, and ensures that each product is precisely tailored to meet customer specifications (Sanoiuk et al., 2023). Customization allows manufacturers to adapt quickly to changing market trends and customer demands. With the ability to reconfigure production setups rapidly, businesses can stay ahead of the competition and respond to market shifts with agility (Li et al., 2023).

Personalized production often involves just-in-time manufacturing and inventory management. This minimizes excess inventory, reduces storage costs, and optimizes the supply chain for improved cost-efficiency. Collecting and analyzing customer data in Industry 4.0 systems provides valuable insights. Businesses can make informed decisions, refine their

product offerings, and tailor marketing strategies to resonate with their target audience more effectively (Fjellström, Osarenkhoe, 2023).

Companies that excel in customization and personalization gain a significant competitive advantage (Cherif, Bayarassou, 2023). They differentiate themselves in the market by offering unique and tailored solutions, attracting more customers, and securing a stronger market position. Personalization can lead to more sustainable practices by minimizing overproduction and waste. This aligns with environmental and social responsibility goals, demonstrating a commitment to sustainability (Pearsson, Lantz, 2022).

Customization often results in products that better meet individual needs, leading to higher quality and reduced instances of product returns or complaints. This not only saves costs but also enhances brand reputation. With the ability to cater to diverse customer preferences, businesses can tap into new markets and customer segments. Customization and personalization strategies enable companies to broaden their reach and potential customer base (Pech, Vrchota, 2022).

Customization and personalization are indispensable tools in the Industry 4.0 landscape. They empower businesses to forge stronger connections with customers, optimize operations, and achieve a competitive edge in an increasingly dynamic and customer-centric marketplace. As technology continues to advance, harnessing the potential of customization and personalization will be essential for sustained growth and success. In the table 2 there is an analysis of main benefits and challenges of customization and personalization of product.

Table 2.
The benefits of customization of product

Benefit	Description
Enhanced Customer Experience	Customization and personalization enable companies to tailor products and services to individual customer preferences, leading to higher satisfaction and loyalty.
Increased Sales and Revenue	By offering personalized recommendations and product configurations, businesses can boost sales and revenue as customers are more likely to make purchases.
Improved Operational Efficiency	Industry 4.0 technologies allow for more efficient production processes, reducing waste and lowering production costs, while still meeting personalized demands.
Agile Manufacturing	Customization enables rapid changes in production setups, making it easier for manufacturers to adapt to changing market trends and customer demands.
Supply Chain Optimization	Personalized production often involves just-in-time manufacturing, reducing the need for excessive inventory and optimizing the supply chain for cost savings.
Data-Driven Decision Making	The collection and analysis of customer data in Industry 4.0 systems enable data-driven decision-making, helping companies refine product offerings and strategies.
Competitive Advantage	Businesses that offer superior customization and personalization gain a competitive edge in the market, attracting more customers and differentiating themselves.
Sustainability	Personalization can lead to more sustainable practices by minimizing overproduction and waste, contributing to environmental and social responsibility goals.
Better Product Quality	Customization often results in products that better meet individual needs, leading to higher quality and reduced instances of product returns or complaints.
Market Expansion	With the ability to cater to diverse customer preferences, companies can tap into new markets and customer segments, expanding their reach and potential customer base.

Cont. table 2.

Reduced Time to Market	Industry 4.0 technologies streamline the design and production process, allowing for faster development and launch of customized products, gaining a competitive advantage.
Enhanced Brand Loyalty	When customers feel that a brand understands their unique needs and preferences, they are more likely to develop strong loyalty, leading to repeat business and referrals.
Predictive Maintenance	Personalization can extend to maintenance schedules, with sensors and data analysis predicting when equipment needs servicing, reducing downtime and maintenance costs.
Mass Customization	Industry 4.0 enables businesses to achieve the balance between mass production and customization, offering a wide range of products with individualized features.
Better Inventory Management	Personalization and customization require accurate inventory management, reducing excess inventory and ensuring that products are available when customers want them.
Risk Mitigation	By closely monitoring customer preferences and market trends, companies can adjust their product offerings and strategies proactively, reducing the risk of obsolescence.
Access to Valuable Customer Insights	Customization generates a wealth of customer data that can be leveraged for marketing, product development, and innovation, providing valuable insights for decision-making.
Scalability	Industry 4.0 solutions can be scaled to accommodate changes in demand, making it easier for businesses to grow or adapt to economic fluctuations without significant disruptions.
Personalized Marketing and Advertising	Customization allows for more targeted and effective marketing campaigns, as businesses can deliver personalized messages and recommendations to individual customers.
Regulatory Compliance	Personalization can help businesses meet regulatory requirements more easily by ensuring that products and services align with specific industry standards and guidelines.

Source: Own analysis on basis: (Fjellström, Osarenkhoe, 2023; Castro et al., 2024; Du et al., 2023; Pech, Vrchota, 2022; Wand, Ma, 2023; Yang et al., 2023; Wang et al., 2023; Li et al., 2023; Jiang, 2023; Zhou, Ke, 2020; Damma, 2023, Saniuk et al., 2023).

While customization and personalization in Industry 4.0 offer a plethora of advantages, they also come with their fair share of challenges and complexities. As businesses navigate the transition to this highly advanced and data-driven manufacturing landscape, they must address several key challenges to fully leverage the potential of customization and personalization. One of the foremost concerns in the era of Industry 4.0 is the gathering and management of vast amounts of customer data (Briem et al., 2022). Ensuring data privacy and safeguarding against potential security breaches is a critical challenge. Businesses must implement robust cybersecurity measures and comply with data protection regulations to maintain trust with customers (Wang et al., 2023).

Managing large volumes of customer data can be intricate and resource-intensive. Businesses need efficient data storage, retrieval, and processing systems to ensure data accuracy, relevance, and accessibility. Embracing Industry 4.0 technologies to facilitate customization and personalization can entail substantial initial investments. These costs encompass infrastructure, technology integration, employee training, and ongoing maintenance (Li et al., 2022).

Finding and retaining skilled professionals who can work with advanced technologies like artificial intelligence, IoT, and data analytics can be a significant challenge in the competitive job market. Developing an in-house expertise in these areas is crucial for successful implementation. Not all customers are comfortable with sharing personal information or receiving personalized marketing and product recommendations. Businesses must balance personalization with customer consent and respect for individual preferences to avoid alienating segments of their customer base (Yang et al., 2023).

Integrating different systems and technologies to create a seamless personalization process can be technically challenging. Ensuring compatibility and smooth data flow among various platforms is essential. Complying with data protection laws and regulations, such as GDPR or CCPA, while collecting and using customer data for personalization can be complex and legally demanding. Non-compliance can result in severe penalties (Zhou, Ke, 2020).

Decisions regarding the ethical use of customer data and algorithms for personalization are becoming increasingly complex. Businesses must navigate ethical dilemmas, ensuring that their practices align with societal norms and values. As businesses grow, scaling personalization efforts to accommodate larger customer bases can be challenging. Maintaining the quality of customization while serving a broader audience is a delicate balancing act (Sali et al., 2023).

Inaccurate or incomplete customer data can lead to subpar personalization efforts, undermining the customer experience and business objectives. Maintaining data quality is an ongoing challenge. Employees and organizational culture may need to adapt to new processes and technologies, which can be met with resistance (Garella et al., 2021). Effective change management strategies are essential to ensure a smooth transition. As more businesses adopt personalization strategies, the competitive landscape becomes increasingly intense. To stand out, companies must continually innovate and deliver exceptional personalized experiences (Wand, Ma, 2023).

In the table 3 there are the challenges of customization of product. Addressing these challenges head-on with careful planning, investment, and a commitment to ethical and regulatory standards is essential to unlock the full benefits of customization and personalization in the evolving landscape of Industry 4.0.

Table 3.
The challenges of customization of product

Challenge	Description
Data Privacy and Security	Gathering and storing customer data for personalization purposes can raise concerns about data privacy and the potential for security breaches, requiring robust cybersecurity measures.
Data Management Complexity	Managing large volumes of customer data and ensuring its accuracy, relevance, and accessibility can be complex and resource-intensive.
Implementation Costs	Adopting Industry 4.0 technologies for customization and personalization may require significant initial investments in infrastructure, training, and technology integration.

Cont. table 3.

Skill Shortages	Finding and retaining skilled professionals who can work with advanced technologies like AI, IoT, and data analytics can be a challenge in the job market.
Customer Resistance	Some customers may be uncomfortable sharing personal information or may resist the idea of personalized marketing and products, affecting adoption rates.
Technology Integration	Integrating various systems and technologies to create a seamless personalization process can be technically challenging and may lead to compatibility issues.
Regulatory Compliance	Complying with data protection laws and regulations, such as GDPR or CCPA, while collecting and using customer data for personalization can be complex and legally demanding.
Ethical Considerations	Decisions regarding the ethical use of customer data and algorithms for personalization can be complex, and businesses must consider potential ethical dilemmas.
Scalability	As businesses grow, scaling personalization efforts to accommodate larger customer bases can be challenging without compromising the quality of customization.
Data Quality and Accuracy	Inaccurate or incomplete customer data can lead to subpar personalization efforts, undermining the customer experience and business objectives.
Change Management	Employees and organizational culture may need to adapt to new processes and technologies, which can be met with resistance and require effective change management strategies.
Data Ethics and Bias	Ensuring that algorithms used for personalization do not perpetuate biases and discrimination is a significant challenge, requiring careful monitoring and auditing.
Over-Personalization	Providing too much customization can overwhelm customers or lead to analysis paralysis, causing frustration and reduced engagement.
Infrastructure Compatibility	Legacy systems may not easily integrate with modern Industry 4.0 technologies, making it challenging to implement personalized solutions across the entire organization.
Customer Expectations	Meeting or exceeding customer expectations for personalization can be demanding, especially as expectations evolve with technological advancements.
Interoperability	Ensuring that different devices, platforms, and systems can communicate and share data seamlessly is essential for effective personalization across the IoT ecosystem.
Data Ownership and Consent	Clarifying who owns the customer data and obtaining explicit consent for its use is crucial to avoid legal and ethical issues related to data ownership.
Maintenance and Updates	Keeping Industry 4.0 systems and personalization algorithms up-to-date and free of vulnerabilities requires ongoing maintenance and investment.
Personalization Fatigue	Excessive personalization can lead to customer fatigue, where individuals may opt out of personalized services or ignore customized content.
Testing and Validation	Testing the effectiveness of personalization algorithms and ensuring that they deliver the desired outcomes can be time-consuming and resource-intensive.
Cross-Channel Consistency	Maintaining a consistent personalized experience across various customer touchpoints, including web, mobile, and offline, can be challenging but is essential.
Market Saturation	As more businesses adopt personalization strategies, it becomes increasingly difficult to stand out and offer unique personalized experiences in saturated markets.
Intellectual Property Protection	Protecting the intellectual property of personalized algorithms and strategies can be challenging, as competitors may attempt to replicate successful approaches.

Source: Own analysis on basis: (Fjellström, Osarenkhoe, 2023; Castro et al., 2024; Du et al., 2023; Pech, Vrchota, 2022; Wand, Ma, 2023; Yang et al., 2023; Wang et al., 2023; Li et al., 2023; Jiang, 2023; Zhou, Ke, 2020; Damma, 2023, Saniuk et al., 2023).

4. Conclusion

The era of Industry 4.0 has ushered in a remarkable transformation in the realm of customization and personalization. As we have explored in this publication, the evolution of customization has seen us progress from individual craftsmanship to mass production, and finally to the highly advanced landscape of Industry 4.0, where data-driven personalization is at the forefront of manufacturing. The benefits of customization and personalization in this era are substantial. They enhance the customer experience, increase sales and revenue, improve operational efficiency, and provide a competitive advantage. Moreover, customization aligns with sustainability goals and allows businesses to broaden their market reach while reducing waste and overproduction.

However, these advantages do not come without their set of challenges. Data privacy and security concerns, data management complexity, implementation costs, and skill shortages are among the hurdles businesses must address. Moreover, striking the right balance between personalization and respecting customer preferences, navigating ethical dilemmas, and ensuring regulatory compliance can be complex. Scalability, data quality, change management, and maintaining a consistent personalized experience across various channels are additional challenges that must be carefully managed.

In the evolving landscape of Industry 4.0, it is clear that customization and personalization are indispensable tools for businesses seeking to thrive and remain competitive. To harness their full potential, organizations must tackle these challenges head-on, with careful planning, investment, and a steadfast commitment to ethical and regulatory standards. By doing so, they can unlock the remarkable benefits that customization and personalization offer, paving the way for a more customer-centric and sustainable future in manufacturing.

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