



## The Impact of Industry 4.0 on New Product Development in Small and Medium Enterprises: A Review

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### Abstract

Industry 4.0 has attracted growing scholarly attention for its potential to change new product development (NPD) in small and medium-sized enterprises (SMEs). However, existing studies remain fragmented, methodologically diverse, and often overly optimistic in their assessment of digital technology adoption. This study presents a structured narrative literature review that critically evaluates how Industry 4.0 technologies influence NPD processes in SMEs. Drawing on peer-reviewed journal articles, conference papers, and conceptual studies sourced from major academic databases, the review synthesises qualitative and quantitative evidence to clarify the nature of Industry 4.0's impact, the benefits reported, and the challenges encountered by SMEs. The analysis integrates findings across the NPD lifecycle and highlights how firm-level characteristics, digital readiness, and contextual constraints outline outcomes. Rather than aggregating effect sizes, the study emphasises critical comparison, identification of inconsistencies, and recognition of underexplored trade-offs in the literature. The review contributes to theory by consolidating dispersed insights and to practice by offering evidence-informed perspectives for SME managers and policymakers. Generally, the study offers a balanced understanding of Industry 4.0-enabled NPD and isolates key guidelines for future research.

**Keywords:** Digital transformation, Industry 4.0, Innovation, New product development, Small and medium-sized enterprises.

### 1.0 Introduction

Businesses with staff and income below specific thresholds are classified as SME firms [1, 2]. SMEs account for the majority (about 90%) of enterprises operating globally [3]. SMEs are independent businesses with fewer than 50 employees. However, the maximum number of SME employees varies from one country to another. For most countries, the highest range is around 250. The main factors determining whether an enterprise is an SME are turnover, balance sheet, and staff number. Table 1 depicts SMEs' classification by turnover, balance sheet, and staff number.

Table 1: SME classifications [4]

Company Group	Turnover	Total balance sheet	Staff number
Micro	≤ € 2	≤ € 2	< 10
Small	≤ € 10	≤ € 10	< 50
Medium-sized	≤ € 50	≤ € 43	< 250

I4.0 is transforming numerous sectors globally to simplify business challenges and opportunities [5]. Developing new products is an important strategy for businesses to stay relevant, competitive, and innovative [6]. The steps involved in NPD include generating ideas, Idea screening, concept development and testing, business analysis, product development (PD), market testing, commercialisation, and launch and post-launch. Achieving the NPD is cumbersome and time-consuming, especially for SMEs. The advent of I4.0 technological tools can help to shorten the period to launch a New Product (NP) in the marketplace [7]. However, achieving prompt delivery of NP demand requires expertise and technologically driven tools [8]. Many large business enterprises find it easy to use I4.0 because of the availability of capital turnover and financial capability [9]. This study is tailored towards studying the existing literature on the impact of I4.0 on NPD so that a definite approach can be established for the SME industries to employ I4.0 to quickly launch NP to the market. Figure 1 illustrates the percentage share of enterprises, the number of personnel employed, and the value contributed to the overall economy of the European Nations (EU). The businesses that employ fewer than 250 people are often regarded as the backbone of the European economy, offering

jobs and growth prospects. The 93% of businesses in the EU's non-financial sector employed less than ten people. In comparison, only 0.2% of all firms employed 250 people or more and were thus referred to as major enterprises. According to a 2016 report, there were 24.7 million SMEs in the EU's non-financial business economy, employing 95 million people and contributing EUR 4.018 billion to the economy. SMEs generate over 75% of the total value added in the EU, as depicted in Figure 1.

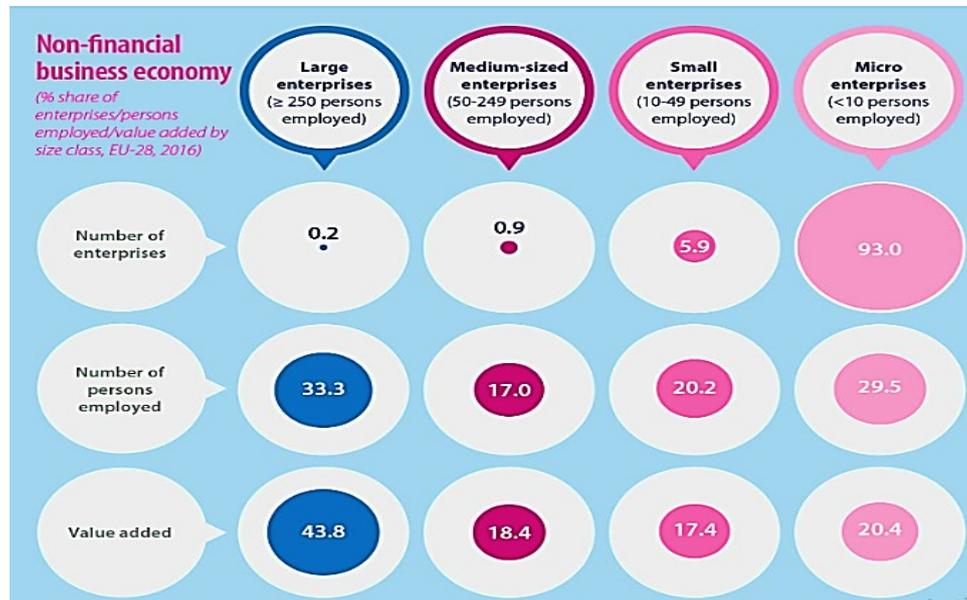


Figure 1: The percentage share of enterprises, and persons employed value added [10]

The high quality of knowledge and data accessibility in I4.0 offers the potential to create higher quality decisions regarding all phases of NPD and in progress improvement [11, 12]. Furthermore, it permits increasing resource utilisation by reducing friction among the development, innovation, production, and market launching phases of NPD [7]. Currently, the market is rapidly changing, and adaptability is turning into a key power for corporations to survive. And we can expect the pace and impact of market changes to keep increasing in the future. Many governments, particularly in Europe and North America, have launched strategic initiative programs to facilitate the development and adoption of I4.0. Nevertheless, there is still a scarcity of proof of how the technological trends embodied by I4.0 address the challenges and opportunities in NPD, particularly in SMEs. The impact of I4.0 on the organization's digital strategy is unclear, as it often highlights the challenge of adopting new technology [13]. The success of digital transformation is a direct descendant of proper NPD [14]. Managerial implications from the study include advice for innovative program design and developing a technology strategy roadmap. Navigating the obstacles and uncertainties inherent in new product development requires excellent communication, collaboration, and flexibility across the NDP stages indicated in Table 2. Furthermore, it's critical to prioritise the wants and preferences of the end user throughout the process to guarantee that the finished product meets customers' needs and expectations and adds value.

Table 2: A simplified overview of the typical steps involved in NPD [15]

S/No.	NPD stage	Description of the NDP stage	Ref.
1	Idea Generation	This stage entails brainstorming and gathering concepts for new products: market research, consumer input, employee suggestions, or developing trends.	[16-18]
2	Idea Screening	Once you have a list of feasible ideas, you must assess and narrow it down according to criteria, including viability, demand in the market, compatibility with business objectives, and possible profitability.	[19-21]

S/No.	NPD stage	Description of the NDP stage	Ref.
3	Concept Development and Testing	Creating comprehensive concepts for the chosen ideas and testing them on the intended audience. This allows for feedback and subsequent concept refinement.	[16, 22]
4	Business Analysis	A thorough analysis is carried out to evaluate the new product's possible financial feasibility, including estimates of expenses, sales forecasts, market potential, and possible hazards.	[23-25]
5	Product Development	The process of developing a product starts after the concept is accepted. This includes developing the product, building prototypes, putting it through performance and quality tests, and then iterating it in response to user input.	[18, 26, 27]
6	Market Testing	Products are frequently tested in a small market before being released on a wider scale to assess their performance, get more input, and find any possible problems.	[18, 28, 29]
7	Commercialisation	The product is prepared for full-scale production and launch if the market testing phase is completed. To do this, marketing plans, pricing, distribution options, and other elements required to launch the product must be finalised.	[30-34]
8	Launch and Post-Launch Evaluation	The product is formally released, and its effectiveness is continuously tracked. Customer feedback and sales information are gathered to evaluate the product's performance and pinpoint areas in need of development.	[35-37]

The highlighted steps in NPD, as shown in Table 2, can help management in SMEs understand what digital technologies and Information technology (IT) resources can be used for NPD and how to use them. Convincingly speaking, though, a lot of businesses are still in the early stages of integrating I4.0 solutions into their NPD initiatives. Critical research on how I4.0 affects the NPD process is lacking, especially when it comes to SMEs [38]. A critical review like this is important for up-to-date and comprehensive examination of current empirical findings and can help practitioners and scholars in the fields of innovation and technology management comprehend the possible influence of I4.0 on NPD. Secondly, this study reveals gaps in the current body of scientific knowledge. This, in turn, informs a forward-thinking research agenda in light of the most recent technological and digital infrastructural advances. Understanding the influence of I4.0 on NPD is crucial for many businesses. On the other hand, opinions differ about how I4.0 will change the NPD process for SMEs. Additionally, nothing is known about the precise advantages and potential drawbacks that I4.0 may present for SMEs' NPD. Thus, it is practically important for business owners and managers of SMEs to comprehend the consequences of I4.0 from this perspective and to get insight into how to successfully use I4.0 in the NPD process. NPD is tied to both a company's performance and its survival [23, 39]. To compete in increasingly competitive industries, the old stage-gate NPD strategy is no longer sufficient to translate I4.0 results into commercial success. The entire NPD process, from conception to launch and post-launch monitoring, must be infused and disrupted by I4.0. That is, the product development lifecycle itself must transform into a new format known as NPD 4.0. Figure 2 enumerates 8 important stages that are involved in NPD.

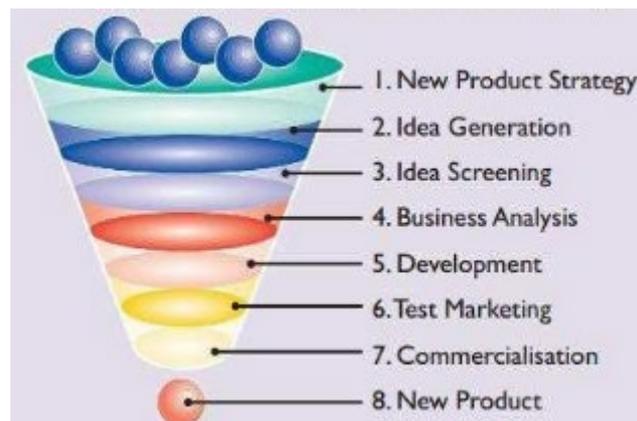


Figure 2: The eight stages of an NP [40]

The stages listed in Table 2 guide how goods are created and produced, and ensure the reasons for starting an NP project are aligned with I4.0. These reasons include the use of new technology, adapting to changes in market demand, complying with new rules, and capturing market share. "Newness" and "innovation" are very important to SMEs. These enterprises lack a broad client base and an established blue-chip. As a result, regularly introducing new products into the market is crucial. Figure 3 depicts how I4.0 is used in promoting NPD.

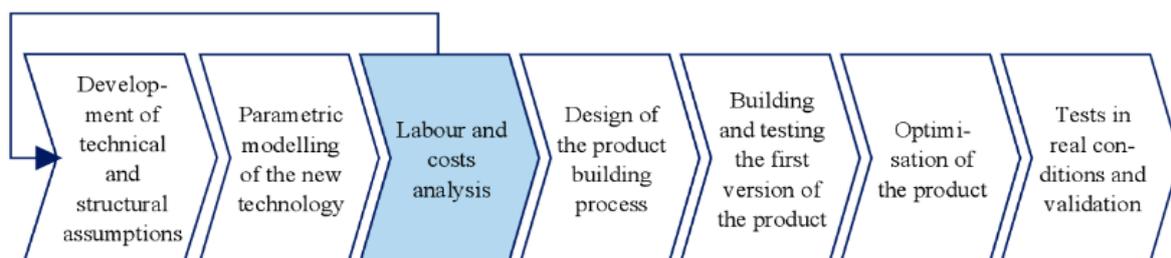


Figure 3: Application of I4.0 to product development process [40]

Globally, there have been incredible advancements in several technological fields in recent times. The current phase of technological progress, known as "I4.0," is distinguished by a growing trend of digitization and interconnectedness. The phrase "I4.0" refers to a group of concepts and technologies related to value chain organisation, namely in industrial production. The internet, which serves as a conduit for free communication between the virtual and real worlds, is the primary force behind this period. This suggests that everyone involved in the value chain upstream and downstream, from the production side as well as the customer side, is connected to everyone else online. The study focuses on discovering the subsets of the previous studies using an organised method of a critical review, summarising the dimensions, and displaying the features. Thus, the study's main goal is to comprehend how I4.0 has affected SMEs' NPD. The study's secondary goal is to pinpoint the key gaps in the body of current literature. It is expected that the study will advance theory and practice in multiple ways. In addition to discussing the present situation and expected future course of NPD in the context of I4.0, it will offer a more coherent conception and operationalization of I4.0 and its constituent parts.

Clearly defining the relationship between I4.0 and NPD can assist investors and policymakers in creating smart operations plans that convert conventional industrial facilities [41, 42]. The review's conclusions will aid technology companies that specialise in offering hardware and software solutions for smart manufacturing (SM) in better coordinating their product development roadmaps with the changing demands of the manufacturing sector. Figure 4 shows that the most important aspect of I4.0 for NPD is connectivity, and technology sellers need to concentrate on improving the systems that link design, manufacturing, and testing for NPD-related software and hardware. Companies that plan to engage in NPD activities and want to leverage the latest digital technologies will benefit from this review's findings, which aim to provide them with valuable insights into the key technology drivers, the organisational readiness required for digital transformation, and the vendor landscape in various technology categories.



Figure 4: New Product Development connectivity with related software and hardware

The critical review's evidence will help plan and implement digital strategies more effectively. Last but not least, for academics and students interested in researching Industry 4.0 and NPD, this study shall serve as an insight for their research. Methodologically, the study suggests doing a critical review of both qualitative and quantitative primary and secondary studies to synthesise material. A complete and exhaustive literature review was undertaken, employing a variety of databases, including Scopus, Web of Science, and IEEE Xplore, as well as databases from major publishers such as Elsevier, Springer, Emerald, and SAGE. Employing mutual surveys, they are determining various stages to organise the search and implementation of inclusion and exclusion criteria. Following the previously specified methodology, it is also necessary to perform a quality assessment, screen the research results, and extract data from the included publications at various stages. Lastly, it is anticipated that this study shall employ narrative and meta-analysis techniques for a more accurate clarification of the findings and the present level of knowledge in the field.

Despite growing scholarly interest in Industry 4.0 and its implications for NPD, existing studies exhibit notable conceptual and empirical limitations, particularly in the SME context [16-25]. Much of the literature adopts an optimistic, technology-centric narrative, frequently assuming that the adoption of digital technologies automatically enhances NPD performance [17-23]. However, many claims are grounded in conceptual arguments rather than rigorous empirical evidence linking Industry 4.0 adoption to measurable NPD outcomes.

Previous studies are dominated by small-sample and single-case studies, often focusing on early adopters or technologically advanced firms [24-28, 35,38]. Although insightful, these studies limit generalisability and risk overstating benefits for resource-constrained SMEs. Furthermore, methodological inconsistency persists across studies, with divergent definitions of Industry 4.0, varied NPD performance indicators, and fragmented analytical scopes, hindering cumulative knowledge development.

Furthermore, SMEs are frequently treated as a homogeneous group, overlooking differences in digital readiness, industry context, and managerial capability that shape NPD outcomes. Although challenges such as financial constraints and skills shortages are acknowledged, they are rarely examined analytically or longitudinally. These limitations underscore the need for this current study, which addresses by consolidating evidence, identifying research gaps, and clarifying the actual impact of Industry 4.0 on NPD in SMEs.

### 1.1 Research Questions

In the context of this section, research questions refer to the focus of the study, and they direct all subsequent decisions, such as the data to be collected, the research design, data analysis, and the presentation of the findings. The research questions of this study include the following: What is the nature of the impact of I4.0 on the NPD processes in SMEs? How has Industry 4.0 brought benefits to the NPD processes in SMEs? What are the challenges faced by SMEs when they want to implement I4.0 in the NPD processes? In what areas, such as theoretical contribution and managerial practice, could the researchers

provide insight through a critical review of the existing studies? The number one question focuses on the impacts of I4.0 on the NPD processes. This question is quite important as it is trying to investigate the nature of the impact of I4.0 on the NPD processes in SMEs. Answering this question would provide more information on how I4.0 has restructured the NPD processes and overcome the traditional inefficiency and high cost in the SMEs. The number two question is on the benefits brought by I4.0 in the NPD processes. During the review, the researchers would like to understand how Industry 4.0 has brought benefits to the NPD processes in SMEs. The benefits include efficiency increases, innovations in product design, and reduced time to market [43]. Answering this question could give more substantiated evidence to support the idea of introducing advanced technology in the NPD processes and what benefits can be expected. The number four question is about the areas in which the researchers could provide insight. The researchers must identify and introduce what kind of contribution they can make to the academic field and what practical help can be offered to the managers. Through a critical review of the existing studies, insights could be brought into the current body of knowledge in the field of both NPD and Industry 4.0. It is expected that such reviews will contribute to learning in academics and provide guidance to the industry.

## 1.2 Understanding I4.0

I4.0, sometimes called the fourth industrial revolution, is the process of incorporating digital technologies into production processes, which eventually results in smart factories. Figure 5 showcases the I4.0 framework configurations and interconnectivity technologies, which include artificial intelligence, big data analytics, robotics, and the Internet of Things (IoT). Companies, especially small and medium-sized ones (SMEs), need to understand I4.0 because it presents enormous potential for increasing efficiency, cutting expenses, and boosting competitiveness. SMEs can improve efficiency in bringing new goods to market, expedite innovation, and streamline operations by utilising Industry 4.0's potential [44, 45].



Figure 5: I4.0 Framework Configurations

Furthermore, Industry 4.0 enables greater connectivity and collaboration across the product development ecosystem, facilitating the integration of suppliers, partners, and customers. This interconnected approach enhances agility, responsiveness, and adaptability in a business environment.

This review contributes to knowledge by explicitly aligning evidence with the study's research questions. Addressing RQ1, it clarifies the nature of Industry 4.0's impact on NPD processes beyond assumed efficiency gains. For RQ2, it critically distinguishes empirically demonstrated benefits from presumed advantages. In relation to RQ3, it consolidates evidence on financial, skills, and integration constraints shaping SME outcomes. Finally, responding to RQ4, the review identifies methodological gaps and underexplored contexts, offering clearer theoretical and managerial insights globally.

## 2.0 The Role of I4.0 in NPD

Within the framework of NPD, I4.0 creates a collaborative environment where knowledge about resources, production processes, and market data may be shared to produce high-quality estimated products

[46]. Due to the technological revolution in manufacturing, I4.0 has had a major impact on new product creation in SMEs [47]. SME productivity has increased, time-to-market has decreased, and product quality has improved with the incorporation of artificial intelligence, big data analytics, the Internet of Things (IoT), and autonomous robots. To make data-driven decisions during the development process, e.g., businesses can use IoT sensors to gather real-time data on product performance [48, 49]. The design of novel items can be guided by artificial intelligence algorithms that can evaluate enormous volumes of market data to find trends and consumer preferences [50]. Additionally, autonomous robots can automate repetitive tasks, freeing up human resources to focus on creative aspects of product development. Generally, I4.0 technologies have empowered SMEs to compete on a global scale by fostering agility, customization, and innovation in new product development processes, as shown in Table 3.

Table 3: Estimated durations of the PDP Processes using the I4.0 Concept [40]

Phase	Duration of PDP	Changes Affected by I4.0	Duration of PDP Under I4.0
1. Development of technical and structural assumptions	8 weeks	<ul style="list-style-type: none"> <li>i. Provides a single communication platform for customers and manufacturers.</li> <li>ii. Define preliminary construction objectives precisely.</li> <li>iii. Effective project presentation, taking into account future use situations</li> <li>iv. Reduced time needed to identify initial targets</li> <li>v. Energy-efficient material selection and construction.</li> </ul>	7 weeks
2. Parametric modelling of the new technology	8 weeks	<ul style="list-style-type: none"> <li>i. Early feedback from experts in diverse fields on critical project features</li> <li>ii. facilitates teamwork</li> <li>iii. Improved material selection and standard elements.</li> <li>iv. Use databases and automatic wizards to reduce modelling time.</li> <li>v. Using digital prototypes saves energy compared to producing physical prototypes.</li> </ul>	6 weeks
3. Labour and costs analysis	4 weeks	<ul style="list-style-type: none"> <li>i. Improved and accelerated documentation flow.</li> <li>ii. Simplifying environmental impact assessments for materials used.</li> <li>iii. streamlining the project appraisal process</li> <li>iv. Energy-efficient production planning and scheduling</li> </ul>	2 weeks
4. Design of the product-building process	36 weeks	<ul style="list-style-type: none"> <li>i. Streamlining technical documentation development</li> <li>ii. Makes CNC machining programs faster and easier to create.</li> <li>iii. Improved supervision of work progress</li> <li>iv. Improved machining tool choices and durability.</li> </ul>	48 weeks

Phase	Duration of PDP	Changes Affected by I4.0	Duration of PDP Under I4.0
		<ul style="list-style-type: none"> <li>v. Multidirectional data sharing among process participants.</li> <li>vi. Improved production planning leads to reduced energy use</li> <li>vii. Improved prediction by leveraging data from intelligent sensors</li> </ul>	
5. Building and testing the first version of the product	32 weeks	<ul style="list-style-type: none"> <li>i. Simplified data collection procedures for prototype tests</li> <li>ii. Increased data precision</li> <li>iii. Reduction of prototype production and testing costs</li> <li>iv. Reduced energy consumption by eliminating sensors and prototype test stands</li> </ul>	
5. Building and testing the first version of the product	32 weeks	<ul style="list-style-type: none"> <li>i. Simplified data collection procedures for prototype tests.</li> <li>ii. Increased data precision</li> <li>iii. Reduction of prototype production and testing costs</li> <li>iv. Reduced energy consumption by eliminating sensors and prototype test stands</li> </ul>	
6. Optimisation of the product	16 weeks	-	-
7. Tests in real conditions and validation	40 weeks	<ul style="list-style-type: none"> <li>i. Facilitates and accelerates work on subsequent projects</li> <li>ii. Experts from other domains can verify the information.</li> <li>iii. Gathering data from aware sensors for product improvement.</li> </ul>	40 weeks
Total PDP time:	176 weeks		103 weeks

## 2.1 Case Studies: Adopting I4.0 in SMEs

Case studies have been quite useful in understanding the application of I4.0 technologies in SMEs. Previously, academics emphasised the use of case studies as a significant method for investigating the obstacles and opportunities connected with I4.0 adoption in SMEs. By evaluating real-world cases, researchers were able to uncover best practices and lessons learned that can help other SMEs on their I4.0 journey. For example, a case study on the application of smart manufacturing technology in a small manufacturing company showed how the integration of sensors and data analytics increased operational efficiency and product quality. These case studies provide real examples for SMEs wishing to use I4.0 technology to improve their new product development processes. The adoption of I4.0 technologies has significantly affected the landscape of NPD in SMEs [51]. Previous studies have shown that SMEs that embrace I4.0 concepts such as automation, artificial intelligence (AI), and the IoT have been able to streamline their PD processes, reduce time-to-market, and enhance product quality [52, 53]. However, challenges such as the lack of a skilled workforce, high initial investment costs, and cybersecurity risks still pose significant barriers to the widespread adoption of I4.0 in SMEs [54]. Moving forward, SMEs need to continue investing in technology to leverage the potential benefits of I4.0 in NPD. More research is needed to explore the long-term impacts of I4.0 on SMEs and to identify strategies for overcoming existing challenges [55-57].

## 2.2 Challenges and Opportunities for SMEs in Adopting I4.0

Challenges and opportunities exist for SMEs in adopting I4.0 technologies as they pilot the complexities of integrating these advanced tools into their operations. One significant challenge for SMEs is the initial high cost associated with implementing I4.0 solutions [58, 59], such as upgrading existing equipment or investing in new technologies like IoT devices and AI software. This financial barrier can often deter SMEs from fully embracing I4.0, limiting their ability to compete in the digital age. However, there are also opportunities for SMEs to leverage I4.0 technologies to enhance their NPD processes. For example, by utilizing advanced data analytics and machine learning algorithms, SMEs provide valuable insights into consumer preferences and market trends, allowing them to develop more innovative and customer-centric products. Therefore, while challenges exist, SMEs that successfully adopt I4.0 to transform their NPD strategies and gain a competitive edge in the marketplace.

## 3.0 Methodology

A critical literature review was conducted, encompassing diverse databases and utilizing predefined inclusion and exclusion criteria. The selected studies were analytically analysed to extract key insights into the impact of Industry 4.0 on NPD in SMEs. The methodology outlined suggests a structured approach to conducting a literature review on the impact of I4.0 on NPD in SMEs. The following is the analysis of the steps followed:

*Predefined Inclusion/Exclusion Criteria* indicate that criteria were established to determine which studies would be included in the review. These criteria likely pertain to the relevance of the studies to the topic, the type of research (e.g., empirical studies, case studies, theoretical papers), publication date, language, and other factors deemed important for the review.

*Diverse Databases:* The review encompassed a wide range of databases. This indicates a comprehensive search strategy to gather relevant literature. Databases might include academic databases like PubMed, IEEE Xplore, Scopus, and Web of Science, as well as other resources like Google Scholar, industry reports, and governmental publications.

*Methodical Analysis:* The selected studies were thoroughly analysed. This suggests a structured approach to data extraction and synthesis. This analysis involved techniques such as thematic analysis, content analysis, or meta-analysis to identify patterns, themes, and insights across the literature.

*Extraction of Key Insights:* The primary goal of the analysis was to extract key insights into the impact of I4.0 on NPD in SMEs. This involves identifying and summarising findings, trends, challenges, opportunities, and implications from the literature.

## 4.0 Adoption Patterns of I4.0 in SMEs

I4.0 adoption in SMEs is characterised by diverse patterns influenced by factors such as resource constraints, technology readiness, and industry-specific requirements [42]. The review identifies commonalities and variations in the implementation of technologies like IoT, AI, and robotics across different SME sectors. SMEs play a crucial role in the global economy, accounting for a significant portion of employment and GDP in many countries [60]. As technology continues to advance rapidly, understanding the adoption patterns of SMEs in integrating new technologies is essential for their growth and sustainability. Research has shown SMEs face unique challenges when it comes to technology adoption [61]. Limited resources, lack of technical expertise, and concerns about return on investment are some of the key barriers that hinder the adoption of new technologies in this sector. However, despite the challenges facing SME adoption, there is an increasing recognition of the importance of embracing technology to stay competitive in today's digital age. One common adoption pattern observed in SMEs is the gradual integration of technology into different aspects of their operations. Rather than implementing large-scale technological changes all at once, many SMEs prefer to start small by incorporating technology in specific areas such as customer relationship management or inventory management. This incremental approach allows SMEs to test and assess the impact of technology on their business before committing to larger investments [62].

Also, collaborative partnerships with technology providers and other SMEs can influence adoption patterns. By sharing resources and knowledge, SMEs can leverage each other's expertise to overcome barriers and accelerate the adoption of new technologies. This collaborative approach not only reduces costs but also facilitates knowledge transfer and innovation within the SME ecosystem [63, 64].

#### 4.1 Enhanced Collaboration and Connectivity

I4.0 promotes collaboration and connectivity in SMEs' NPD processes. Interconnected systems enable smoother communication between departments and stakeholders, promoting a more integrated approach to product development. I4.0, with its emphasis on digitalisation and automation, has brought significant advancements in collaboration and connectivity for SMEs' NPD processes. The key feature of I4.0 is the incorporation of various digital technologies, such as IoT, cloud computing, and big data analytics. These technologies enable SMEs to gather and process large volumes of data throughout the NPD lifecycle, providing valuable insights for decision-making and improving the overall efficiency and effectiveness of the process. With the aid of I4.0 technologies, SMEs can enhance collaboration among team members and stakeholders involved in the NPD process [65, 66]. For example, cloud-based platforms and project management tools can facilitate real-time communication and collaboration, allowing team members to collaborate seamlessly regardless of location. This enables quicker decision-making and fosters a more agile and streamlined NPD process [67]. Also, I4.0 enables improved connectivity between different stages of the NPD process [68, 69]. With the application of IoT devices, SMEs can collect real-time data from prototypes, test sites, and production lines. This data can be analysed to enhance productivity. I4.0 technologies have the potential to greatly enhance collaboration and connectivity in SMEs' new product development processes. Some of the key technologies that can aid in this effort include the IoT, AI, and cloud computing. By leveraging these technologies, SMEs can create more integrated and data-driven processes that facilitate communication and collaboration across teams and stakeholders. Additionally, they can use these technologies to streamline decision-making, reduce lead times, and improve overall efficiency. Overall, I4.0 presents exciting new opportunities for SMEs to compete on a global scale and drive innovation in their respective industries.

#### 4.2 Cost-effective Prototyping and Testing

SMEs benefit from I4.0 by gaining access to cost-effective prototyping and testing capabilities [70]. Advanced technologies facilitate rapid iterations, reducing time-to-market and minimising development costs. Create a concise and action-oriented description for a workflow that highlights the benefits of I4.0 for SMEs in terms of cost-effective prototyping and testing capabilities. I4.0 technologies offer significant benefits to SMEs, particularly in terms of prototyping and testing capabilities in the following ways:

*Reduced Costs:* I4.0 technologies such as 3D printing, simulation software, and virtual prototyping enable SMEs to significantly reduce the costs associated with traditional prototyping and testing methods [71, 72]. This is because these technologies often require less material, time, and labour when compared to conventional methods.

*Faster Prototyping:* With digital technologies, SMEs can rapidly prototype and iterate designs, leading to faster product development cycles [73]. This agility allows SMEs to respond more quickly to market demands and changes in consumer preferences [74].

*Customization and Personalization:* I4.0 technologies enable SMEs to create customized and personalized products more easily [71, 75]. This is particularly beneficial in markets where consumers are seeking unique and tailored products.

*Improved Accuracy and Quality:* Digital prototyping and testing tools provide greater accuracy and reliability when compared to traditional methods [76]. This helps SMEs ensure that their products meet quality standards and regulatory requirements from the early stages of development.

*Risk Mitigation:* Through the usage of virtual simulations and prototypes, SMEs recognise and address potential issues or defects before investing in physical prototypes or production [77, 78]. This helps mitigate risks and reduces the likelihood of costly errors during the manufacturing process.

*Global Collaboration:* Industry 4.0 technologies facilitate collaboration and communication across geographical boundaries [44, 79]. SMEs can work with suppliers, partners, and customers from around the world in real-time, enabling faster decision-making and innovation.

*Competitive Advantage:* Adopting I4.0 technologies can give SMEs a competitive edge in the market [80]. SMEs may stand out from rivals and draw in clients who appreciate efficiency and creativity by adopting digital transformation and utilising sophisticated prototyping and testing skills.

#### 4.3 Skill Development and Workforce Challenges

SMEs face challenges in staff skill development and talent acquisition while implementing I4.0 [81]. Addressing these challenges is critical for SMEs to exploit the potential benefits of Industry 4.0 in NPD.

Addressing the challenges related to workforce skill development and talent acquisition is indeed crucial for SMEs to fully exploit the potential benefits of Industry 4.0 in new product development. Here are some strategies that SMEs can consider:

*Investment in Training and Development:* SMEs should consider staff training programs to upskill their workforce in areas relevant to I4.0 technologies, such as data analytics, artificial intelligence, robotics, and automation. This can include internal training initiatives and external partnerships with educational institutions or training providers [82].

*Collaboration and Knowledge Sharing:* SMEs can benefit from collaborating with larger companies, research institutions, and industry associations to gain access to expertise and resources in I4.0 technologies [64, 83]. This collaboration can also facilitate knowledge sharing and best practices, enabling SMEs to accelerate their learning curve and adopt new technologies more effectively.

*Adopting Flexible Work Arrangements:* SMEs can attract and retain talent by offering flexible work arrangements such as remote work options, flexible hours, and opportunities for professional development. This can help SMEs appeal to a broader pool of candidates and retain skilled employees who may value work-life balance and flexibility.

*Recruitment Strategies:* SMEs should develop targeted recruitment strategies to attract talent with relevant skills and expertise in I4.0 technologies. This may involve leveraging social media platforms, professional networks, and skilled job boards to reach potential candidates with the desired skill sets.

*Employee Engagement and Retention:* SMEs should consider employee engagement and retention efforts to ensure workers retain their skilled workforce. This can involve fostering a positive work culture, providing opportunities for career advancement, and rewarding employee contributions.

*Investment in Technology Infrastructure:* SMEs should invest in the necessary technology infrastructure to support their workforce in adopting I4.0 technologies [84]. This may include upgrading IT systems, implementing collaboration tools, and providing access to software and hardware resources.

#### 4.4 Customisation and Flexibility

I4.0 enables SMEs to offer customised products and flexible manufacturing processes. Adaptive NPD approaches empowered by smart technologies cater to niche markets, providing a competitive edge for SMEs in dynamic industries. Indeed, I4.0 has reformed manufacturing processes, particularly benefiting SMEs by enabling them to offer customized products and flexible manufacturing processes. The following are some methods I4.0 facilitates customised products and flexible manufacturing processes:

*Advanced Data Analytics:* I4.0 utilises big data analytics and machine learning algorithms to analyse customer preferences and market trends. This enables SMEs to gain insights into customer demands and tailor their products accordingly.

*Internet of Things (IoT):* IoT devices allow machines and equipment to communicate with each other in real time. This connectivity enhances the efficiency of production processes and enables SMEs to quickly adjust manufacturing setups to accommodate custom orders.

*Additive Manufacturing (3D Printing):* Additive manufacturing technologies have become more accessible and affordable, allowing SMEs to produce customised parts and products on demand without the need for expensive tooling or setup changes.

*Robotics and Automation:* Collaborative robots and automated systems can be programmed to perform various tasks, including intricate assembly processes for customised products [83]. This reduces production time and increases flexibility in manufacturing operations.

*Cloud Computing and Cyber-Physical Systems (CPS):* Cloud-based platforms and cyber-physical systems enable SMEs to integrate and manage their manufacturing processes efficiently. This allows for real-time monitoring and control of production lines, facilitating quick adjustments to meet custom requirements.

*Digital Twin Technology:* Digital twins create virtual replicas of physical assets, enabling SMEs to simulate and optimise production processes before real implementation [85]. This reduces the risk of errors and allows for more flexible and adaptive manufacturing practices.

*Supply Chain Integration:* I4.0 facilitates seamless integration across the supply chain, from sourcing raw materials to delivering finished products [86]. This interconnectedness enables SMEs to collaborate with suppliers and partners more effectively, ensuring the timely delivery of custom components and materials [87].

#### 4.5 The impact of I4.0 on NPD

The I4.0 impact on the NPD SMEs is significant and multifaceted [68, 88]. Some of the key aspects are as follows:

*Speed and Efficiency:* I4.0 technologies such as automation, IoT, and AI enable SMEs to streamline their NPD processes, reducing time to market and enhancing efficiency. Tasks that were once manual and time-consuming can now be automated, allowing for quicker iterations and faster product launches.

*Data-Driven Decision Making:* I4.0 enables SMEs to collect vast amounts of data throughout the NPD lifecycle [89]. This data can be leveraged to gain insights into customer preferences, market trends, and product performance, facilitating more informed decision-making at every stage of the NPD process.

*Collaboration and Connectivity:* I4.0 technologies facilitate enhanced collaboration among cross-functional teams involved in NPD. Cloud-based platforms and digital communication tools enable real-time collaboration irrespective of geographical location, leading to improved communication, knowledge sharing, and synergy among team members [90].

*Customization and Personalization:* I4.0 enables SMEs to offer customized and personalized products to meet the diverse needs and preferences of their customers. Technologies such as additive manufacturing (3D printing) allow for on-demand production of bespoke products, while data analytics enable the customization of products based on individual customer preferences and feedback [91].

*Agility and Flexibility:* I4.0 equips SMEs with the agility and flexibility to adjust rapidly to changing market conditions and customer demands [92]. Agile NPD methodologies, coupled with digital tools and technologies, enable SMEs to quickly respond to market feedback, iterate on product designs, and pivot their strategies as needed to stay competitive in dynamic market environments.

*Risk Management:* While I4.0 offers numerous benefits to SMEs in NPD, it also introduces new challenges and risks, such as cybersecurity threats, data privacy concerns, and the need for upskilling and reskilling of the workforce. SMEs need to invest in robust cybersecurity measures, data governance frameworks, and training programs to mitigate these risks and the benefits of I4.0 in NPD processes.

#### 4.6 Benefits of I4.0 in NPD Processes

The advent of I4.0 could provide a lot of opportunities for the rapid development of NPD in SME industries, as listed below:

*Improved Efficiency:* Automation and digitization of NPD processes have significantly improved efficiency within SMEs [93]. Jobs that were once manual and time-consuming, such as data collection, analysis, and prototype development, can now be automated, leading to faster product development cycles and reduced time to market.

*Enhanced Collaboration:* Industry 4.0 technologies facilitate seamless collaboration among cross-functional teams involved in NPD [94]. Cloud-based platforms, project management tools, and digital communication channels enable real-time collaboration and knowledge sharing among team members, regardless of their geographical locations. This enhances teamwork and accelerates decision-making processes.

*Data-Driven Decision Making:* Industry 4.0 enables SMEs to collect and analyse vast amounts of data throughout the NPD lifecycle [95]. This data includes customer feedback, market trends, and performance metrics, which can be leveraged to make informed decisions at every stage of the product development process. Data-driven insights help SMEs identify market opportunities, anticipate customer needs, and optimize product designs for better market fit.

*Cost Reduction:* Automation and digitization of NPD processes lead to cost savings for SMEs [93]. By eliminating manual labour, reducing material waste, and optimizing resource allocation, SMEs can lower their overall production costs and improve profitability. Additionally, the ability to simulate and test product designs digitally before physical prototyping reduces the need for expensive iterations and rework.

*Innovation Acceleration:* Industry 4.0 technologies foster innovation within SMEs by providing access to advanced tools and resources for product development [56]. Technologies such as additive manufacturing, virtual reality (VR), and artificial intelligence (AI) enable SMEs to explore new design concepts, iterate rapidly, and develop cutting-edge products that meet evolving customer demands.

*Market Responsiveness:* I4.0 equips SMEs with the agility and flexibility to respond quickly to changes in market demand and the competitive landscape [96]. Digital manufacturing technologies enable SMEs to produce small batches of custom or personalized products cost-effectively, allowing them to capitalise on niche markets and stay ahead of larger competitors.

*Competitive Advantage:* By adopting I4.0 in NPD processes, SMEs help to increase a competitive edge in the market [97]. The ability to innovate rapidly, customize products, and deliver superior customer experiences positions SMEs as agile and innovative players capable of meeting the diverse needs of today's consumers.

#### 4.7 SMEs' challenges in implementing I4.0 in the NPD processes

Implementing I4.0 in the NPD processes of SMEs presents several challenges:

*Financial Constraints:* The primary challenge for SMEs is the financial investment required to adopt I4.0 technologies [98]. Many SMEs operate on tight budgets and may lack the resources to invest in the expensive hardware, software, and training needed for I4.0 implementation. *Lack of Expertise and Skills:* SMEs often face a shortage of skilled personnel with expertise in I4.0 technologies such as data analytics, IoT, and AI [99]. Recruiting and retaining qualified talent, as well as providing ongoing training for existing employees, can be challenging for SMEs.

*Technology Integration:* Integrating disparate I4.0 technologies into existing NPD processes can be complex and requires careful planning [100]. SMEs may struggle with compatibility issues between different systems and platforms, as well as with ensuring seamless data flow and communication across the organization.

*Data Security and Privacy Concerns:* The increased connectivity and data sharing inherent in I4.0 pose significant cybersecurity risks for SMEs [101]. Protecting sensitive NPD data from cyber threats, ensuring compliance with data privacy regulations, and building robust cybersecurity measures can be daunting tasks for SMEs with limited resources.

*Resistance to Change:* Resistance to change among employees and organizational inertia can hinder the successful implementation of I4.0 in SMEs [102]. Some employees may be reluctant to embrace new technologies or processes, fearing job displacement or increased workload, leading to resistance and friction within the organization.

*Scalability and Customization:* I4.0 solutions may not always be scalable or customizable to the unique needs and constraints of SMEs [103]. Off-the-shelf solutions designed for larger enterprises may be too complex or costly for SMEs, requiring customization or adaptation to suit their specific requirements.

*Risk of Overreliance on Technology:* While I4.0 offers numerous benefits, SMEs must be cautious not to become overly reliant on technology at the expense of human judgment and creativity. Balancing the use of technology with human expertise and intuition is essential for successful NPD outcomes.

*Regulatory Compliance:* Compliance with industry regulations and standards related to product development, data management, and intellectual property rights can pose additional challenges for SMEs implementing I4.0 in their NPD processes. Ensuring compliance with relevant regulations is essential to avoid legal risks and penalties [104].

Addressing these challenges needs a strategic approach that considers the unique needs, resources, and capabilities of SMEs [105]. Collaboration with industry partners, government agencies, and technology providers can also help SMEs overcome barriers to I4.0 implementation and unlock the full potential of digital transformation in their NPD processes.

#### 5.0 Future of I4.0 SME Performance

Future evolving trends, successful implementation strategies, and potential policy interventions to support SMEs in embracing I4.0 for NPD. The analysis highlights the need for forthcoming research to delve into several key areas regarding the integration of I4.0 technologies in the context of SMEs, particularly in the area of NPD. Some of the focal points that should be addressed in future studies are as follows:

*Evolving Trends:* Investigating the ongoing developments and advancements in I4.0 technologies and how they can be harnessed effectively by SMEs for NPD [106]. This includes exploring evolving technologies such as artificial intelligence, the IoT, advanced robotics, and additive manufacturing, and understanding their implications for NPD processes.

*Successful Implementation Strategies:* Identifying and analysing the strategies that have proven successful for SMEs in implementing I4.0 technologies for NPD [92]. This entails examining case studies and best practices to understand the challenges faced by SMEs during the implementation process and the strategies they employ to overcome these challenges.

*Potential Policy Interventions:* Assessing the role of policy interventions at the governmental or organizational level in facilitating SMEs' adoption of I4.0 for NPD [107]. This may include evaluating existing policies, incentives, and support programs aimed at promoting technological adoption among SMEs and proposing new policy measures to address any existing gaps or barriers.

*Barriers and Challenges:* Investigating the barriers and challenges that hinder SMEs from embracing I4.0 technologies for NPD. This could include factors such as lack of resources, expertise, infrastructure, and resistance to change, and exploring strategies to mitigate these challenges.

*Impact on NPD Processes and Performance:* Examining the impact of I4.0 technologies on various aspects of NPD processes, such as ideation, design, prototyping, testing, and commercialization [108]. Additionally, assessing the influence of I4.0 adoption on SMEs' NPD performance indicators, such as speed to market, product quality, innovation, and competitiveness.

*Collaborative Ecosystems:* Exploring the role of collaborative ecosystems, including partnerships with larger enterprises, research institutions, and technology providers, in facilitating SMEs' adoption of I4.0 for NPD, understanding how SMEs can leverage external resources and expertise to overcome their limitations and accelerate their technological transformation.

## 6.0 Conclusion

In conclusion, the critical review underscores the transformative potential of I4.0 on NPD within SMEs. While challenges exist, the benefits of enhanced collaboration, cost-effective prototyping, and flexible manufacturing processes position SMEs to thrive in a rapidly evolving technological landscape. Strategic adoption of Industry 4.0 is imperative for SMEs aiming to bolster their innovative capacities and ensure long-term competitiveness in the global market.

- i. The impact of I4.0 technologies in NPD necessitates a shift in the skill set required by employees. SMEs may need to invest in training programs to ensure their workforce is equipped to handle the digital tools and technologies effectively [109].
- ii. I4.0 has the potential to significantly impact new product development in SMEs by enhancing efficiency, promoting data-driven decision-making, enabling customization, fostering collaboration, and optimizing supply chains. However, challenges such as cybersecurity and skill set requirements should be carefully addressed to fully leverage the benefits of these technological advancements [110].
- iii. Understanding the adoption patterns of SMEs in technology implementation is crucial for identifying effective strategies to support their growth and competitiveness. By recognizing the unique challenges faced by SMEs and exploring collaborative approaches to technology adoption, policymakers and industry stakeholders can help SMEs navigate the digital landscape successfully [111].
- iv. I4.0 presents SMEs with a wealth of opportunities to enhance their prototyping and testing capabilities, ultimately leading to improved product development processes, cost savings, and competitive advantages in the marketplace [112, 113].
- v. By resolving these challenges and implementing these strategies, SMEs can position themselves to fully exploit the potential benefits of Industry 4.0 in new product development, thereby gaining a competitive edge in the market
- vi. By leveraging these I4.0 technologies, SMEs can overcome traditional barriers to customization and flexibility in manufacturing, thereby enhancing their competitiveness in the market and meeting the evolving demands of modern consumers.
- vii. The integration of I4.0 technologies into NPD processes presents SMEs with unprecedented opportunities to innovate, compete, and succeed in today's digital economy [106]. However, realizing these benefits requires strategic planning, investment in technology infrastructure, and a culture of innovation and continuous improvement within the organization.
- viii. Industry 4.0 has transformed NPD processes in SMEs by enhancing efficiency, fostering innovation, and enabling greater market responsiveness, ultimately driving growth and competitiveness in an increasingly digital and dynamic business environment.
- ix. By addressing these research gaps, future studies can provide valuable insights and guidance for SMEs seeking to leverage I4.0 technologies to enhance their NPD capabilities and competitiveness in the global market.

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