The role of clusters in advancing Industry 4.0 solutions: insights from the Polish automotive context

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Abstract

Purpose – *This study is exploratory in nature and designed to address poorly documented issues in the literature. The dimensions of regional distribution or spatial organisation of Industry 4.0 (I4.0), including the potential role of clusters, have only recently been addressed, with most available studies focusing on advanced, mainly Western European countries. Although developing fast, the literature on I4.0 in other countries, such as the Central and Eastern European or post-transition economies like Poland, needs to pay more attention to the spatial distribution or geographical and organisational aspects. In response to the identified knowledge gap, this paper aims to identify the role of clusters in the transformation towards I4.0. This explains why clusters may matter for advancing the fourth digital transformation, how advanced in implementing I4.0 solutions are the residents of Polish clusters and how they perceive the advantages of cluster membership for such implementation. Finally, it seeks to formulate policy recommendations based on the evidence gathered.*

Design/methodology/approach – *The methodology used in this study combines quantitative analysis of secondary data from a cluster benchmarking survey with a case study approach. The benchmarking survey, conducted by the polish agency for enterprise development in 2021, gathered responses from 435 cluster members and 41 cluster managers, representing an estimated 57% of the current clusters in Poland. In addition to quantitative analysis, a case study approach was used, incorporating primary sources such as interview with cluster managers and surveys of cluster members, as well as secondary sources like company documents and information from cluster organisation websites. Statistical analysis involved assessing the relationship between technology implementation and the adoption of management systems, as well as exploring potential correlations between technology use and company characteristics such as revenue, export revenue share and number of employees using Pearson correlation coefficient.*

Findings – *In Poland, implementing I4.0 technologies by cluster companies is still modest. The cluster has influenced the use of I4.0 technologies in 23% of surveyed companies. Every second surveyed company declared a positive impact of a cluster on technological advancement. The use of I4.0 technologies is not correlated with the revenue of clustered companies. A rather bleak picture emerges from the results, revealing a need for more interest among cluster members in advancing I4.0 technologies. This may be due to a comfortable situation in which firms still enjoy alternative competitive advantages that do not force them to seek new advanced advantages brought about by I4.0. It also reflects the sober approach and awareness of associated high costs and necessary investments, which are paramount and prevent successful I4.0 implementation.*

Research limitations/implications – *The limitations inherent in this study reflect the scarcity of the available data. This paper draws on the elementary survey administered centrally and is confined by the type of questions asked. The empirical section focuses on an important, though only one selected sector of the economy – the automotive industry. Nevertheless, the diagnosis of the Polish cluster's role in advancing I4.0 should complement the existing literature.*

Practical implications – *The exploratory study concludes with policy recommendations and sets the stage for more detailed studies. Amidst the research's limitations, this study pioneers a path for future comprehensive investigations, enabling a deeper understanding of Polish clusters' maturity in I4.0 adoption. By comparing the authors' analysis of the Polish Automotive Group (PGM) cluster with existing literature, the authors uncover a distinct disparity between the theoretical prominence of cluster catalysis*

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JEL classification – L1, L2, M2, O3, R1

Received 15 June 2023
Revised 25 September 2023
22 January 2024
18 February 2024
Accepted 22 February 2024

The authors would like to express their gratitude to the Polish Agency for Enterprise Development (PAED), the Polish Automotive Group (PGM), and the Silesia Automotive and Advanced Manufacturing (SA&SM) clusters for providing the data.

and the current Polish reality. Future detailed dedicated enquiries will address these constraints and provide a more comprehensive map of Polish clusters' I4.0 maturity.

Originality/value – *This study identifies patterns of I4.0 implementation and diagnoses the role of clusters in the transformation towards I4.0. It investigates how advanced is the adoption of I4.0 solutions among the residents of Polish clusters and how they perceive the advantages of cluster membership for such transformation. Special attention was paid to the analysis of the automotive sector. Comparing the conclusions drawn from the analysis of the Polish PGM cluster in this case study to those from the literature on the subject, it becomes clear that the catalytic role of clusters in the implementation of I4.0 technologies by enterprises, as emphasised in the literature, is not yet fully reflected in the Polish reality.*

Keywords *Cluster, Industry 4.0, Policy, Automotive, Poland*

Paper type *Research paper*

1. Introduction

The emergence of Industry 4.0 (I.40) has revolutionised the business landscape, necessitating the adoption of advanced technologies and processes to drive digital transformation. However, understanding the implementation of I4.0 requires considering the organisational aspects that shape this transformation (Fraske, 2022). I4.0 encompasses cutting-edge technologies like 3D printing, the Internet of Things (IoT), Big Data, artificial intelligence and cloud computing and recognises the importance of organisational and social dimensions (Cugno *et al.*, 2022). In this era, enterprises must embrace digital innovations to remain competitive (Gupta and Jauhar, 2023), using technologies as enablers to automate logistics, optimise manufacturing performance and streamline production processes. Previous research highlighted the potential of clusters in this context and identified them as ecosystems fostering the fourth industrial revolution and driving digital business transformations (Jankowska *et al.*, 2021). This paper aims to determine the possible importance of clusters in advancing the I4.0 in the Polish context. To achieve this, a selective narrative literature review guided by a straightforward research question and the authors' expertise in working with clusters is conducted (Gancarczyk, 2019). Besides, to gain insights into the relevance of I4.0 technologies, data from "Benchmarking surveys" conducted periodically since 2010 by the Polish Agency for Enterprise Development is used. The study covers an analysis of all Polish clusters in the 2020 "Benchmarking" study, supplemented by a comparative case study of the Polish Automotive Group (PGM) cluster and Silesia Automotive and Advanced Manufacturing (SAAM) cluster. The automotive industry is particularly significant in implementing I4.0 technologies due to its complex nature, high-volume manufacturing and the increasing focus on electric and autonomous vehicles.

While studies on the co-evolution of clusters and I4.0 remain fragmented and patchy (Castelo-Branco *et al.*, 2019; Balland and Boschma, 2021a, 2021b; Lund and Vildåsen, 2022; Hervas-Oliver *et al.*, 2020), recent research has begun to address the spatial and organisational aspects of the fourth industrial revolution (Fraske, 2022). However, the literature predominantly focuses on advanced Western European countries such as Germany, Spain and Italy (Götz, 2023; Hervas-Oliver *et al.*, 2020; Balland and Boschma, 2021a, 2021b). The literature on I4.0 in other countries, including Central and Eastern European (CEE) countries and post-transition economies like Poland, is rapidly developing but mainly concentrates on place-neutral issues like social aspects or technological challenges (Zakrzewska-Bielawska and Staniec, 2020). Thus, this paper aims to bridge this knowledge gap by identifying the potential role of Polish clusters in the transformation towards I4.0. The study investigates the level of advancement in implementing I4.0 among residents of Polish clusters and explores their perceptions of the advantages of cluster membership for such implementation. Through an exploratory pilot study that elucidates the interdependencies between Polish clusters and I4.0 implementation, this research paves the way for more detailed investigations. As the research on the intersection of I4.0 and clusters remains in its infancy any studies, even limited to the analysis of a single country context, provide added value, especially as there is a lack of complementary internationally

comparable studies in this field, such as databases. Such analyses (case studies, countries reports, etc.) have yet to be created so that further meta-studies can be built on them.

Considering the definition of clusters, there is variation in the literature. Some studies refer to "natural clusters", which align with Porter's definition, describing geographically proximate groups of interconnected companies and associated institutions in a particular field linked by commonalities and complementarities (Porter, 2000). Other studies focus on "cluster initiatives" or "organised clusters" in the form of cluster organisations, where firms, educational and research institutions and public bodies come together to form an organised and managed legal entity (Furman *et al.*, 2002; Morgulis-Yakushev and Soelvell, 2017). The existence of a cluster organisation can strengthen and deepen relationships between actors through bridge-building activities, fostering collaboration and innovation (Lechner and Leyronas, 2012; Morgulis-Yakushev and Soelvell, 2017). Moreover, a cluster coordinator or leader has been shown to enhance knowledge flow, information symmetry and overall productivity and innovation within companies in the cluster (Kuczewska and Tomaszewski, 2022).

By investigating and describing the case of the automotive cluster, this study aims to explore the potential contribution of clusters in driving the implementation of I4.0 in Poland. The contextualised nature of the study, deeply rooted in the specificities of the examined case, allows for a comprehensive understanding of the role clusters can play in digital transformation processes. We view the context and particularities of the case not as limitations but as sources of exploratory power. While analytical generalizability is the aim, the study also addresses the tendency to decontextualise, which risks oversimplification and misinterpreting findings (Welch *et al.*, 2022).

In conclusion, this study sheds light on the potential role of clusters in implementing digital transformation, a crucial driver of long-term growth and development. By examining the interplay between clusters and I4.0 in the Polish automotive context, this research contributes to the evolving literature on the spatial and organisational aspects of I4.0. It sets the foundation for more extensive and nuanced investigations.

2. Literature review on possible clusters' impact on Industry 4.0

We start showing the complexity of I4.0, then move to illuminating the regional aspect and accompanying spatial unequal distribution to arrive at the role of clusters as fertile grounds for implementing I4.0.

The presented review provides the current state of the art concerning the evidence on how clusters might contribute to I4.0. The summary in Table 1 synthesises the key findings and can frame the following discussion of our case.

According to Morisson and Pattinson (2019), I4.0 can be defined simply as using recently emerged new technologies in the industrial sector. As I4.0 is a business approach focused on generating value, integrated information and communication technologies systems can synchronise the production process. In this way, traditional isolated production can be substituted by automated and integrated industries (Pelle *et al.*, 2020). Integrating advanced technologies into manufacturing processes requires a conducive environment and may be challenging in a setting that is not ready for change. Naudé *et al.* (2019) presented the differences among the readiness levels of Central and Eastern Europe. The proposed readiness level is based on three components: technological competencies, entrepreneurial competencies and government competencies, analysed through different indicators. Czechia was the readiest of the CEE countries, followed by Lithuania, Hungary and Slovenia. Slovakia ranked sixth, preceding Poland (Naudé *et al.*, 2019). What is missing in the set of components is the social competencies and the readiness of staff to implement the I4.0 technologies. As I4.0 is a business model focused on creating value through integrating advanced technologies and using data-driven insights to optimise operations and improve the customer experience, it must include social aspects (Cugno *et al.*, 2022).

Table 1 Why and how clusters (cluster organisations) may matter for I4.0?

Impact	*Research*
The technological maturity of companies requires not only access to technology but the proper organisation and environment	Gillani *et al.* (2020), Mackiewicz and Pavelkova (2022)
Integration of advanced technologies into manufacturing processes can be done quickly in a conducive environment offering technological, entrepreneurial and government competencies; social competencies and the readiness of staff	Pelle *et al.* (2020), Naudé *et al.* (2019)
I4.0 as a consistent combination of both technological and business aspects, contingent on an enabling industrial ecosystem and policy regime; adaptation of significant disruptions such as I4.0 requires structure and agency for value creation and capture	Labory and Bianchi, (2021), Ortt *et al.* (2020)
Context; collaborative synergies; and network intermediaries; a critical mass of technologies but emerging new technological solutions must find an audience that can implement them	Baker *et al.* (2021), Russo *et al.* (2022)
Skills, investments, infrastructure, innovative capacity, entrepreneurship and collaboration – enabling conditions	Van de Velde *et al.* (2019). Radosevic, (2019)
Skilfully guided public policies; adoption of policy instruments; the network structure and government subsidy's role in crossing the valley of death (transformation of scientific and technological achievements); clusters as organisational vehicles for the diffusion of innovation achievements	Teixeira and Tavares-Lehmann, (2022), Yin *et al.* (2022)
Boundaries between firms are blurring; traditional value chain configuration implies joint participation, increased attention to competition and cooperation	González-Torres *et al.* (2020)
Changing market needs and increasing pressure for innovation; geographical proximity and interaction with other companies and external agents; micro-geographic proximity for the formation of knowledge transfer relationships and different types of inter-organisational relationships: importance of the "neighbourhood effect"	Tavares *et al.* (2021), Ferretti *et al.* (2021)
Cognitive proximity between firms; collaboration between businesses and industries, an alternative inter-organisational network driven by competition and cooperation	Molina-Morales and Exposito-Langa, 2012, Yström and Aspenberg (2017), Strand *et al.* (2017)
The positive effects of agglomeration related to knowledge transfer; the use of highly specialised knowledge and the importance of social capital and local institutions	Capello and Lenzi, (2014) Belussi *et al.* (2010), Molina-Morales and Exposito-Langa, 2012, Ortega-Colomer *et al.* (2016)
Intermediaries in open innovation, mutual trust, compatibility, close cooperation and standard rules; overcoming barriers; raising awareness of industrial associations, business organisations and cluster initiatives as knowledge gatekeepers, transfer intermediaries and mediators of spontaneous diffusion	McPhillips (2020), Dyba and De Marchi (2022)

Source: Authors' elaboration based on literature review

Ortt *et al.* (2020) stress that I4.0 is not just a collection of new technologies. It is a consistent combination of both technological and business aspects. Therefore, it is advisable to develop dynamic capabilities that would foster successful adaptation of significant disruptions such as I4.0 (Labory and Bianchi, 2021). Such capabilities mediate between structure and agency in regional development and promote value creation and capture (Labory and Bianchi, 2021).

Other case studies depicted how policies and modalities for collaboration facilitate I4.0. Based on case studies of Ontario, Canada and Massachusetts, the authors selected four principal factors that play a crucial role: industrial clusters; context; collaborative synergies; and network intermediaries (Baker *et al.*, 2021). Other factors that may be necessary include skills, investments, infrastructure, innovative capacity, entrepreneurship and collaboration (Van de Velde *et al.*, 2019; Radosevic, 2019).

Because the competencies needed to develop digital technologies are not evenly distributed, not all regions can develop through their use. This is a phenomenon that has been widely described in the literature, especially concerning regional development and innovation. To get on the path of development, a critical mass is needed, as emerging new technological solutions must find an audience that can implement them. The same applies

to the IoT and other enabling technologies (Russo *et al.*, 2022). The authors argue that the competence base of regions, particularly the mix of competencies in the IoT, is a critical factor in developing their technological bases in emerging digital technologies. Public policies also influence digitisation and the implementation of I4.0 solutions. Skilfully guided, they can reduce disparities between regions.

The European Member States implement policies to stimulate the adoption of I4.0 technologies and the European Commission motivates the Member States to adopt digitalisation strategies at the national level. Teixeira and Tavares-Lehmann (2022) identified 25 different national I4.0-focused plans in the years 2011 and 2020 revealing significant variations in the conditions for implementing policies and in adopting policy instruments (Teixeira and Tavares-Lehmann, 2022).

As González-Torres *et al.* (2020) note, the boundaries between firms are blurring regarding value creation. As a result, increasing attention is paid to global value chains and industry clusters combining competition and cooperation in this context.

Many studies confirm the role of clusters in generating benefits for clustered companies (Enright, 1996; Fløysand and Jakobsen, 2001; Molina-Morales and Exposito-Langa, 2012; Porter, 1998; and others). Participation in a cluster may offer various benefits ranging from economies of scale, reduced costs, transfer of technologies to increased innovative potential. Previous studies conducted on Polish clusters show that participation in a cluster affects the technological maturity of companies (Mackiewicz and Pavelkova, 2022).

There are also research results that indicate that clusters cannot be treated as a remedy for various problems of business operations. For example, the results of analyses conducted by Pavelkova *et al.* (2021) on the company-level data for 2009–2016 do not confirm the significant impact of membership in a cluster organisation on financial performance for companies in the sectors studied. Various studies confirmed the cluster benefits (Ben Abdesslem and Chiappini, 2019; Li and Geng, 2012; Stojčić *et al.*, 2019). However, some reports showed that clustering contributes to performance only at certain life cycle stages (Aranguren *et al.*, 2014; Branco and Lopes, 2018) or not at all (Kukalis, 2010). Therefore, it is reasonable to ask whether clusters accelerate the deployment of I4.0 technologies and what role clusters can play in implementing them.

Tavares *et al.* (2021) diagnosed that the factors responsible for developing innovation capabilities in cluster-based companies are changing market needs and increasing pressure for innovation. In the case of I4.0 technologies, similar factors will play a role. The authors found some evidence regarding geographical proximity and interaction with other companies and external agents, emphasising their importance for the innovation process in industrial clusters (Tavares *et al.*, 2021).

What matters for the implementation of advanced technologies such as I4.0 technologies is cognitive proximity between firms. The exchange and the creation of a joint knowledge base between cluster companies were explained by Molina-Morales and Exposito-Langa, 2012. Industrial clusters also have the potential to increase collaboration between businesses and industries (Yström and Aspenberg, 2017), as they provide an alternative inter-organisational network driven by competition and cooperation (Strand *et al.*, 2017).

Previous studies relating to industrial districts, which are precursors to clusters, have indicated that they provide a suitable environment for I4.0 development due to the positive effects of agglomeration related to knowledge transfer and the importance of social capital and local institutions (Capello and Lenzi, 2014; Belussi, Sammarra, and Sedita, 2010; Molina-Morales, Capó-Vicedo, Teresa Martínez-Fernández, and Expósito-Langa, 2013; Ortega-Colomer, Molina-Morales, Fernández de Lucio, and Lucio, 2016). A study conducted by Yin *et al.* (2022) assumed that clusters are effective organisational vehicles for the diffusion of innovation achievements. Concerning the innovation diffusion dynamics model, it was found that government subsidies play a vital role at the innovation adoption

stage, especially in highly innovative industrial clusters. In contrast, at the innovation diffusion stage, internal factors play an essential role (Yin *et al*., 2022).

The technological scenario of I4.0 emphasises distributed, technologically connected operations and distributed knowledge management capabilities, while clusters focus on proximity, so many researchers question the attractiveness of clustering for companies (Jankowska *et al*., 2021).

Clusters play the role of intermediaries in open innovation. As McPhillips (2020) notes, open innovation can become one of the pillars of realising the fourth industrial revolution in clusters. This is linked to changes in management style favouring ecosystem management, in which companies can create innovations together. Transformation in this direction requires conditions inherent in clusters - mutual trust, compatibility, close cooperation and standard rules (McPhillips, 2020).

A study of the role of inter-organisational micro-geographic proximity in the formation of knowledge transfer relationships showed that micro-geographic proximity is associated with forming different types of inter-organisational relationships confirming the importance of the "neighbourhood effect" (Ferretti *et al*., 2021).

Companies face many barriers to adopting I4.0 technologies, including companies in clusters. As Dyba and De Marchi (2022) note, these barriers include unawareness of the features and potential of these technologies. Helpful in overcoming this barrier is the dissemination of knowledge among companies. This role can be undertaken by business support organisations, acting in three roles: gatekeepers of knowledge, intermediaries of targeted knowledge transfer and mediators of spontaneous knowledge diffusion.

Based on the literature, clusters seem important in implementing I4.0. The presence of specialised institutions can provide access to cutting-edge research and development. This can help cluster companies to stay at the forefront of scientific developments and to adopt new technologies more quickly. The strong networks of suppliers, customers and other partners can facilitate the information and best practices sharing, making it easier for companies to learn from each other and collaborate on implementing I4.0 technologies. In addition, industrial clusters tend to have a high density of small- and medium-sized enterprises, which often have limited resources to invest in innovation and digitalisation. However, being part of an industrial cluster can provide them access to shared resources such as technology and knowledge and allow them to collaborate with larger companies and research institutions (Baum and Oliver, 1991; Götz, 2023).

The potential cluster contribution towards the digital transformation seems diverse, ranging from simply offering a better environment and business-friendly conditions (something is "in the air", as famously stated by Marshall) to the precise, tailor-made instruments, implying the multiple channels of possible cluster impact on I4.0 technologies adoption. During the digital transformation, as the industry tends to evolve towards intelligent technical systems) based on cyber-physical systems and business models built upon intelligent product-service systems, firms can take advantage of clusters as hybrid systems that are growing collocated transformative capabilities. Summing up (Table 1), the presented review suggests that clusters can indeed contribute to the advancement of the fourth industrial revolution and, in particular, offer a conducive environment to the progressive implementation of I4.0 solutions.

3. Methodology

The methodology used in this research paper is structured around two key components: the utilisation of data collected for the "Benchmarking" study, and a case study approach. This methodological design integrates quantitative analysis of secondary data collected for the cluster "Benchmarking" study with a case study framework, encompassing the use of both

primary and secondary data sources. The primary objective of this research methodology is to provide insights into the role of clusters in promoting I4.0 solutions within the context of Poland.

The case study procedure adheres to the methodological framework outlined by Yin (2014). It encompasses the following steps:

- A comprehensive literature review was conducted, focusing on the domain of digital transformation and the specific context of Poland.
- Research questions were formulated to guide the investigation into the role of clusters in advancing I4.0 solutions within the Polish context.
- Two clusters, namely, PGM and SAAM, operating within the automotive sector, were selected for the case study. These clusters were chosen due to their relevance to the research questions.
- A questionnaire was developed to gather data from members of the selected clusters. This questionnaire aimed to collect information related to I4.0 practices and their impact within these clusters.
- Data collection was carried out using the developed questionnaire.

Additionally, data from secondary sources were also incorporated into the study.

The "Benchmarking" survey conducted by the Polish Agency for Enterprise Development in 2021 provided a substantial data set, with responses obtained from 435 cluster members and 41 cluster managers. It is worth noting that this data set was estimated to represent approximately 57% of the total clusters operating in Poland. The absence of an official cluster register necessitated this estimation, excluding Key National Clusters.

The second component of the methodology involved a comparative case study of two clusters, PGM and SAAM, both active in the automotive sector. This component leveraged both primary and secondary data sources. Primary data was collected through interviews with cluster managers and surveys distributed to cluster members. Secondary data was derived from documents and publicly available information on the companies and cluster organisations involved.

In the case of the PGM cluster, a comprehensive online survey was conducted, achieving a response rate of 76% from a total of 60 member companies. This survey assessed the adoption of various technologies, including the IoT, Big Data, intelligent industrial robots, data cloud, simulation and 3D printing. Data collection for this survey took place between August and September 2022. Similar data was collected from a second National Key Cluster operating in the same industry, SAAM, which included foreign companies with branches in the Katowice Special Economic Zone. Notably, SAAM comprised a different enterprise structure, characterised by a significant presence of large enterprises, while PGM consisted exclusively of Polish companies. The sample was 91 companies.

The study examined various company characteristics to identify potential factors influencing the implementation of I4.0 technologies. In this study, the Phi coefficient was used as a statistical measure to quantify the association between binary variables. Specifically, it was used to assess the relationship between the adoption of management systems listed in Table 2 and the implementation of I4.0 systems within the clusters under investigation. The Phi coefficient provides insights into the strength and direction of this association. Pearson's correlation coefficient was used to examine the relationship between the implementation of I4.0 technologies and various company characteristics, including revenue, export revenue share and the number of employees. This analysis helps to determine both the degree and direction of correlations between these continuous variables.

Table 2 Questions asked to the cluster members (435) and cluster managers (41)

Q to cluster members	*Q to cluster managers*
How do you assess the impact of participation in the cluster on the level of technological sophistication of your company's operations? Has participation in the cluster influenced your company's use of I4.0 technology solutions (such as the IoT, Big Data, intelligent industrial robots, data cloud, simulation, 3D printing)?	What percentage of enterprises in the cluster use at least two of the following management systems: enterprise resources planning (ERP), customer relationship management (CRM), content management system (CMS), material requirements planning (MRP), document management system (DMS), supply chain management (SCM), warehouse management software (WMS), working time registration (RCP), business intelligence (BI)? What percentage of cluster members use such I4.0 systems (IoT, industrial IoT, 3 D printing, digital factory, artificial intelligence, data cloud, Big Data)?

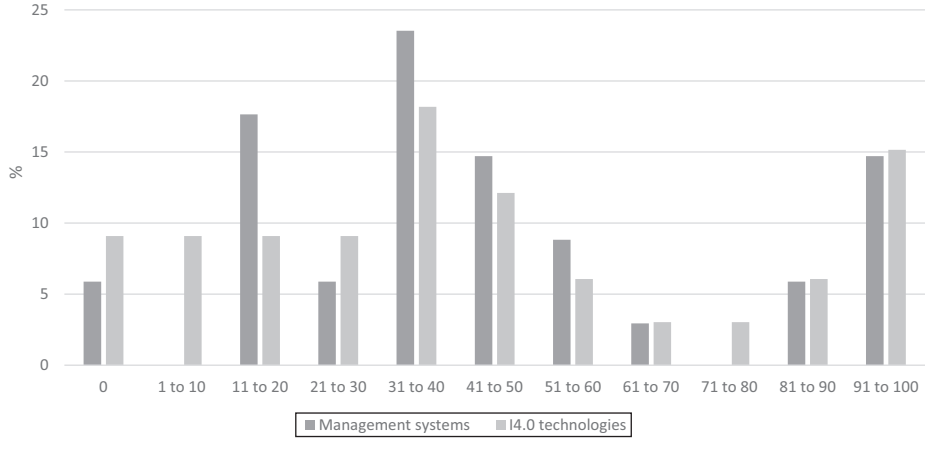
Source: Authors' elaboration based on available data

In our research, triangulation is implemented through the combination of quantitative analysis of the "Benchmarking" survey data, qualitative insights obtained from interviews with cluster managers and supplementary information extracted from secondary sources like documents and clusters' websites.

4. Results and discussion

The general landscape of the Polish clusters can be presented based on the data collected for "Benchmarking". To this end, the answers to the two questions mentioned above regarding the share of cluster members applying management systems and those harnessing the I4.0 systems were presented. We first grouped the responses into ranges. Then we counted the percentage of responses in each range (Figure 1). Notably, the distribution patterns of I4.0 technology usage closely resemble those of data management systems, albeit with some variations among individual clusters. To quantify the relationship between these two variables, Pearson's correlation coefficient was calculated. It measures the strength and direction of the relationship between variables. The value of correlation coefficient $r = 0.7985$ signifies a strong positive relationship between implementing management systems and adopting I4.0 technologies.

Figure 1 Implementation of management systems and I4.0 technologies in Polish cluster organisations



Source: Authors' elaboration based on PAED data

When calculated for individual observations (the cluster level), the correlation appears even stronger with Pearson's coefficient equal to 0.841 and *p*-value equal to 3.035e–09 (29 degrees of freedom) (Figure 2).

Combining technologies such as artificial intelligence, supply chain management, distribution management systems or warehouse management systems helps companies to improve their efficiency, reduce costs and increase profitability. This issue requires further detailed research but confirms the earlier claims by Gupta and Jauhar (2023), who highlighted that using digital innovations such as artificial intelligence, machine learning, robotics programming, augmented reality, cloud computing or big data analytics enabled firms to lower operating and storage costs, automate their functions, provide better services to their customers and make their operations more fluid and flexible.

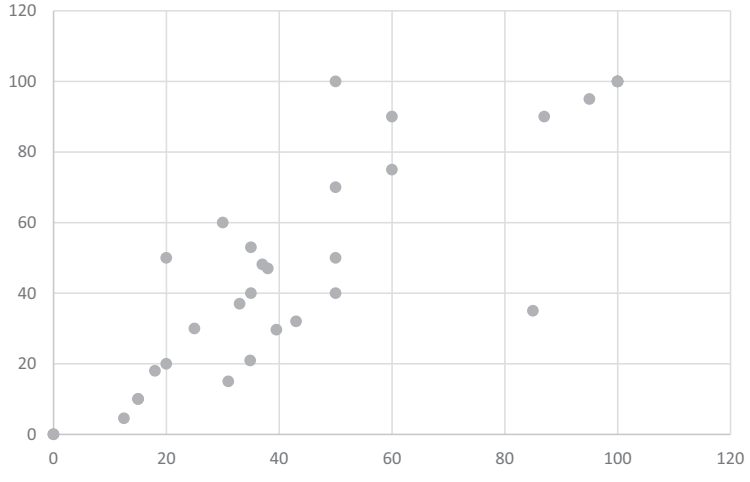
The survey of cluster members (435) shows that less than a quarter assess that participation in the cluster has influenced the use of I4.0 technologies (Figure 3). In contrast, almost a third recognise that the use of these technologies is unrelated to participation in the cluster. At the same time, 45.5% admit that they do not use any I4.0 technology.

An analysis of the cluster's role in the overall technological advancement of companies offers more optimistic conclusions, as more than half assessed that participation in the cluster has a positive impact on technological advancement (Figure 4).

The research results suggest that Polish cluster organisations have been slow in implementing I4.0 technologies. However, it is important to note that companies that are already "I4.0 mature" or ready for the fourth industrial revolution greatly appreciate the assistance they receive from clusters in this regard. A publication titled "I4.0 – A Step Towards Industrial Security" reveals that nearly one in three large- and medium-sized companies in Poland are actively undergoing digital transformation. Nevertheless, there is still a need for change in 11% of companies, with 7% of large companies and 17% of medium-sized companies yet to implement these technologies.

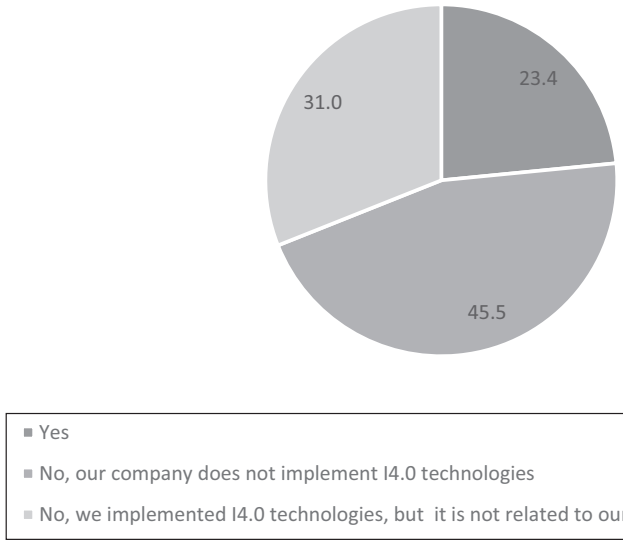
To delve deeper into our research, we now turn our focus to the automotive cluster, providing concrete evidence of how clusters contribute to accelerating the implementation of I4.0 business models. The automotive industry, known for its complexity and high-volume

Figure 2 Correlation between implementation of management systems and I4.0 technologies



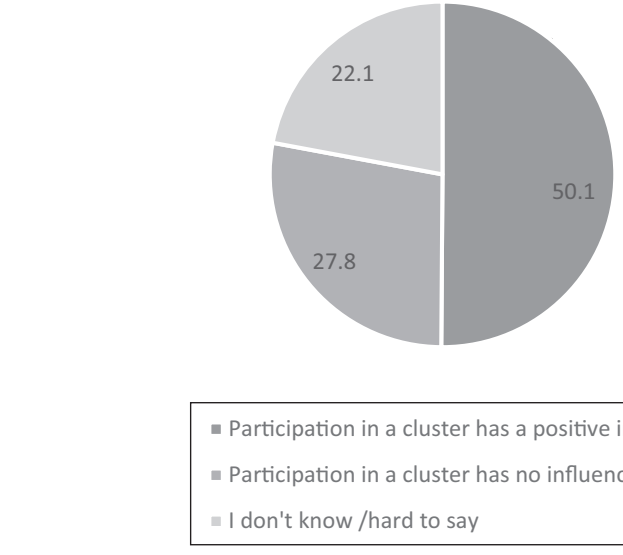
Source: Authors' elaboration based on PAED data

Figure 3 Estimated impact of participation in a cluster organisation on implementing I4.0 technologies by cluster members ($N = 435$)



Source: Authors' elaboration based on PAED data

Figure 4 Estimated impact of participation in a cluster organisation on technological advancement ($N = 435$)



Source: Authors own creation based on PAED data

production, stands to benefit significantly from integrating advanced technologies that improve efficiency, productivity and cost reduction (Pelle *et al.*, 2020; Cséfalvay and Gkotsis, 2020). One critical area within the automotive industry where I4.0 technologies are making a difference is advanced robotics and automation. By leveraging automation, tasks

that are dangerous or challenging for humans, such as welding or painting, can be performed with precision. Additionally, real-time monitoring of production lines using sensors and cameras enables defect identification and quality control.

Furthermore, these technologies offer immense potential to enhance supply chain management and logistics in the automotive industry. For instance, IoT devices are being used to track the movement of parts and materials throughout the supply chain, while big data analytics optimise production and delivery schedules. By providing a contextualised description of the automotive cluster's I4.0 implementation, we want to shed light on the potential role these entities can play in driving digital transformation in Poland.

One prominent cluster in the automotive industry is the PGM cluster, a National Key Cluster that brings together Polish parts and components manufacturers. The cluster primarily comprises small- and medium-sized companies that supply various parts for new and used vehicles. Research institutes, such as the Industrial Automotive Institute and the Military Institute of Armoured and Automotive Technology, play a crucial role in stimulating innovation, conducting research and development work and certifying and homologating products within the PGM Cluster.

To facilitate the adoption of I4.0 technologies, the Cluster has established a working group, where representatives from member companies regularly exchange information, experiences and best practices and discuss challenges. The main objective of this working group is to prepare companies for structured implementation of I4.0 technologies. Moreover, the PGM Cluster has been actively organising various activities to raise awareness and promote modern production technologies among its members. Notably, the cluster organisation makes it relatively easier to provide tailored training as cluster members can express their specific needs to the cluster manager.

A comprehensive training needs analysis conducted in 2022 revealed the members' keen interest in acquiring knowledge related to the fourth industrial revolution and implementing I4.0 concepts in enterprises. Topics of interest included I4.0 technologies, flow management and manufacturing system design within the I4.0 framework.

The aforementioned examples illustrate the cluster manager's active role in accelerating the implementation of I4.0 technologies, as outlined in Table 3.

To evaluate the I4.0 maturity of PGM members, an online survey was conducted with responses analysed from 60 member companies. Of those, 34 companies use at least one technology, such as the IoT, Big Data, Intelligent Industrial Robots, Data Cloud, Simulation or 3D Printing. Out of the 60 surveyed cluster companies, 21 use two or more technologies. The authors studied various company characteristics to determine which factors may influence the implementation of I4.0 technologies. Results from the survey analysis revealed a weak positive correlation between I4.0 technology implementation and implementation of a management system. Statistical tests showed that intensity does not matter; it does not matter whether companies have implemented one management system or more. Therefore, in this case, the Phi coefficient was used for binary variables (implemented I4.0 technology = 1, no

Table 3 Activities undertaken by the PGM cluster to facilitate the I4.0 adoption

Type of activity	*Examples*
Awareness-raising	Study visits; Organisation of meetings "In the World of Smart Factory"; PGM Cafeteria;
Dual studies and tailored training	MBA studies in cooperation with the Warsaw University of Technology on I4.0; Academy of I4.0 Manager
Providing assistance in solving current problems	I4.0 Cluster Working Group; Cooperation with the Industrial Automotive Institute PIMOT

Source: Authors' elaboration based on data provided by the cluster manager

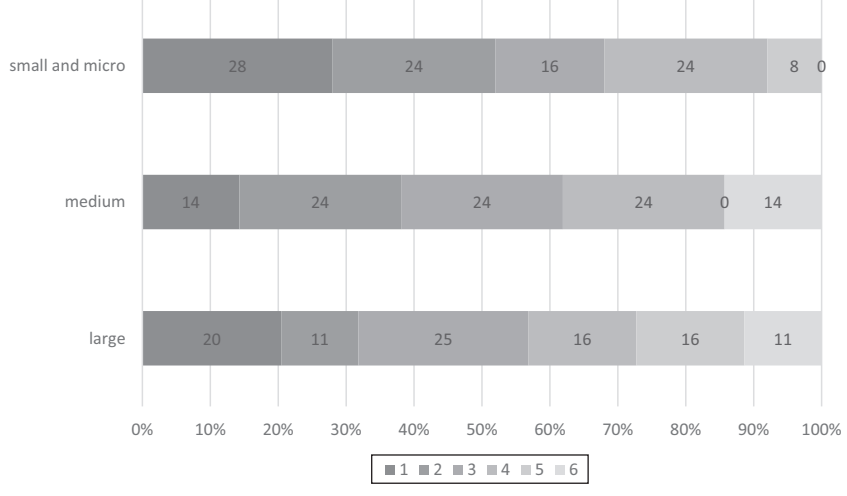
I4.0 technology implemented = 0; implemented management system = 1, no management system = 0). The value of Phi coefficient $\Phi = 0.2719$, which along with p-value = 0.03562, indicates a weak association between the implementation of management systems and the implementation of I4.0 technologies in a company.

Statistical tests did not confirm the correlation of the use of I4.0 technologies with the amount of revenue in the last three years nor the share of export revenue in total revenue, using data from the last three years for the analysis. However, there is a weak correlation with the number of employees, where larger companies tend to be more likely to implement these technologies. The Pearson correlation coefficient ($r = 0.2334$) indicates a relatively low correlation with p-value = 0.07274, which leaves much doubt about confirming the hypothesis of the importance of employment size in implementing I4.0 technologies.

The same range of data was collected in a second National Key Cluster operating in the same industry – SAAM. In this cluster, 58% of the 155 enterprises, or 90 companies, apply I4.0 solutions, with 59% using at least two management systems. The survey included 44 large enterprises, all of which apply these solutions. Among these, nine companies apply one I4.0 technology, five companies apply two technologies, 11 companies apply three technologies, and the remaining 19 companies apply four technologies or more. In small and micro companies that declared the use of I4.0 technologies, more than half (52%) have implemented one or two technologies. In large companies, 43% have implemented four or more, and in small and micro companies, 32%. Therefore, dependence on the company's size is apparent (Figure 5).

In the article, we show that the automotive industry is predestined to implement I4.0 and that clusters create a favourable environment for technology implementation. We also provide numerous examples that the PGM cluster supports the implementation of I4.0 technologies, or at least the coordinator's actions have an impact on raising awareness of the need for transformation in this direction. This imposes the question of why 26 out of 60 cluster companies surveyed are not using any of these technologies. The answer may be provided by future in-depth qualitative research.

Figure 5 Share of companies in the SAAM cluster that use one to six I4.0 technologies by size ($N = 90$)



Source: Authors' elaboration based on the survey

5. Conclusions

Industrial clusters can play a crucial role in implementing I4.0 technologies by providing access to cutting-edge research and development, facilitating the exchange of information and best practices and promoting collaboration between companies. Our literature review highlights the benefits of these spatial entities and their potential contribution to advancing the fourth industrial revolution. Although research on the regional or spatial organisational aspects of business digital transformation, referred to as I4.0, has been steadily progressing in Western Europe, other economies such as the post-transition new Member States, including Poland, seem to remain a relatively uncharted area. This gap justifies our exploratory study.

This paper aims to verify the potential role of clusters in implementing I4.0 in the Polish context of cluster organisations. Based on available data and findings provided by the case study of PGM, we found that despite the efforts undertaken by the cluster managers, the implementation of these technologies by cluster companies is still modest. Our literature review provides evidence of a link between industrial clusters and implementing I4.0 technologies, also in the case study, we show examples of how clusters can play a role in implementing I4.0 business models. However, the diagnosed limited or at least moderate actual impact still needs to be investigated. Comparing the conclusions drawn from the analysis of the PGM cluster in this case study to those from the literature on the subject, it becomes clear that the catalytic role of clusters in the implementation of I4.0 technologies by enterprises, as emphasised in the literature, is not yet reflected in the Polish reality. The results presented for the case of the PGM cluster raise further research questions: Are I4.0 technologies not attractive to companies at this time? What is the situation in other industries? How do companies perceive the need to implement these technologies to improve their competitive advantage?

A rather bleak picture emerges from the results, revealing a need for more interest among cluster members in advancing I4.0 technologies. Notably, less than 22% of members in the PGM cluster have formalised digitisation strategies. This may be due to a comfortable situation where firms are still enjoying alternative competitive advantages that do not force them to seek new advanced advantages brought about by I4.0. It also reflects the sober approach and awareness of associated high costs and necessary investments, which are paramount and prevent successful I4.0 implementation.

The results of the study may enrich the current state of conceptual knowledge in the field of clusters and the fourth digital revolution by emphasising the specificity of I4.0 understood in terms not only of technology but also in terms of organisational and institutional aspects requiring evoking elements that are typical for clusters. In general, the literature on the digital industrial revolution highlights more and more this institutional, organisational and not technological dimension, as was the case in the initial phase. Clusters' benefits such as economies of scale, trust and knowledge spillovers predispose these ecosystems as facilitators of digital revolution. Our research findings, although with a somewhat sceptical tone, should shed fresh light on these seemingly favourable conditions and hence suggest the need for further analysis. These should aim at diagnosing the reasons for this either actual *irrelevance* or perhaps rather simply *ignorance* among cluster members in this regard for instance by applying a more nuanced approach or factoring in the soft aspects such as the real awareness among cluster members of the available benefits, the adequate articulation of these benefits by cluster managers or the actual appreciation by cluster members of the existing assistances, hence provoking further discussion.

In summary, while our study relies on a case study of the automotive cluster, it offers valuable contributions to still-emerging research concerning the digital transformation processes. Our analysis provides insights into the role of the cluster as a potential facilitator of digital transformation, contributes to empirical evidence developments, supports policy

formulation and facilitates replication and comparison with other clusters. We fully acknowledge the limitations of case studies regarding generalizability but want to emphasise their significance in generating context-specific knowledge in this nascent research area.

Implications

In light of the findings presented in this research study, it becomes evident that a critical need exists for a more precise alignment between the requirements of cluster firms and the support rendered by cluster managers. Presently, the supply of assistance and the range of support services provided do not closely correspond to the actual demand. Consequently, it is imperative to enhance awareness among cluster members regarding the inexorable nature of I4.0 processes and the intrinsic challenges associated with them. Initiating this awareness-building process is a fundamental step. Once companies acknowledge the unavoidable nature of the digital revolution and the necessity to translate it into competitive advantages through adequate preparation, more advanced policy measures can be implemented.

This study contributes to evidence-based policy-making by shedding new light on the challenges associated with cluster roles as facilitators of digital transformation. The results are notably sobering and indicate that substantial efforts are still required to harness the potential of clusters in advancing I4.0 in Poland. Specifically, a harmonious blend of top-down measures and bottom-up actions, aligning with the genuine needs and interests of cluster members, is essential. Our study highlights the presence of misconceptions and limited interest among firms in joint initiatives aimed at I4.0 implementation. This lack of awareness and interest leads to passivity and impedes meaningful collaborative actions, which are central to the essence of a cluster. Hence, transparent measures aimed at raising awareness and providing comprehensive information are imperative to cultivate commitment and conviction among cluster members, fostering their grasp of the benefits offered by the cluster.

From a theoretical perspective, our study underscores the fact that cluster benefits, while well-documented in existing literature, do not materialise automatically and necessitate modulatory interventions for full realisation. These findings are consistent with previous studies emphasising the conditional nature of cluster benefits (e.g. Pavelkova *et al.*, 2021). This implies that cluster externalities and economies of scale, though inherently present, require appropriate channels to manifest and be fully absorbed by cluster members. This may necessitate the further development and refinement of existing conceptual frameworks to comprehensively capture the transmission aspects of cluster benefits.

Our case study accentuates the distinctive attributes and challenges of clusters in the digital era, which can ultimately inform strategies for enhancing regional competitiveness and fostering innovation. In terms of policy recommendations, the primary focus should be on eliminating identified barriers, such as improving access to training, enhancing digital skills, facilitating joint learning, experimentation and knowledge exchange. Additionally, regulatory frameworks supporting the development and adoption of these technologies should be established, encompassing the development of standards for interoperability, data protection regulations and guidelines for the ethical utilisation of artificial intelligence, among others. Furthermore, cluster organisations should be encouraged to play an integral role in Digital Innovation Hubs, thereby facilitating interaction with companies within the cluster and motivating cluster managers to actively assist in the implementation of I4.0 technologies. Strengthening networking between manufacturing firms and knowledge-intensive business services can reinforce the adoption of digital business models.

In addition, supporting collaborative research projects would be instrumental in advancing the adoption of these technologies within clusters. Developing the digital competencies of cluster coordinators' office personnel in handling extensive data sets, programming and

data visualisation is expected to elevate the level of digitisation within cluster value chains. This is of paramount importance, given that the development of clusters in Poland is significantly contingent upon their competence in digital transformation capabilities.

Limitations and further research

Of course, we are fully aware of the limitations inherent in our study, which reflect the scarcity of available data. We relied on the elementary survey administered centrally and were confined by the type of questions asked. Nevertheless, the diagnosed situation concerning the Polish cluster's role in advancing I4.0 should complement the existing literature. We hope that future detailed dedicated inquiries will address these constraints and provide a more comprehensive map of Polish clusters' I4.0 maturity. Future research could replicate our study by drawing on another Polish cluster or investigating similar entities in other regional economies. Analysing the automotive cluster's importance for digital transformation enables other researchers to replicate our study in similar or different contexts. This promotes knowledge accumulation and supports the development of empirical insight that can be tested and refined across multiple cases.

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