Sustainable Production through Advanced Manufacturing, Intelligent Automation and Work Integrated Learning, J. Andersson et al. (Eds.)

doi:10.3233/ATDE240166

Navigating Production Automation as a Service: Unveiling Drivers, Benefits, and Challenges in Manufacturing Companies

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Abstract. The integration of production automation drives innovation in manufacturing by enhancing efficiency, quality, and cost reduction. However, the capital requirements of conventional automation solutions hinder many manufacturing companies. Production Automation as a Service (PAaaS) emerges as a cost-effective alternative, offering improved flexibility and efficiency. Yet, adopting PAaaS faces challenges: a lack of expertise, awareness, and cultural resistance. This study explores PAaaS implementation in manufacturing, identifying its specific needs and challenges. Qualitative research across ten diverse manufacturing companies reveals two key drivers: technological advancement and evolving business models. It highlights four primary benefits—cost-effectiveness, flexibility, efficiency, and product quality. Simultaneously, it addresses five significant challenges—legacy system integration, cybersecurity, internet dependency, expertise gaps, and downtime risks. To aid early decision-making, the study proposes a framework covering drivers, benefits, challenges, and suitable strategies. This study contributes to the ongoing discussion on smart production and automation development by focusing on business model innovation and the pay-as-a-service approach.

Keywords. Production automation, pay-per-use, business model innovation, smart production, automation as a service.

1. Introduction

Production automation is a crucial driver of success in the manufacturing industry, as it enhances efficiency, quality, and cost reduction [1]. However, its adoption can be hindered by substantial capital requirements [2]. To address these financial challenges, the manufacturing industry is turning to a new model: Production Automation as a Service (PAaaS) [3].

PAaaS allows manufacturers to access cloud-based automation technologies, including sensors, robotics, and control systems [4]. This approach offers increased flexibility, improved efficiency, and enhanced productivity, making it an attractive solution with notable benefits, such as increased productivity and reduced costs [5]. It enables automation of low-value processes, allowing workers to focus on higher-value tasks.

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Despite these advantages, PAaaS implementation in manufacturing presents challenges, notably a lack of expertise and knowledge [6]. This knowledge gap complicates decision-making and training for companies aiming to cost-effectively automate production [7]. Financial constraints further limit smaller manufacturing firms [7]. There is a lack of research on the key drivers, benefits, and challenges of PAaaS implementation [5], creating difficulties in informed decision-making [8]. Closing these research gaps is crucial to guiding successful PAaaS implementation in manufacturing. This study aims to investigate PAaaS implementation, identify its benefits and challenges, and answer the following research questions:

RQ1: What are the drivers and benefits of PAaaS in the manufacturing industry and the needs it fulfills?

RQ2: What are the challenges of implementing PAaaS, and how can they be overcome for successful scale-up?

By addressing these questions, this study contributes to the PAaaS literature and provides guidance for companies implementing PAaaS in manufacturing.

2. Theoretical background

2.1. Production Automation as a Service (PAaaS)

Production automation as a service (PAaaS) has recently emerged as a solution for manufacturing companies [9]. PAaaS offers automation services through cloud-based subscriptions or pay-per-use models, reducing upfront investment costs [10]. In contrast to traditional automation systems, which demand significant equipment and in-house development investments, PAaaS presents a cloud-based alternative for manufacturing companies seeking to enhance their production capabilities [11]. This approach allows companies to scale their production according to demand, improving operational efficiency [10]. PAaaS is particularly beneficial for small and medium-sized enterprises (SMEs) that may struggle with high costs and integration complexities [12]. PAaaS-integrated systems enhance productivity, quality, and efficiency by performing tasks more rapidly and accurately than human labor, reducing errors and defects in the production process [13].

2.2. Benefits of PAaaS.

The Product-as-a-Service model allows automation solution providers, acting as manufacturers, to offer results to customers as services rather than through traditional ownership [14]. In this model, providers offer pre-configured solutions, enhancing implementation efficiency [15]. This business model benefits both customers and providers by reducing costs, improving efficiency, and minimizing equipment downtime [16]. Additionally, it supports a circular business model, optimizing resource use and waste reduction throughout the automation's lifecycle [15]. By offering access to automation technologies without upfront investments, this model reduces financial barriers and promotes sustainability [17]. It also enables automation manufacturers to design more resilient, reparable, and recyclable products, further reducing waste and advancing sustainability [18].

PAaaS helps manufacturers avoid expensive hardware costs by utilizing cloud-based manufacturing [19]. This approach eliminates the need for upfront hardware investments,

as the PAaaS provider handles infrastructure maintenance and upgrades [20]. The flexible pricing model, including pay-as-you-go and subscriptions, allows manufacturers to try new technologies and services without significant upfront expenses [21].

PAaaS offers a wide range of automation solutions that outperform manual labor in terms of speed and accuracy, reducing cycle times and enhancing overall productivity [22]. It also enables real-time data collection and analysis through sensor integration and Internet of Things (IoT) devices, providing manufacturers with insights to identify areas for improvement [23]. PAaaS optimizes production schedules using algorithms and machine learning, predicting demand and inventory levels and suggesting optimal production schedules [24]. This reduces the risk of overproduction and costly rework, focusing on value-added tasks and improving product quality [25].

PAaaS increases manufacturing flexibility and agility, allowing rapid adaptation to new demands and changes, improving overall efficiency [26]. Modular production systems enable quick reconfiguration, enhancing flexibility [27]. Real-time data analytics help identify errors more quickly and precisely, improving operations [28]. Cloud-based platforms offer access to real-time production data, facilitating precise decision-making [29]. Predictive analytics enable manufacturers to adjust production according to future demand, maintaining a consistent production level while responding to changes [30].

2.3. Challenges of PAaaS

Integration with legacy systems is a primary challenge in implementing PAaaS in the manufacturing industry. Many companies have invested heavily in older systems with outdated hardware and software, making integration with PAaaS solutions more challenging [31]. Incompatibility between systems can result in fragmented workflows, causing delays and errors in production [32]. Cultural resistance from employees accustomed to existing systems can also hinder the transition to new technologies [32].

Internet dependency is another significant challenge as PAaaS relies on stable and reliable internet connections due to its cloud-based nature [33]. Unreliable internet connectivity can disrupt manufacturing processes and lead to production delays. It also poses cyber security risks, especially for smaller companies with limited investments in cyber security [34].

Unpredictable downtime is a common challenge due to the complexity of automated systems, leading to issues such as software glitches, electrical faults, and human errors [35]. Without real-time equipment monitoring, manufacturers face an increased risk of production downtime [36]. The lack of technical expertise concerning new technologies required for PAaaS integration poses a significant challenge. This knowledge gap is linked to issues like downtime and system complexity [35]. Cloud-based manufacturing, in particular, demands expertise due to its complex solutions and technologies. Lack of expertise can hinder successful implementation and prolong the transition [9].

3. Research method

This study seeks to provide a comprehensive understanding of the drivers, benefits, and challenges of PAaaS in the manufacturing industry while identifying strategies for successful implementation. Therefore, an exploratory research design using a qualitative approach [37, 38] is deemed appropriate. Exploratory research is well-suited when the

phenomenon under investigation is emerging, lacks a clear definition, and has not been extensively studied [39, 40]. This design proves valuable for uncovering new insights, understanding ongoing developments, and revealing underlying motivations and strategies [37, 40]. Additionally, it aligns well with inductive research, where data collection and analysis inform subsequent work, particularly effective for theory-building in areas with limited or nonexistent existing theories [41]. Qualitative research is particularly suitable for exploring complex phenomena, advancing their understanding [42], and well-suited for identifying and interpreting phenomena within real industrial settings [43].

The data were primarily collected through semi-structured interviews [44] to gather detailed and contextual information about the PAaaS implementation phenomenon. Their flexibility and ability to yield insightful information are well-suited for comprehending complex issues [42]. Ten different manufacturing companies participated in these interviews, representing a variety of sectors, including 3 automotive industry companies, 1 electronic part manufacturer, 3 steel manufacturing companies, 1 wood manufacturer, and 2 technical solutions providers. The ten respondents held diverse roles and backgrounds, including production, automation, project engineers, managers in production, quality assurance, automation, technology, a sales expert, a VD, and CEO, providing in-depth knowledge from various perspectives. The respondents collectively have 170 years of work experience in production, which is a valuable source of insight. The average interview duration was 40 minutes. All interviews were recorded and transcribed. The collected data were analyzed using thematic analysis and pattern matching to enhance internal validity. Thematic analysis is a method for identifying and analyzing patterns within the data [41, 45], ensuring that the identified patterns and themes are relevant to the research questions and accurately reflected in the analysis.

4. Results

4.1. Drivers and motivations of PAaaS implementation

The analysis reveals that the drivers for PAaaS implementation vary based on the industry context.

4.1.1. Technological advancements

A primary driver motivating the implementation of PAaaS solutions is the technological advancements they offer. The interviewed companies acknowledge that certain manual tasks consume valuable time and effort, diverting attention from more value-adding processes. PAaaS implementation enables these companies to access relatively simple and cost-effective automation solutions. As stated by an automation competence leader in a transportation manufacturing company:

> *"The ability for any company to access automation solutions is a great driver for this concept. They gain access to relatively simple and cost-effective solutions, which makes it attractive for them."*

Automation solutions also significantly enhance flexibility in production processes by automating repetitive and time-consuming tasks like inventory management, system management, and quality control. This automation-driven flexibility allows companies to dynamically scale resources and adapt to changes in demand and market conditions.

4.1.2. Business model transformation

Another crucial driver for companies is the potential for business model transformation through PAaaS implementation. Companies recognize that PAaaS can lead to the improvement of existing business models and the creation of new ones. An essential element of this transformation is the shift from traditional ownership-based models to service-based models. This shift empowers companies to access advanced production automation solutions without substantial upfront investments and in-house training, as well as to adopt cost-saving pay-per-use models. An experienced production manager in an automotive part manufacturing company emphasized this in the interview:

> "*I can see the possibility of a business model transformation acting as a driver and motivation for the implementation. This is because it enables us to provide our products as a service to new customers who want to test it before investing in it. By doing that, I think it will increase our flexibility and expand our competitive reach*."

Moreover, PAaaS implementation not only grants companies access to additional services but also allows them to provide additional services to customers, fostering customer loyalty and attracting new customers from different sectors. The implementation promotes collaboration between companies and stakeholders in the value chain. Business model transformation also enables collaboration with other PAaaS providers, facilitating the creation of innovative and customized solutions.

4.2. Benefits of PAaaS Implementation

PAaaS offers various benefits that enhance efficiency and productivity, with the specific advantages depending on the industry in which it is implemented. The following benefits emerged from the empirical analysis:

4.2.1. Cost effectiveness

The majority of the companies recognized that PAaaS implementation eliminates the need for upfront investments in in-house training and required infrastructure. It also allows companies to test automation solutions before making a final investment decision. Utilizing flexible pricing models such as pay-per-use, companies can pay only for the automation when it is in use. A Vice President of an electronic manufacturing company stated during an interview:

> "*The major benefit of this approach is that it allows us to pay for capacity and performance based on actual usage, thereby eliminating capital binding*."

This cost-saving model is particularly well-suited for small and medium-sized enterprises (SMEs) that may lack the capital required for traditional automation solutions. SMEs can lease automation solutions at a more affordable price, including support and maintenance. Large companies with the capital for traditional solutions can also benefit by implementing PAaaS for support functions, allowing them to allocate resources more efficiently.

4.2.2. Improved flexibility and scalability

The second most common benefit is the improved flexibility and scalability that companies can experience with PAaaS implementation. Companies without prior

experience with PAaaS recognized its potential for enhancing flexibility, while companies with experience highlighted its ability to easily integrate with existing systems. For example, a collaborative robot (Cobot) implemented as a PAaaS solution improved flexibility by integrating with existing systems. A sales technician at a digital solution provider explained:

> "*The flexibility is a great benefit because it allows companies to use an automation solution for a specific time and return it to the provider*."

Companies that have not implemented PAaaS recognized its potential to improve flexibility from both hardware and software perspectives. PAaaS solutions, whether hardware or software, allow companies to implement them into existing systems, making it easier to adopt new automation solutions.

4.2.3. Increased efficiency and productivity

PAaaS implementation offers a significant benefit by increasing efficiency and productivity in production. Enhanced efficiency and productivity enable companies to produce at a faster rate while maintaining high product quality and reducing operating costs. By integrating PAaaS with Industry 4.0 technologies, such as AI, it becomes possible to make more informed decisions based on real-time data collection. Some companies also saw the potential for PAaaS solutions to reduce downtime and production stoppages. A project engineer at a steel manufacturer noted:

> "*I would like to integrate a solution responsible for availability, security, and platform monitoring to ensure that the automation system functions properly*."

4.2.4. Improved product quality and consistency

The ability to implement automation solutions in the production process leads to increased productivity and consistency. Techniques such as predefined workflows, standardized automation solutions, and real-time monitoring, all provided through PAaaS, contribute to this improvement. An automotive parts manufacturer's production manager explained:

> "*The use of predefined workflows and instructions with automation solutions would increase product quality, as the error rate would be lower when people follow predefined workflows and instructions*."

Recognized benefits also included the potential to improve production safety, particularly significant for manufacturing companies due to industry-specific production processes. PAaaS implementation can boost productivity, enhance efficiency, and maintain consistent product quality while improving production safety.

4.3. Challenges of PAaaS Implementation

The empirical analysis has identified several challenges associated with the implementation of PAaaS in companies:

4.3.1. Cyber security and privacy

One of the primary challenges reported by companies pertains to the cyber security and privacy concerns when implementing PAaaS. Many companies are cautious about granting third-party providers access to sensitive intellectual properties (IP) and data,

fearing the risks associated with potential security breaches. Any error leading to a security breach would have severe consequences for the companies.

In addition to cybersecurity concerns, companies also expressed apprehension about the residency of user data, meaning where the data is stored. Sharing sensitive IP and data with PAaaS providers is often necessary for successful implementation. A CEO at a steel manufacturing company highlighted this issue during an interview:

> "*For me, the biggest challenge with this concept is where the data will be stored and how safe it is to provide the PAaaS provider with sensitive data such as IPs. This question is often on my mind when discussing leasing automation solutions from a third-party provider*."

Companies also perceived a higher risk of distributed denial-of-service (DDoS) attacks during PAaaS implementation. DDoS attacks can disrupt servers and software, potentially leading to production stoppages and increased downtime.

4.3.2. Lack of expertise

The most common challenge faced by companies in implementing PAaaS is the lack of expertise required to understand and successfully implement the concept. The absence of expertise poses a significant challenge, particularly for companies seeking to adopt PAaaS, as it demands a sound understanding of systems and software. A technology manager at a truck part manufacturing company expressed concerns about this challenge:

> "*Making customers understand what they are paying for and how it benefits them is a challenge. Smaller companies may find it easier to grasp because they are willing to experiment and learn. However, convincing larger companies that typically prefer to own the solution rather than lease it as a service can be challenging*."

While PAaaS providers offer support, the challenge remains when individuals within companies lack knowledge of the concept and its potential benefits. Some systems require strong IT skills, posing a challenge for small companies without a dedicated IT team. A quality management leader at a steel manufacturing company discussed the challenge of inadequate expertise in the IT sector:

> "*It is vital to have a competent IT team capable of handling new technologies and providing support promptly, without disrupting production. While we have the necessary resources to maintain a dedicated IT team working on these solutions around the clock, smaller companies with limited capital may face IT-related challenges, leaving them vulnerable to IT attacks*."

Another challenge associated with the lack of expertise is the possibility of implementation disruptions and failure to achieve the desired results, leading to management decisions such as removing PAaaS from the production process. Some companies also resist having third-party employees working in areas where PAaaS is implemented, as they believe that it is the company, not the PAaaS provider, that creates value.

4.3.3. Integration with legacy systems

The challenge companies in the manufacturing industry see with integrating PAaaS with legacy systems is that these systems are often highly specialized and custom-tailored to meet specific requirements, making integration more complex. An automation engineer at a steel manufacturing company stated:

> "*Primarily, I believe this can be particularly challenging within the steel industry, which is highly specialized and custom-tailored. There are only a limited number of*

companies worldwide that manufacture machinery specifically for our industry. When visiting different competitors and steel manufacturers, the overall landscape tends to look quite similar everywhere."

The integration process requires meticulous planning, involving steps like data mapping and a thorough understanding of technological gaps. Legacy systems are often certified according to ISO certifications, adding complexity to the implementation of new systems through PAaaS.

4.4. Strategies to overcome the challenges

The empirical analysis has revealed the following strategies that companies should consider overcoming the challenges:

4.4.1. Training strategy

To address challenges related to the lack of expertise and knowledge, both theory and companies recommend investing in training programs to develop personnel. Theory underscores the importance of training employees, explaining the necessity of change, and detailing its contributions to production. When employees understand the rationale for change, they become more receptive to new technologies, simplifying their implementation. An experienced production engineer at a wood manufacturing company stated:

"*I believe it's important for more companies to allocate resources to train their own personnel to handle new technologies, rather than relying on third-party companies to provide skilled personnel. This not only saves money but also enhances the competence and adaptability of their own staff.*"

The technology manager at the truck parts manufacturer emphasized the need to educate management about the changes and their significance to overcome resistance to change:

"*I think it's crucial to explain to management what the solution offers and why this change is important. Their lack of knowledge contributes to their fear of change. Therefore, it's essential to educate management about the changes and their contributions to enable further automation in production*."

4.4.2. Connectivity strategy

To address challenges associated with internet dependency, both theory and practice suggest conducting a thorough area analysis where the manufacturer plans to establish operations. This analysis helps determine the quality of internet connectivity in the area and aids in locating reliable local internet service providers. A sales technician from a digital solution provider explained the significance of good and reliable internet connectivity, especially for companies with cloud-connected machines:

"*Robust and dependable internet connectivity is crucial for every company, particularly those with cloud-connected machines. Ensuring the factory is situated in an area with good internet access and choosing a reliable internet service provider can eliminate connectivity concerns*."

4.4.3. Investment strategy

Both theory and the interviewed companies underscore the importance of having a strategy to address the challenge of integrating with legacy systems. The theory suggests

that investments in new upgraded systems are essential for successful implementation. Management should also allocate time and resources to train their own personnel. Combining these elements forms the basis of a strategy to overcome this challenge. A project engineer from a steel part manufacturing company elaborated on the importance of identifying systems that don't align with the new systems and the need for competent individuals to handle new systems and integrate them successfully into existing systems:

> "*It's crucial to identify which systems are not compatible with the new ones. This understanding makes it easier to address the issues. Competent individuals are essential to handle new systems and ensure their successful integration with existing systems*."

In summary, the study findings can be visualized in a framework, as illustrated in Figure 1, to assist companies in comprehending and navigating the drivers, benefits, and challenges associated with PAaaS.

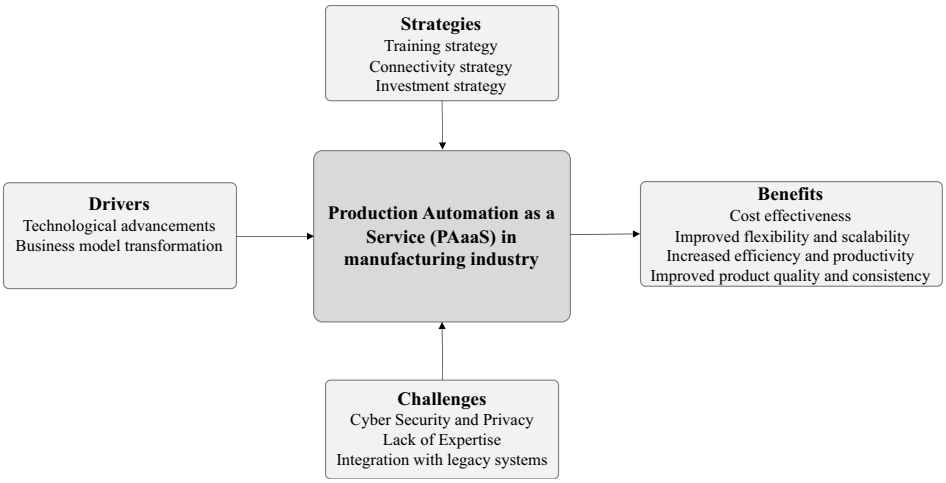

Figure 1. A Framework for Navigating PAaaS Solutions in the Manufacturing Industry

5. Discussion and conclusions

5.1. Theoretical implications

This study makes two significant contributions to the manufacturing industry and its associated theory.

First, it offers valuable insights into the drivers and benefits of PAaaS implementation in the manufacturing sector, which can serve as a catalyst for further adoption of PAaaS in production. By identifying and analyzing drivers such as technological advancements and business model transformation, this research enhances our understanding of the PAaaS concept and its implications for manufacturing companies [9, 11, 12, 13, 17]. The insights from this study contribute to the existing PAaaS theory and provide a foundation for new models related to technological advancements and business model transformation. Furthermore, this research fills a critical gap in the current literature on PAaaS implementation in the manufacturing industry. Despite the existing studies emphasizing the importance of technological

advancements and the need for a business model transformation [11], this study offers a deeper understanding of the drivers and motivations that influence decision-making processes in the manufacturing industry regarding production automation.

Second, this study extends our understanding of PAaaS implementation by identifying and analyzing the associated benefits and challenges in the manufacturing industry. These identified benefits, including cost-effectiveness, enhanced flexibility, scalability, productivity, efficiency, and improved product quality, provide additional information that supports PAaaS implementation in manufacturing [9, 19, 20, 23, 24, 28]. While previous studies have acknowledged cost-effectiveness and increased flexibility through the adoption of production automation [22, 30], this study further contributes to the theory by providing empirical evidence of these benefits, thus establishing a more comprehensive theoretical framework supported by real-life experiences.

Addressing challenges is equally vital, as it equips manufacturing companies with the knowledge to overcome obstacles and anticipate issues during PAaaS implementation. The identified challenges in this study, including integration with legacy systems, internet dependency, and the lack of expertise and knowledge, align with existing literature [9, 31, 33, 35]. The findings from this study can contribute to the development of frameworks related to technology adoption and stimulate theoretical discussions in areas such as service-oriented business models for manufacturing companies and digital transformation in the manufacturing industry.

5.2. Managerial implications

This study offers valuable insights to manufacturing companies and those engaged in the manufacturing industry who seek guidance on implementing production automation with limited capital and expertise. The findings and framework proposed here can aid these companies in decision-making by providing a comprehensive understanding of the drivers, benefits, and challenges associated with PAaaS implementation. Manufacturing companies are recommended to assess the identified drivers of PAaaS to determine the most suitable driver for their specific needs. Understanding the relevance of these drivers to their production processes and business context enables more informed decision-making regarding PAaaS implementation. This evaluation not only helps in comprehending the drivers but also in identifying the most beneficial one for the company.

Furthermore, the identification of benefits eliminates the need for manufacturing companies to conduct extensive research independently. This study streamlines the process by outlining how PAaaS implementation can impact production and the benefits it offers. By comparing these benefits with real-time data, companies can gauge the potential advantages. Management can also use these insights to train personnel effectively. The framework presented in this study enables manufacturing companies to explore service-oriented business models and their advantages through PAaaS implementation. A detailed understanding of these benefits assists management in making informed decisions about automation and identifying areas within the company that can benefit from PAaaS solutions, thereby increasing efficiency.

Additionally, manufacturing companies and management can employ the strategies provided in this study to proactively address potential challenges that may arise during implementation. By identifying and analyzing challenges such as integration with legacy systems, internet dependency, and the lack of expertise and knowledge, this study equips manufacturers with effective strategies to overcome these obstacles. To conclude, this

research facilitates informed decision-making, offers insights into benefits, and provides practical strategies for addressing challenges associated with PAaaS implementation in the manufacturing industry.

5.3. Limitations and future research directions

While this study provides valuable insights into the implementation of PAaaS in the manufacturing industry, there are certain limitations to consider. First, the study's sample was limited to interviews with a specific number of manufacturing companies. To enhance the generalizability of the findings, it may be necessary to include a larger and more diverse sample, encompassing companies from various categories, sectors, and sizes. Conducting longitudinal studies to track the evolving landscape of PAaaS implementation in the manufacturing industry over an extended period is also beneficial. This can help in understanding how drivers, benefits, and challenges may change or adapt. Second, this research focused primarily on the drivers, benefits, challenges, and strategies associated with PAaaS implementation. However, other factors influencing PAaaS adoption, such as regulatory considerations, environmental impacts, and economic conditions, were not explored in depth. Future research could delve into these areas to provide a more holistic view. Investigate how compliance with evolving regulations and sustainability requirements may influence adoption. Third, the study primarily employed qualitative research methods, including semi-structured interviews. While this approach offers valuable insights, it may benefit from complementing quantitative research methods to assess the prevalence and significance of drivers, benefits, challenges, and strategies based on the characteristics of the companies. These characteristics include types of products, sizes in terms of staff numbers, geographical locations, as well as economic factors such as annual turnovers. There is great potential to research PAaaS from multiple perspectives to enable smart and sustainable production.

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