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Resilience, Sustainability and Industry 4.0 in PPC: A Survey of German Manufacturers

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Abstract

Manufacturing companies face increasing demands related to supply-chain resilience, sustainability, and digitalisation, creating new requirements for production planning and control (PPC). This paper presents selected findings from the 2024 PPC Report, a recurring survey of German manufacturing companies conducted by four production technology research institutes. Based on 39 completed questionnaires, the study provides a descriptive benchmarking snapshot of resilience, sustainability practices, and Industry 4.0 adoption and complements descriptive results with selected bivariate subgroup comparisons.

The findings show that most respondents expect their production systems to be similarly or better positioned for future crises than during past disruptions, while no clear relationship with company size emerges. Respondents reporting the use of risk-management approaches predominantly assess their future resilience as stable or improved. Material and energy efficiency are among the most frequently selected measures for reducing the carbon footprint of production, while the reported composition of energy-data practices differs across company-size groups, with operational uses accounting for larger shares among medium-sized and large companies. Regarding Industry 4.0, advanced integration remains limited: mostly or fully connected OPC UA implementations and Asset Administration Shell adoption are still uncommon. An analysis of software use in commissioning further reveals descriptive differences between implementation approaches.

Across the three areas, the findings highlight the growing importance of combining organisational practices, data availability, and system integration within PPC. Given the exploratory design and small sample, the results should be interpreted as a benchmarking snapshot rather than as representative of German manufacturing as a whole.

Keywords

Production Planning and Control; Survey; Resilience; Sustainability; Industry 4.0; Digital Production

1. Introduction

Manufacturing companies are increasingly confronted with recurring supply chain disruptions, rising cost pressure, and growing sustainability requirements. At the same time, advances in digital technologies and

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Industry 4.0 provide new opportunities to enhance production planning and control (PPC) through data availability, real-time information, and increasingly adaptive planning and control approaches [1,2]. Understanding how manufacturing companies respond to these developments and which organisational and technological measures they adopt has become increasingly important for both research and practice.

The PPC Report (German: PPS Report), jointly organised by four German research institutes, was established as a recurring survey to provide systematic insights into production planning and control practices in German manufacturing. It adopts an integrated perspective by combining technological, organisational, and strategic aspects within a single survey instrument. While maintaining this integrated perspective, the thematic emphasis varies across survey waves. The 2024 survey focuses on three topics of particular relevance to PPC: resilience to disruptions, sustainability in production, and the adoption of Industry 4.0 technologies. Against this background, this paper addresses the following research questions:

- RQ1: How do manufacturing companies respond to disruptions, and how do they assess the resilience of their production systems against future crises?
- RQ2: How do companies pursue sustainability objectives within production planning and control?
- RQ3: To what extent are Industry 4.0 technologies adopted in production planning and control?

Contributions. Preliminary findings from the 2024 survey were disseminated in German through the PPS Report 2024 ("Studienergebnisse PPS-Report 2024") [3] to provide participating companies with timely benchmarking information. Although the data were collected in 2024, the topics addressed reflect long-term structural developments rather than short-lived trends and therefore remain highly relevant. This paper makes three contributions:

- it documents the survey design and questionnaire in sufficient detail to support transparency, replication, and use in future benchmarking;
- it reports and analyses current PPC practices using descriptive statistics and selected stratified bivariate comparisons to explore descriptive patterns across survey variables;
- it provides an empirical snapshot of PPC practice in German manufacturing (resilience, sustainability, and Industry 4.0 adoption) to an international research audience.

The remainder of this paper is organised as follows. Section 2 describes the study design, questionnaire, and survey participants. Section 3 presents the survey results. Section 4 discusses their implications for research and practice. Finally, Section 5 concludes the paper and outlines directions for future survey waves.

2. Study design and Survey Participants

The study was jointly conducted by four German production technology research institutes: the Institute of Production Management and Technology, the Fraunhofer Institute for Casting, Composite and Processing Technology, the Laboratory for Machine Tools and Production Engineering, and the Institute of Production Systems and Logistics.

It is based on an online survey administered using LimeSurvey during the second and third quarters of 2024. Participants were recruited through direct invitations to industrial contacts of the participating institutes and through announcements on LinkedIn. Since the survey link was also distributed through open channels, a precise response rate cannot be determined. Where referrer information was available, the recorded referrer URLs predominantly indicated LinkedIn-related sources; however, referrer data were incomplete and are therefore reported only as an indication of recruitment channels.

The questionnaire was developed jointly by the participating institutes and covered four thematic areas: general company characteristics, resilience, sustainability, and Industry 4.0 adoption in production planning

and control. Depending on the objective of each question, the instrument combined categorical single-choice questions (e.g., industry sector, production type, company size, and degree of vertical integration), multiple-choice questions (in which respondents could select all applicable options), predefined ordinal response categories (e.g., percentage intervals), Likert-type scales, and slider-based ratings. Selected questions additionally provided optional free-text fields.

Branching logic was incorporated to reduce respondent burden and ensure that participants were only presented with relevant questions (e.g., respondents indicating that commissioning was not part of their value chain automatically skipped the corresponding question block). Respondents were also allowed to leave individual questions unanswered if they were not applicable to their company. Consequently, the number of valid responses varies across questions and figures. A "completed" questionnaire refers to a respondent who reached the final page, irrespective of whether individual items had been skipped. A total of 39 questionnaires meeting this criterion were included in the analysis. Each completed questionnaire was treated as one observation in the analysis. Since respondents reported company-level characteristics and practices, the results are interpreted as respondent-reported assessments of their respective companies rather than as independently verified company-level observations. Because the survey link was distributed via open channels, multiple responses from the same company cannot be fully ruled out.

The sample includes respondents from a range of German manufacturing firms. Figure 1 summarises reported company size, order-fulfilment type, and production type. The sample is skewed towards larger firms: in 25 of the 39 questionnaires, respondents indicated that their company had 1,000 or more employees. With respect to order fulfilment, make-to-order is the most frequent category, while the combined category of single-unit and low-volume production represents the largest production-type group.

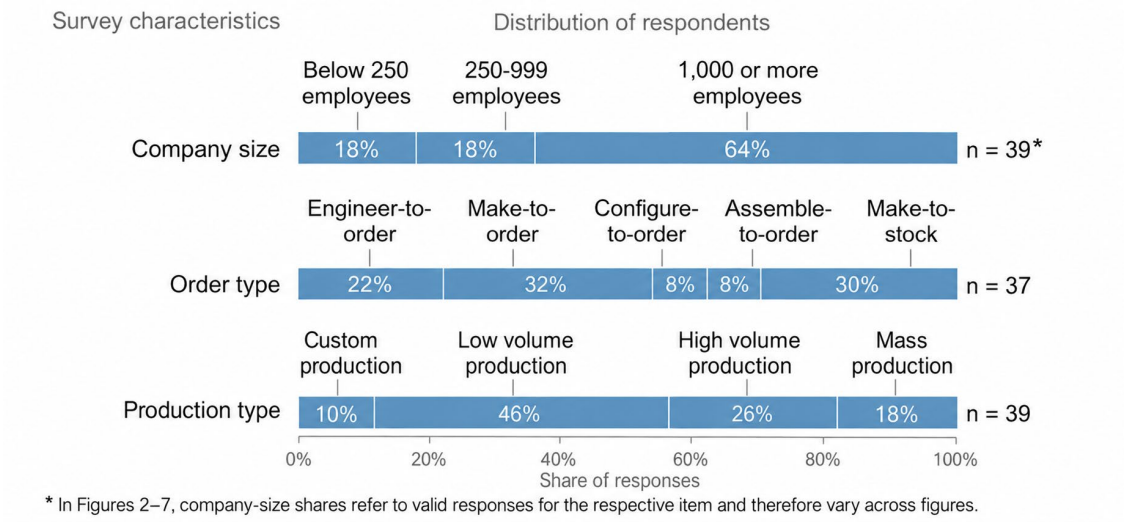


Figure 1: Survey participants: company size, order-fulfilment type, and production type.

The analyses presented in this article are primarily descriptive and are intended to provide an exploratory benchmarking snapshot of current PPC practices. In addition to marginal distributions, selected results are examined using stratified bivariate comparisons, for example by company size or reported PPC practices. These comparisons are used to identify descriptive patterns and provide additional context rather than to test statistical hypotheses. No inferential statistical tests are performed because of the small overall sample and, in particular, the small subgroup sizes. Due to the rotating thematic focus across PPC Report issues, the present survey wave was not designed for direct longitudinal inference.

3. Results and Findings

3.1 Resilience

Disruptive events increasingly affect global supply chains in both frequency and impact. Examples include geopolitical conflicts such as the war in Ukraine and major disruptions to global transport routes, such as the blockage of the Suez Canal [4] or the blockage of the Strait of Hormuz [5]. In this context, resilience has emerged as an important capability of production systems for coping with change, with production planning and control playing a relevant role in its implementation [6]. The survey examines how companies assess their resilience to future disruptions and whether these assessments differ across company-size groups and reported risk-management practices. Company size is considered as a structural characteristic, while the use of risk-management approaches in PPC represents an organisational practice potentially related to resilience.

In this study, the assessment of future resilience is based on a comparison of each respondent's reported performance decline during past crises with the expected decline in future crises. Both items refer to the decline in delivery reliability or utilisation, depending on the respondent's production context, and were measured using predefined ordinal percentage intervals (0–5%, 5–10%, 10–20%, 20–30%, and 30–50%). The ordered decline categories are compared at the respondent level. If the expected future decline is one category lower than the reported past decline, the assessment is classified as better positioned for future crises; if it is at least two categories lower, the assessment is classified as much better positioned. If past and future decline fall into the same category, the assessment is classified as unchanged ("same"). If the expected future decline is higher than the reported past decline, the assessment is classified as less well positioned. Thus, the measure captures respondents' comparative assessment of their company's expected resilience to future crises relative to reported past crisis experience. The resulting resilience indicator should therefore be interpreted as an ordinal comparative assessment rather than as a direct or metric measure of resilience.

Figure 2 relates this resilience assessment to company size. Across all company-size groups, most respondents assess their expected future resilience as unchanged ("same") or improved compared with past crises. Among companies with fewer than 250 employees, 2 of 5 respondents (40%) report a better expected position, another 2 of 5 (40%) report no change, and 1 of 5 (20%) report being less well positioned. Among companies with 250–999 employees, 4 of 5 respondents (80%) report no change and 1 of 5 (20%) reports an improved expected position. Among companies with 1,000 or more employees, 4 of 12 respondents (33%) report an improved or much improved expected position, 7 of 12 (58%) report no change, and 1 of 12 (8%) reports being less well positioned.

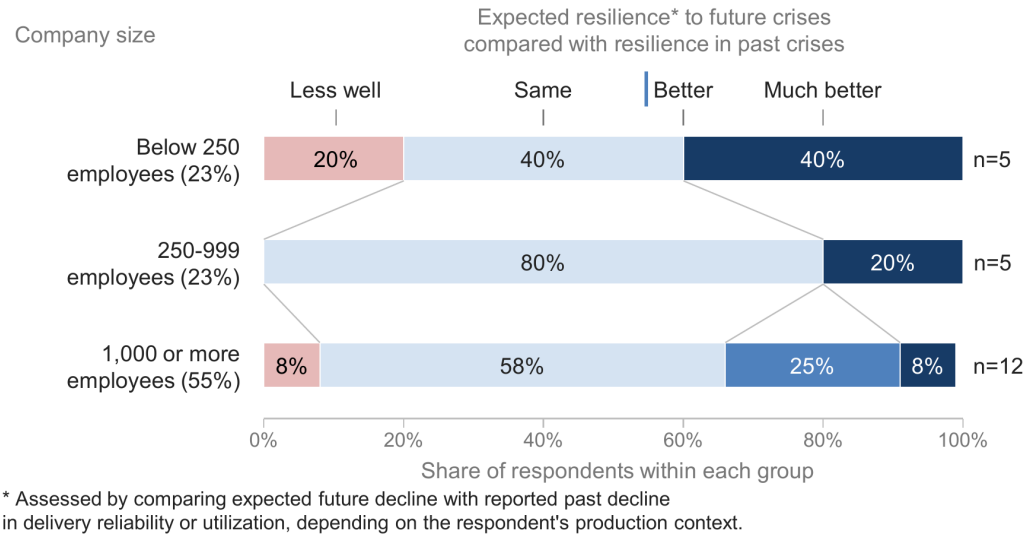


Figure 2: Assessment of future resilience (expected vs. past crisis-related decline) by company size.

No clear pattern between company size and the assessment of future resilience emerges from the descriptive comparison.

Figure 3 compares the same resilience assessment across different levels of risk-management use. Risk-management use is derived from a five-point Likert item asking whether the company uses risk-management approaches in production design, planning and control. The term "risk-management approaches" was not further specified in the questionnaire and therefore reflects the respondents' own understanding. Responses indicating agreement ("applies" and "rather applies") are grouped as used, the neutral response is retained as neutral, and responses indicating disagreement ("rather does not apply" and "does not apply") are grouped as not used. Among respondents reporting the use of risk-management approaches in production design, planning and control, 3 of 8 (38%) assess their future position as better or much better, while 5 of 8 (63%) report no change; none report being less well positioned. Among respondents not using risk-management approaches, 3 of 7 (43%) report a better expected position, 3 of 7 (43%) report no change, and 1 of 7 (14%) reports being less well positioned. Among respondents with a neutral response, 5 of 7 (71%) report no change, while 1 of 7 (14%) reports a much better expected position and 1 of 7 (14%) reports being less well positioned.

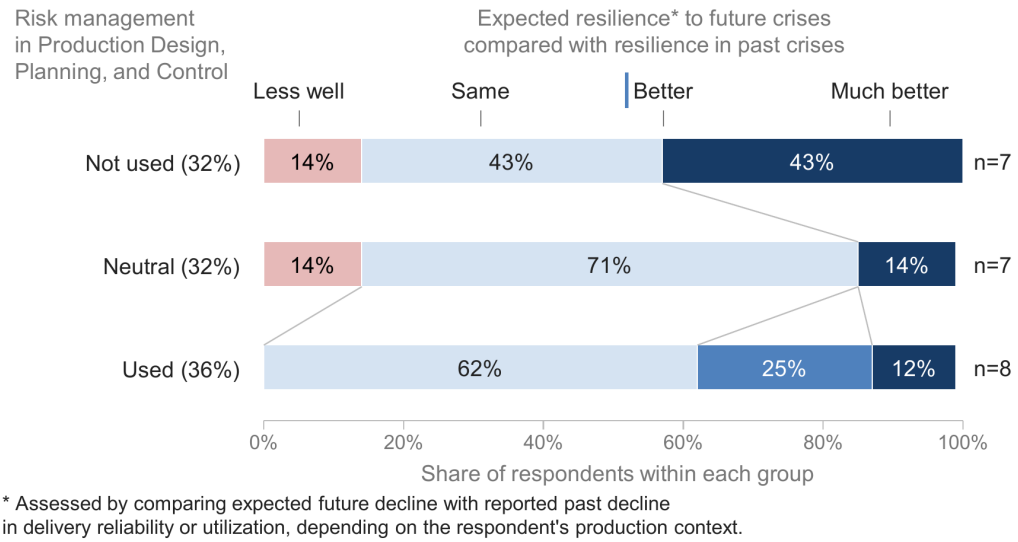


Figure 3: Assessment of future resilience (expected vs. past crisis-related decline) by risk-management use in production design, planning, and control.

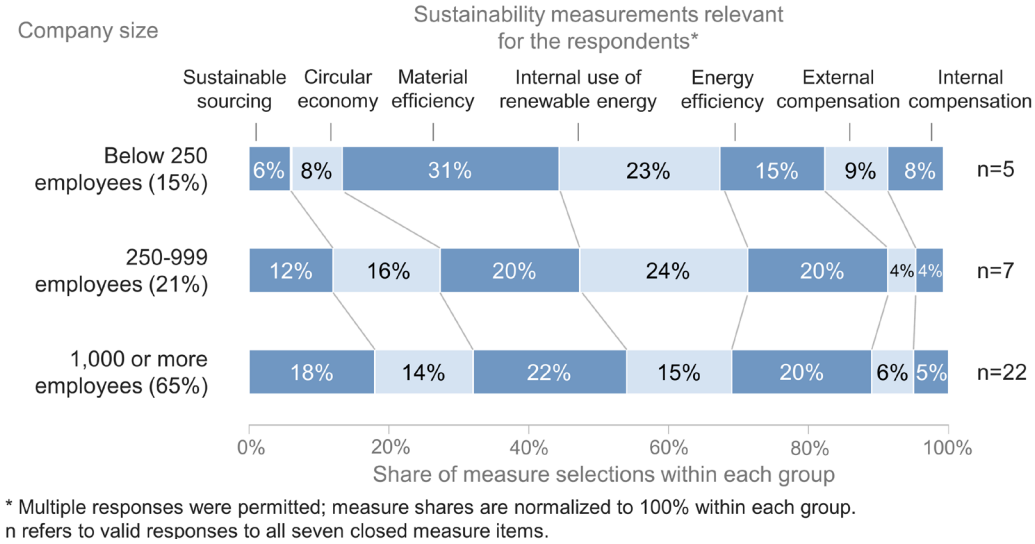
Descriptively, respondents reporting the use of risk-management approaches show exclusively stable or improved assessments of future resilience in this sample, whereas less favourable assessments also occur in the other response groups. This pattern is consistent with a potentially more favourable assessment of future preparedness among respondents reporting the use of risk-management approaches. However, given the small subgroup sizes, the broad respondent-defined understanding of risk-management approaches, and the descriptive survey design, the finding should be interpreted as exploratory rather than as evidence of a causal effect.

3.2 Sustainability

Manufacturing companies in Germany and beyond are under increasing pressure to produce and operate sustainably. Regulatory and market requirements, carbon-emission reduction targets, and increasing energy and material costs are among the challenges associated with sustainable operations [7]. Carbon-pricing mechanisms and regulatory instruments such as the EU Carbon Border Adjustment Mechanism (CBAM) [8] further increase the relevance of monitoring and reducing carbon emissions along industrial supply chains. Against this background, the survey examines which measures companies consider relevant for reducing the

environmental impact of their production and how energy data are collected and used across company-size groups.

Figure 4 compares the sustainability measures considered relevant across the company-size groups. Because respondents could select multiple measures, the percentages do not represent the share of companies selecting each measure. Instead, they represent the relative distribution of all measure selections within each company-size group, normalised to 100% to facilitate comparison of the composition of selected measures across groups. Among companies with fewer than 250 employees, material efficiency accounts for the largest share of selections (31%), followed by the internal use of renewable energy (23%) and energy efficiency (15%). Among companies with 250–999 employees, the selections are more evenly distributed, with the internal use of renewable energy (24%), material efficiency (20%), and energy efficiency (20%) accounting for the largest shares. Among companies with 1,000 or more employees, material efficiency (22%) and energy efficiency (20%) account for the largest shares, followed by sustainable sourcing (18%) and the internal use of renewable energy (15%).



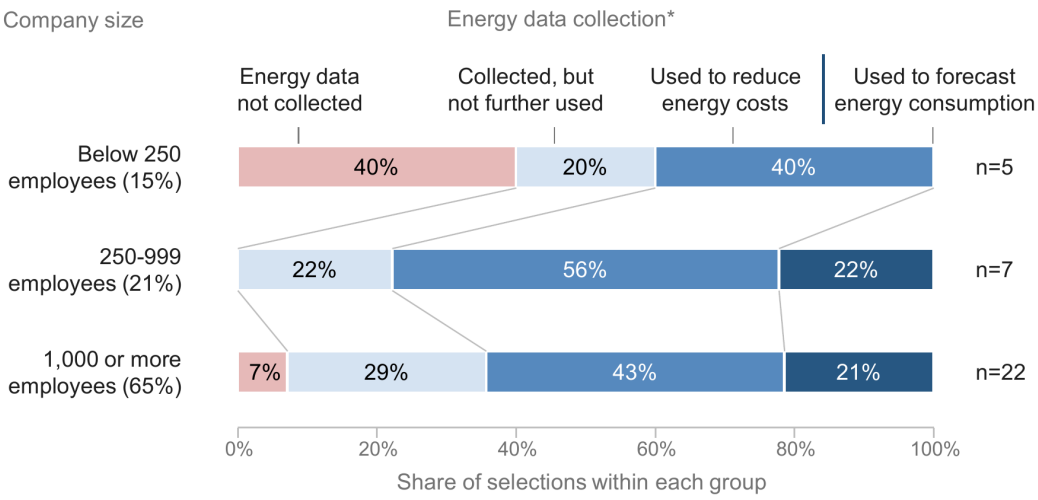
* Multiple responses were permitted; measure shares are normalized to 100% within each group.
n refers to valid responses to all seven closed measure items.

Figure 4: Sustainability measures considered relevant by respondents, stratified by company size.

Overall, efficiency-related measures account for substantial shares of the selections across all company-size groups, whereas internal and external compensation measures are selected less frequently. At the same time, the descriptive distribution of selected measures varies across company-size groups.

In addition to the sustainability measures considered relevant, the survey examined how companies collect and use energy data. Such data can provide a basis for identifying energy-saving potential and supporting decisions aimed at improving energy efficiency and reducing the environmental impact of production [9]. Figure 5 compares energy-data collection and use across company-size groups. As multiple responses were permitted, these percentages likewise do not represent company-level prevalence rates. They show the relative distribution of all selected energy-data practices within each company-size group, normalised to 100%. Among companies with fewer than 250 employees, 40% of the selections relate to energy data not being collected, while 20% relate to data being collected but not further used. The remaining 40% relate to the use of energy data for reducing energy costs. Among companies with 250–999 employees, 56% of the selections relate to the use of energy data for reducing energy costs and 22% to forecasting energy consumption, while the remaining 22% relate to data being collected but not further used.

Among companies with 1,000 or more employees, the largest share of selections relates to the use of energy data for reducing energy costs (43%), followed by data being collected but not further used (29%) and the use of data for forecasting energy consumption (21%). Energy data not being collected accounts for the remaining 7%.



* Multiple responses were permitted; selection shares are normalized to 100% within each group.
n refers to valid responses to all four closed energy-data items.

Figure 5: Energy-data collection and use stratified by company size.

The descriptive comparison indicates differences in the reported use of energy data across company-size groups. Among medium-sized and large companies, a larger share of selections relates to the operational use of energy data for reducing energy costs or forecasting energy consumption, whereas the absence of energy-data collection accounts for a larger share among companies with fewer than 250 employees. This pattern is consistent with a more extensive operational use of energy data in the medium-sized and large-company groups represented in the sample. Given the small subgroup sizes and the descriptive survey design, these differences should be interpreted as exploratory.

3.3 Industry 4.0 Adoption and Current Use

Industry 4.0 is associated with increasing interoperability, connectivity, and data availability across production systems [10]. Industry 4.0 technologies can also contribute to the resilience of manufacturing systems [11] and support sustainable manufacturing through the integration and use of production and resource-related data [12]. In production planning and control, technologies and standards such as OPC UA can support interoperable information exchange between heterogeneous production and information systems [13], while the Asset Administration Shell (AAS) provides a standardised digital representation of industrial assets and their information across the life cycle [14]. Against this background, the survey examined the current use of selected Industry 4.0 technologies and, using commissioning as an application example, different forms of digital support within a PPC-related process.

Figure 6 shows the reported level of OPC UA connectivity by company size. Among companies with fewer than 250 employees, 2 of 5 respondents (40%) report no connection to PPC systems, 1 of 5 (20%) rely on other standards or gateways, and 2 of 5 (40%) report a partial OPC UA connection. Among companies with 250–999 employees, 3 of 7 respondents (43%) report no connection, another 3 of 7 (43%) report a partial OPC UA connection, and 1 of 7 (14%) reports being mostly or fully connected via OPC UA. Among companies with 1,000 or more employees, 3 of 15 respondents (20%) report no connection, 6 of 15 (40%) rely on other standards or gateways, 4 of 15 (27%) report a partial OPC UA connection, and 2 of 15 (13%) report being mostly or fully connected.

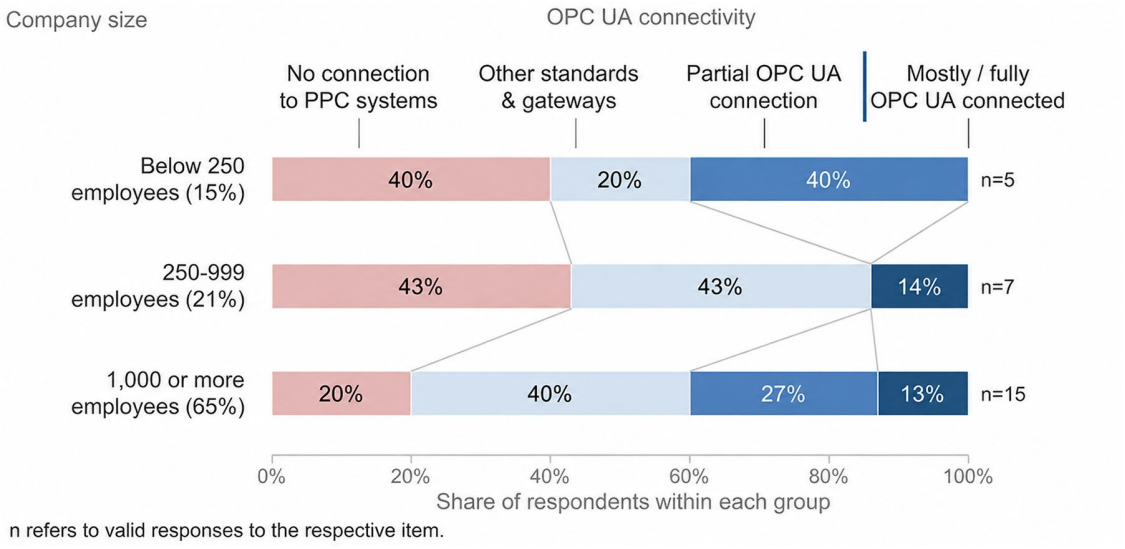


Figure 6: OPC UA connectivity by company size.

Mostly or fully connected OPC UA implementations remain limited across all company-size groups. However, companies with 1,000 or more employees less frequently report having no connection to PPC systems, while alternative standards and gateways as well as partial OPC UA connectivity remain common.

A similar picture emerges for the Asset Administration Shell (AAS), which represents another key Industry 4.0 concept for the standardised digital representation of assets. Figure 7 shows descriptive differences in AAS adoption across company-size groups. Among companies with fewer than 250 employees, all 5 respondents (100%) report that the AAS concept is not known. Among companies with 250–999 employees, 4 of 6 respondents (67%) report that the concept is not known, while 1 of 6 (17%) plans implementation and 1 of 6 (17%) reports an implemented AAS for production resources. Among companies with 1,000 or more employees, 7 of 15 respondents (47%) report that the AAS concept is not known, 1 of 15 (7%) report no implementation and no implementation plans, 5 of 15 (33%) plan implementation, and 2 of 15 (13%) report an implemented AAS for production resources.

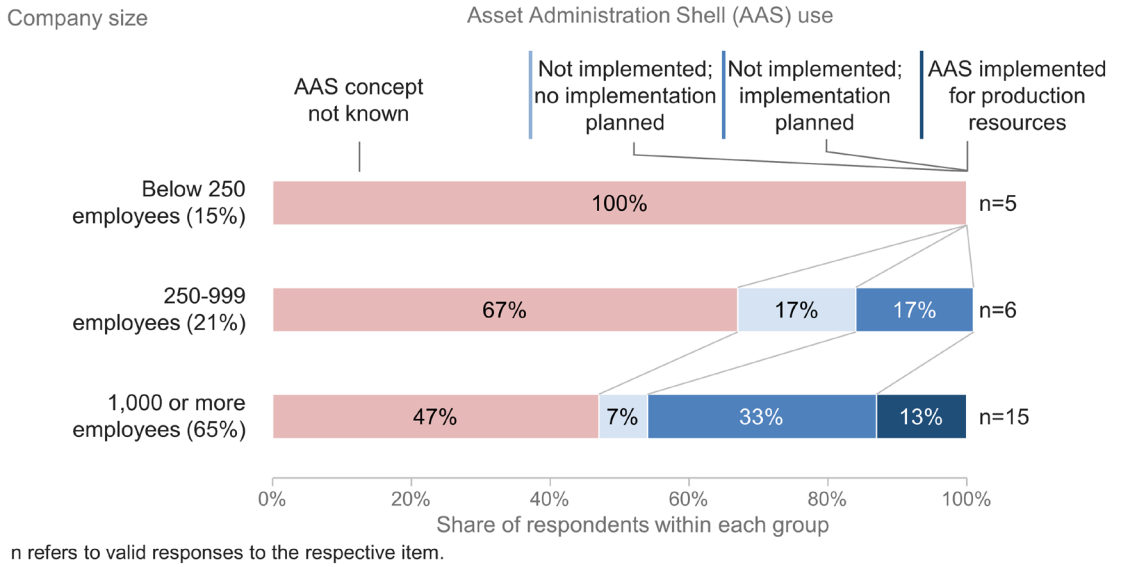


Figure 7: Asset Administration Shell (AAS) use by company size.

Taken together, AAS adoption remains limited in the surveyed companies. Descriptively, lack of awareness is most pronounced in the smallest company-size group, whereas planned implementation and actual use are observed more frequently in the larger company-size groups represented in the sample. Given the small

subgroup sizes, these differences should be interpreted as exploratory and not as evidence of a general company-size effect.

Beyond the adoption of OPC UA and AAS, commissioning is included as an application example to examine different forms of digital support within a specific PPC-related process. Commissioning is an important phase in the value chain of complex products, particularly in one-of-a-kind production, during which a technically completed product is brought into operation and its intended functionality is verified [15]. Seventeen respondents indicated that commissioning is a relevant phase within their company's value chain. For these companies, the survey examined how commissioning planning and control is implemented digitally and how respondents assess commissioning organisation, goal achievement, and operational challenges. The three observed implementation approaches comprise integration into the primary ERP system, specialised commissioning software, and generic applications such as Excel or MS Project. Six of the 17 companies use ERP-integrated commissioning planning and control, another six companies use specialised commissioning software, and five rely on generic applications. No company in the commissioning subsample reported operating without digital support. Figure 8 compares respondents' assessments of commissioning organisation and goal achievement, as well as reported operational challenges, across these three implementation approaches. The comparison thus provides an illustrative view of how these assessments differ across forms of digital implementation.

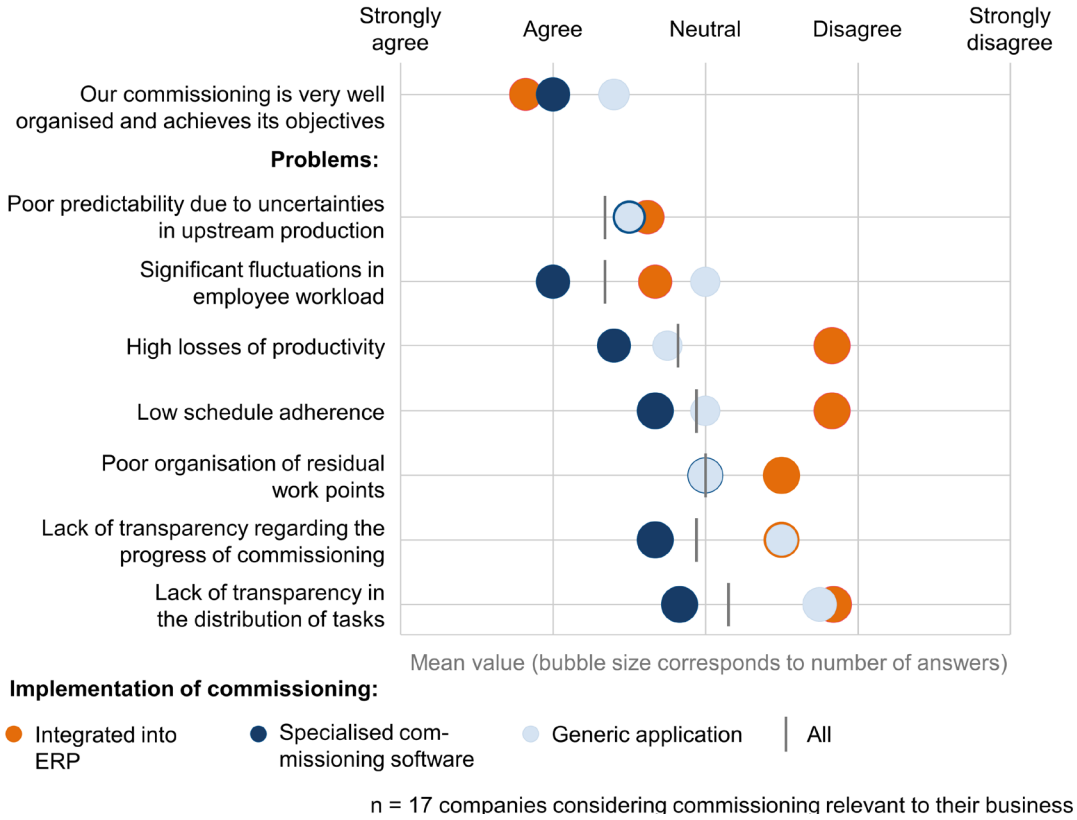


Figure 8: Assessment of commissioning organisation and challenges by software implementation approach. Mean responses are shown on a five-point Likert-type scale (1 = strongly agree; 5 = strongly disagree).

Companies with commissioning planning and control integrated into their ERP system tend to assess the organisation and goal achievement of commissioning positively. Companies using specialised commissioning software also report positive assessments, while companies relying on generic applications show somewhat less favourable assessments. At the same time, the assessment of individual commissioning challenges varies across the three implementation approaches, with specialised solutions showing comparatively pronounced challenges for several aspects. Overall, the commissioning results therefore

indicate descriptive differences between implementation approaches. Given the commissioning subsample of 17 companies, these findings should be interpreted as exploratory.

4. Discussion

4.1 Key Findings

The findings provide three main insights into current PPC practice and illustrate how resilience, sustainability, and Industry 4.0 adoption intersect within production planning and control.

First, the resilience results suggest that organisational practices may be relevant alongside structural characteristics such as company size. While no clear company-size pattern emerges, respondents reporting the use of risk-management approaches predominantly expect their resilience to remain stable or improve compared with past crises. Although the small subgroup sizes prevent causal interpretation, the descriptive pattern indicates differences in perceived preparedness between respondents with different levels of reported risk-management use. Further research with larger samples and more specific measures of risk-management practice would be required to determine whether these differences reflect a systematic relationship with resilience outcomes.

A second insight concerns the increasing operational relevance of sustainability. Efficiency-related measures, particularly material and energy efficiency, account for substantial shares of the sustainability measures considered relevant, whereas compensation measures are selected less frequently. This suggests that respondents place particular emphasis on sustainability measures directly linked to production processes. Such measures can address environmental objectives while simultaneously affecting resource consumption and production costs. The results on energy-data use complement this picture. Among medium-sized and large companies, larger shares of the reported energy-data selections relate to cost reduction or forecasting, whereas the absence of energy-data collection accounts for a larger share among smaller companies. The findings therefore point to differences not only in the sustainability measures considered relevant but also in the extent to which data are already used to support operational sustainability-related decisions.

The third insight concerns the maturity of Industry 4.0 adoption. The results indicate that advanced technological integration remains limited among the surveyed companies. Mostly or fully connected OPC UA implementations are relatively uncommon, and AAS adoption is still at an early stage. The commissioning analysis provides a complementary application example: digital support is present throughout the commissioning subsample, but the form of implementation varies between ERP-integrated solutions, specialised commissioning software, and generic applications. Taken together, these findings point to system integration and standardisation as relevant areas for further development in PPC. Given the small commissioning subsample, differences between the three implementation approaches should be interpreted as exploratory.

Taken together, the findings point to a common theme across resilience, sustainability, and Industry 4.0 adoption: the growing importance of integrating information, organisational practices, and digital technologies into production planning and control. Resilience requires information about potential disruptions and structured organisational responses; sustainability depends on the availability and operational use of resource-related data; and Industry 4.0 focuses on the technical integration and standardised exchange of such information. Rather than representing separate fields of action, the three topics therefore converge around data availability, system integration, and structured decision support within PPC.

4.2 Practical Implications

The results provide several implications for industrial practice. With regard to resilience, the findings highlight systematic risk consideration within production design, planning, and control as a relevant area for industrial practice. The descriptive results do not establish a causal effect of risk-management approaches, but they indicate that structured risk consideration can form part of a broader approach to preparing production systems for future disruptions. This may not necessarily require a separate risk-management system; rather, risk information can increasingly be incorporated into existing planning and control processes and considered when evaluating production alternatives and operational decisions.

For sustainability, the results highlight the potential value of linking sustainability objectives more closely to operational PPC processes. The prominence of material and energy efficiency suggests potential synergies between sustainability objectives and traditional productivity and cost considerations. In particular, energy data can support the identification of improvement potential and can be incorporated into planning, forecasting, and operational decision making. The differences observed across company-size groups indicate that this may be especially relevant for smaller companies, where advanced use of energy data appears less established. For these companies, improving data availability and developing practical mechanisms for using such data in PPC may represent an important step towards more data-supported sustainability management.

The Industry 4.0 findings further suggest that companies should focus not only on adopting digital applications but also on integrating them. The limited penetration of mostly or fully connected OPC UA solutions and AAS implementations indicates that interoperability and standardised information exchange remain areas for further development. The commissioning example illustrates differences in perceived process organisation, objective achievement, and operational challenges across different forms of digital implementation. For practitioners, the findings therefore emphasise the importance of moving beyond isolated digital applications towards greater system integration and standardised information exchange within PPC.

These implications are closely related. Improved system integration can increase the availability of information required for both sustainability-oriented decision making and disruption management, while structured organisational practices determine how this information is translated into operational decisions. From this perspective, resilience, sustainability, and digitalisation should not necessarily be addressed through separate initiatives. Coordinating these activities within PPC may enable companies to use common data and system infrastructures for multiple operational objectives.

4.3 Limitations

Several limitations should be considered when interpreting the findings. First, the survey is based on a relatively small sample of 39 completed questionnaires, and the number of valid responses varies across individual questions. The subgroup analyses therefore have to be interpreted descriptively rather than as statistically generalisable evidence. This is particularly relevant for comparisons by company size and for the commissioning subsample, where individual responses can have a substantial influence on the reported percentages.

Second, the data rely on self-reported assessments. This approach is suitable for capturing perceived practices, priorities, and maturity levels, but it does not directly measure objective performance outcomes. Reported adoption levels, expected impacts, and perceived capabilities may therefore be influenced by respondent interpretation or organisational optimism. The resilience assessment, for example, represents respondents' expectations regarding future crisis impacts rather than an observed measure of future resilience.

Third, the survey was distributed through targeted industrial contacts of the participating institutes and open channels such as LinkedIn. Since a precise response rate cannot be determined and the sample is skewed

towards larger manufacturing firms, the results should be understood as a benchmarking snapshot rather than a representative picture of the entire German manufacturing sector. In particular, patterns observed across company-size groups should not be interpreted as population-level differences.

Some constructs were also intentionally captured at a relatively broad level. For example, risk-management approaches were not further specified in the questionnaire and therefore reflect respondents' individual understanding of the concept. Similarly, selected multiple-response analyses report normalised distributions of selections within company-size groups rather than prevalence rates at company level. These design choices support an exploratory benchmarking perspective but should be considered when interpreting the corresponding results.

Finally, the PPC Report is designed as a recurring survey with a rotating thematic focus. While this enables the survey to address current developments in production planning and control, it limits direct longitudinal comparisons across all variables. Future survey waves should therefore further harmonise recurring core questions to enable more systematic comparisons over time. Where feasible, future studies could also complement self-reported assessments with objective operational indicators and larger samples, enabling the descriptive patterns identified in the present survey to be examined more systematically.

5. Conclusion

This paper presented selected findings from the 2024 PPC Report, a recurring survey of German manufacturing companies, with a focus on resilience, sustainability, and Industry 4.0 adoption in production planning and control. In addition to documenting the survey design, the study provides a descriptive benchmarking snapshot and uses selected bivariate comparisons to explore differences across organisational and technological characteristics.

With regard to resilience, most respondents expect their production systems to be similarly or better positioned for future crises than during past disruptions. No clear pattern emerges across company-size groups, whereas respondents reporting the use of risk-management approaches predominantly assess their future resilience as stable or improved. In the area of sustainability, efficiency-related measures, particularly material and energy efficiency, are among the measures considered most relevant, while the reported use of energy data differs across company-size groups. Among medium-sized and large companies, a larger share of reported energy-data practices relates to operational uses such as cost reduction and forecasting, whereas the absence of energy-data collection accounts for a larger share among smaller companies. Regarding Industry 4.0, advanced technological integration remains limited among the surveyed companies. Mostly or fully connected OPC UA implementations are relatively uncommon, and AAS adoption is still at an early stage. The commissioning analysis provides a complementary application example, illustrating descriptive differences in perceived process organisation, goal achievement, and operational challenges across different software implementation approaches.

Across the three areas, the findings point to the common importance of organisational practices, data availability, and system integration within PPC. The results illustrate how PPC extends beyond conventional planning and control tasks towards the coordinated use of information and digital technologies for multiple operational objectives.

Given the exploratory survey design and the small sample, the findings should be interpreted as descriptive indications rather than generalisable evidence. Future PPC Report waves can build on the present study by retaining selected core questions to enable more systematic comparisons over time, while continuing to address emerging topics in production planning and control. Larger samples and the inclusion of objective operational indicators would further strengthen future analyses and allow the descriptive patterns identified in this study to be examined in greater depth.

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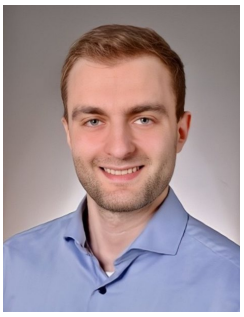
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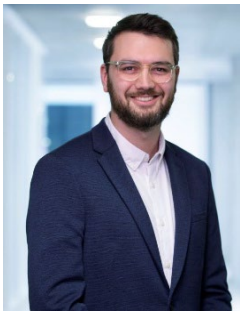
Biography



Julian Petersen (*1997) completed his master's degree in Industrial Engineering at the University of Applied Sciences Wedel. Since 2023, he has been working as a research associate at the Institute of Production Management and Technology (IPMT) at Hamburg University of Technology. His research combines the fields of production planning and control and digital production management. His focus lies on developing a multi-method approach for analysing make-to-order manufacturers.



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