

Enhancing Integrative Product and Production System Development: 42 Improvement Measures

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Abstract: Global cost pressure and increasing competition require manufacturing companies to rethink how their systems are designed and engineered. Cross-functional collaboration between product development and production system development offers significant cost-saving potential, while emerging technologies such as Model-Based Systems Engineering (MBSE) and digital collaboration tools enable new forms of integration. However, despite their technical promise, studies show that integrative product and production system development (IPP) is still rarely implemented in practice, often due to technical, organizational, and cultural challenges. Addressing this gap, this paper presents a systematic literature review that identifies actionable recommendations for improving IPP in complex engineering contexts. In total, 42 improvement measures are derived and structured, including not only technological enablers but also collaborative practices and organizational aspects. The findings provide an overview and recommendations that support organizations in systematically improving IPP adoption and exploiting technological and organizational integration potentials.

Keywords: Integrative Product and Production System Development, Digital Engineering, Organizational Collaboration, Systems Engineering, Concurrent Engineering

1 Introduction

The increasing interconnectedness of technical systems and the growing complexity of modern products and production systems necessitate a close integration of product and production system development. The advantages of an integrative approach include shorter development times, reduced costs and greater flexibility in response to market requirements. Although they have been argued in research and acknowledged in practice, such approaches have only been implemented to a limited extent in industry (Albers, 2023; Dumitrescu et al., 2021; Ehrlenspiel and Meerkamm, 2017; Forschungsbeirat der Plattform Industrie 4.0 and acatech, 2024; Schäfer et al., 2023; Steimer and Aurich, 2016). Persistent implementation gaps can be attributed to manifold reasons like organizational and procedural challenges, a lack of standards, insufficient interoperability of IT systems, and unclear conceptual clarity (Disselkamp et al., 2024a). Consequently, integrative product and production system development (IPP) often remains subject to ad hoc coordination efforts rather than a coherent, institutionalized development paradigm. Against this background, the study addresses the following research question:

“Which actionable recommendations can be derived to enhance integrative product and production system development?”

To answer this question, a systematic literature review (SLR) was conducted to consolidate existing scientific and practice-oriented contributions on integrative product and production system development. The contribution of this paper lies in identifying and structuring actionable improvement measures that address technological enablers, collaborative practices, and organizational aspects, thereby supporting a more systematic adoption of integrative product and production system development in complex engineering contexts.

The paper is organized as follows. After analyzing the existing challenges and the current state of research (Section 2), the research methodology is described (Section 3). Based on this analysis, the recommendations for action are presented systematically (Section 4). Finally, the results are discussed, and an outlook on future research is provided (Section 5).

2 Problem analysis

Product and production system development is increasingly shaped by rising complexity, shorter innovation cycles and higher cost efficiency and sustainability demands (Dumitrescu et al., 2021). Products are evolving from predominantly mechanical artifacts into mechatronic and cyber-physical systems, creating greater interdependencies between mechanics, electronics, controls and software. At the same time, production systems must handle greater product variety, faster changeovers and shorter ramp-up times. Under these conditions, the sequential handover between product development and production system planning often results in late rework, extended feedback loops and additional costs. The concept of integrative product and production system development addresses these challenges by defining a simultaneous and

coordinated development approach in which product and production system perspectives are continuously aligned from early development phases onward (Disselkamp et al., 2026; Ehrlenspiel and Meerkamm, 2017).

Although the potential benefits of integrative approaches have been widely discussed in the literature, they remain underutilized in industrial practice. Companies often continue to rely on sequential or only partially parallelized approaches, such as simultaneous engineering or design for manufacturing and assembly. These approaches support selected aspects of integration, but do not fully address the interdependencies between product and production system development (Graner, 2015; Hagström and Bergsjö, 2024a; Säfsten et al., 2022).

Prior work identifies a broad set of challenges to the adoption of integrative product and production system development (IPP), ranging from fragmented organizational structures and unclear interfaces to incompatible IT landscapes, insufficiently integrated data models, and heterogeneous methodological frameworks (Disselkamp et al., 2025a; Disselkamp et al., 2024a; Disselkamp et al., 2023). Table 1 summarizes and expands upon these challenges, providing a descriptive basis for the subsequent analysis. The challenge numbers in Table 1 are used in Section 4 to trace each recommendation back to the specific implementation problems it addresses.

Table 1. Overview of IPP implementation challenges

No.	Description
1	Increasing complexity of products, production systems and engineering processes challenges integrated planning, modeling and implementation, particularly because dependencies between product features and production processes become increasingly difficult to identify, structure and control. (Hagström and Bergsjö, 2024a; Martin et al., 2024; Stark et al., 2017)
2	Insufficient modeling and analysis of reciprocal technical dependencies between product architecture, production processes and production system capabilities hinder integrated product and production engineering and can result in suboptimal design decisions, costly iterations and delayed industrialization. (Martin et al., 2024; Schäfer et al., 2022; Stoffels et al., 2021)
3	Unclear organizational interfaces, poorly defined handover points and insufficient interface management between product development, production system development and factory planning impede coordinated decision-making and reinforce isolated “over-the-wall” development practices. (Demir and Schmidt, 2025; Martin et al., 2024; Orejuela et al., 2022; Thompson et al., 2018)
4	Fragmented information management, heterogeneous legacy IT systems and limited interoperability across engineering tools create discontinuities in the digital development chain and restrict consistent information flows between product development, production system development and factory planning. (Hagström et al., 2022; Martin et al., 2024; Orejuela et al., 2022; Riege, 2005; Säfsten et al., 2022)
5	Disruptive product shifts, such as electrification and battery production, require production systems with fundamentally different characteristics and create a need for new production-process knowledge within engineering organizations. (Hagström and Bergsjö, 2024a)
6	The absence of consistent, shared and semantically structured data models limits the early analysis of product-change effects on processes, production systems and ramp-up, since dependencies and change impacts are often identified only at later stages or with considerable uncertainty. (Martin et al., 2024; Säfsten et al., 2022)
7	Although product and production engineering activities are increasingly parallelized and synchronized at the process level, interdisciplinary collaboration often remains limited because knowledge transfer, joint decision-making and shared problem understanding are not sufficiently institutionalized (Albers et al., 2023; Orejuela et al., 2022).
8	Knowledge transfer is a critical success factor in integrated product and production engineering; however, knowledge from previous projects, current products and future generations is often insufficiently documented, formalized, reused and transferred across development teams, reducing both the efficiency and effectiveness of engineering decisions. (Albers et al., 2023; Albers and Gausemeier, 2012; Hagström et al., 2022; Hagström and Bergsjö, 2024b; Shafiee, 2024)
9	Production system design frequently underutilizes the design phase for anticipating later operational challenges, while empirical studies addressing operational performance objectives during early production system design remain limited. (Islam et al., 2020)
10	Integrative and agile development approaches are often associated with limited comprehensibility, insufficiently transparent models and weak visualization of cross-domain dependencies, which can reduce their communicability, acceptance and practical applicability in engineering contexts. (Hagström and Bergsjö, 2024b; Orejuela et al., 2022)
11	Established development models and guidelines, such as VDI 2206, provide structured support for product or system development, but offer limited explicit methodological guidance for coordinating the corresponding production system development within an integrated engineering process. (Gräßler et al., 2021)

No.	Description
12	Cross-domain and cross-organizational exchange of engineering data requires systematic governance of interoperability, privacy, ethical implications, data usage conditions and supply-chain integration, particularly when data is shared across tools, companies and lifecycle phases. (Shafiee, 2024)
13	Sustainability and resource-efficiency objectives, such as lifecycle energy consumption, require integrated cross-domain analysis and decision-making because product-related and production-related decisions are mutually interdependent. (Stoffels and Vielhaber, 2015)
14	Existing integrative methods and platform-based approaches often entail substantial time, resource and maintenance requirements for initial development, feasibility assessment and continuous adaptation, thereby limiting their scalability and practical adoption in industrial contexts. (Hagström et al., 2022; Orejuela et al., 2022; Shafiee, 2024)
15	Late product changes driven by customer requirements conflict with early production investment decisions and long production setup lead times, creating a central tension in efforts to reduce time-to-market. (Wlecke et al., 2019)
16	Operational collaboration with suppliers, customers and equipment partners is constrained by the need for controlled access to shared master data, reliable documentation interfaces, transparent exchange routines and robust partner relationships during joint product and production development. (Islam et al., 2020; Tschiltshcke et al., 2024)
17	Divergent roles, objectives and domain-specific languages between design and production create communication challenges and complicate the alignment of cost, performance, environmental, safety and ergonomic targets in integrated development. (Hagström et al., 2022; Orejuela et al., 2022)
18	Digital, cyber-physical and human-centric production system engineering requires systematic engineering design methods and explicit consideration of human factors, both of which remain insufficiently embedded in current production system design practice. (Hagström and Bergsjö, 2024a)
19	Companies lack generally valid evaluation and decision-support models for assessing the factory-wide effects and cost implications of new product variants and integrative product and production decisions before implementation. (Demir et al., 2025)

There is a broad body of literature addressing these challenges. Domain-specific methods, such as condition-based factory planning, and standards, such as ISO/IEC/IEEE 15288 (2023) and VDI 2206 (2021), offer well-established practices, but only address product and production integration to a limited extent. In contrast, integrative frameworks, such as platform-based co-development models (Michaelis, 2013), double-helix approaches (Disselkamp et al., 2024b; Wiktorsson, 2014), product-production co-design (Albers et al., 2022), taxonomies for integrative product and production system development (Disselkamp et al., 2025b), and System-of-Systems approaches to synergetic product, factory, and spatial planning (Demir et al., 2025; Demir and Schmidt, 2026, 2025), explicitly target the joint development of products and production systems.

However, several limitations remain. Existing approaches often cover only selected dimensions of IPP, with a particular focus on processes, models, or engineering methods (Stoffels et al., 2021), while organizational aspects, governance structures, IT and data integration, and implementation capabilities receive less attention. Terminological and structural differences across approaches further complicate comparison and transfer into industrial practice. Moreover, although existing contributions describe important aspects of integrative development, they often provide limited guidance on how IPP can be advanced under real-world constraints. As a result, there remains a need for evidence-based, implementation-oriented recommendations that support organizations in systematically improving their IPP capabilities.

3 Research methodology

A systematic literature review (SLR) was conducted to systematically investigate the research objectives following Kitchenham and Charters (2007) and Lame (2019). SLRs provide a transparent and reproducible process for identifying, evaluating and synthesizing relevant publications (Lame, 2019). Figure 1 gives an overview of the research process.

The research question “*Which actionable recommendations can be derived to enhance integrative product and production system development?*” guided the search strategy, the selection process, and the subsequent analysis of the literature. The review protocol defined the database, the search string, and the inclusion and exclusion criteria. The SCOPUS database was selected as the primary source, as it provides multidisciplinary coverage and supports reproducible results using Boolean operators (Gusenbauer and Haddaway, 2020; Xiao and Watson, 2019). The search string, adapted from Shafiee (2024) and Disselkamp et al. (2023), included various synonyms and terms related to the development of integrated products and production systems:

"integrated product and manufacturing" OR "integrated product and production" OR "integrative product and production" OR "integrative product and manufacturing" OR "design and manufacturing

integration" OR "design-manufacturing integration" OR "product-process co-design" OR "product-production-codesign"

Research Question:

Which actionable Recommendations can be derived to enhance integrative Product and Production System Development?



Search-String:

SCOPUS-Search:

- Article Title
- Abstract
- Keywords



"integrated product and manufacturing" OR
 "integrated product and production" OR
 "integrative product and production" OR
 "integrative product and manufacturing" OR
 "design and manufacturing integration" OR
 "design-manufacturing integration" OR
 "product-process co-design" OR
 "product-production-codesign"

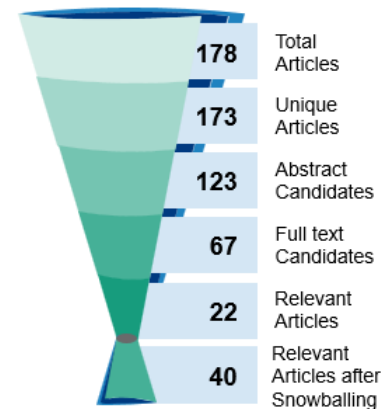


Figure 1. Overview of the conducted Systematic Literature Review.

To ensure a focused identification of relevant literature, the search string was applied to article titles, abstracts and keywords. The search process was conducted in July 2025. The initial database search yielded 178 publications, of which 173 were retained after duplicates were removed.

The next stage involved title and abstract screening. Articles were excluded if they did not match the scope of the research question. Examples of exclusion criteria include publications 1) focusing exclusively on individual manufacturing processes, e.g., die casting, 2) focusing only on specific manufacturing domains, e.g., sheet metal working, 3) connecting IPP and other topics, e.g., environmental issue, or 4) highlighting specialized products, e.g., printed circuit boards. Additionally, outdated studies that no longer reflected the current state of research and practice were discarded (e.g., publications from the 1980s describing the advantages of computer usage). After applying these criteria, 123 articles were retained for further review.

During subsequent full-text screening, each publication was examined in detail regarding its quality, relevance to integrative product and production system development, and potential contribution to derive recommendations. Studies that did not explicitly address aspects of integrative product and production system development were excluded, resulting in 67 articles being retained for further review. 22 publications provided relevant insights for answering the research question. To complement this process, backward snowballing was employed, involving the review of the reference lists of these publications to ensure that no significant contributions were overlooked. 18 further publications relevant for the study were identified that way leading to a total literature corpus of 40 publications that revealed insights for answering the research question.

4 Findings

The systematic literature review resulted in 42 actionable recommendations for improving integrative product and production system development (IPP). To strengthen their prescriptive value, the recommendations are structured into eight action-oriented groups instead of being presented as isolated measures. Table 2 summarizes the recommendations, the sources cited for each recommendation, and the challenges from Table 1 addressed by each measure.

The first group (no. 1–3) focuses on **strategic orientation and portfolio alignment**, framing IPP as a long-term strategic capability through the integration of product generations, interdisciplinary strategic planning, and the alignment of product and production system portfolios. Recommendations 4–11 address **integrated process and interface architecture**. These recommendations define processes, change management routines, interface descriptions, synchronization points, iterative planning cycles and the integration of Systems Engineering with production system engineering. The third group (no. 12–16) focuses on **shared problem framing, requirements and value transfer**. This group aims to translate customer, value, sustainability, and production constraints into integrated product and production decisions at an early stage. The **model-based and digital backbone of IPP** (no. 17–26) group comprises information models, semantic data representations, IT toolchains, ontologies, subsystem models, modeling toolboxes, digital twins, product lifecycle management (PLM), standardized data formats and consistency management. With **analysis, uncertainty handling, and decision support** (no. 27–32), the recommendations enable production system configuration, hypothesis-based work under incomplete information, cost forecasting, change-impact analysis, maturity assessment of early product information, and factory-level

variant evaluation. **Feedback, validation and lifecycle learning** (no. 33–34) are addressed through feedback loops and early interdisciplinary prototypes to help validate assumptions and transfer practical production knowledge back into development. To promote **adaptability, platforms, and resource reuse** (no. 35–38), scalability and reuse across projects and product generations are supported by integrated platforms, flexible production systems, AI-based assistance, and standardized procedures or parts. Finally, **cross-domain collaboration, roles and competence development** (no. 39–42) highlight collaboration mechanisms, knowledge transfer, and the early involvement of production experts, as well as project-, team- and method-related competence development.

The challenge mapping shows that some issues are addressed much more frequently than others. The most frequently addressed challenge is Challenge 15, concerning the tension between late customer-driven product changes and early production investment decisions, which is addressed by 19 recommendations. It is followed by Challenge 19 on missing evaluation and decision-support models with 14 recommendations, and Challenges 6 and 17 on semantic data models and cross-domain communication challenges with 13 recommendations each. These numbers reflect how often each challenge is addressed within the set of recommendations reflecting the coverage in our sample. In contrast, Challenge 18, concerning human-centric and cyber-physical production system engineering, is addressed by only three recommendations. Challenges 4, 11, and 12, related to fragmented IT landscapes, insufficient methodological guidance in established development models, and governance of cross-company engineering data, are each addressed by five recommendations. None of the challenges remain unaddressed, although some challenges are addressed by comparatively few recommendations. This uneven distribution also helps to distinguish between mainstream and more niche areas of IPP research. Some recommendations, such as PLM use, feedback loops, and the early involvement of production experts, represent well-established practices that are repeatedly confirmed in the literature. Others, such as cross-domain consistency management, maturity assessment of early product information, product–process–space planning, and factory-level variant evaluation, are less frequently discussed and therefore point to more niche or context-specific areas of IPP research. Overall, the grouping shows that IPP improvement requires a combination of strategic, procedural, digital, analytical, and organizational measures. At the same time, some recommendations stand in tension and must be balanced considering the concrete contingencies. For example, design freezes and synchronization milestones (no. 8) limit the continuous incorporation of late customer requirements (no. 14), while standardization, platforms and reuse (no. 35, 38) can conflict with the flexibility required by disruptive product shifts (no. 36).

Table 2. Identified recommendations for action

Recommendation and supporting sources	Challenges (Table 1)
1) Develop a strategy for product development across generations (Albers et al., 2025; Albers et al., 2022)	1, 5, 8, 14, 15
2) Introduce a systematic process for interdisciplinary strategic corporate planning (Flatscher and Riel, 2016; ISO/IEC/IEEE 15288, 2023)	5, 13, 15, 17, 19
3) Align product portfolios and production system portfolios in strategic planning (Bruch and Bellgran, 2014; Jayaram and Vickery, 2000)	5, 13, 14, 15, 19
4) Define the overall integrated product and production development process, including phases, activities, roles, and sub-processes (Gausemeier et al., 2011; Jania and Ulrich, 2008; May et al., 2023; Stoffels and Vielhaber, 2016)	3, 7, 9, 11, 14, 17
5) Implement formal engineering change management, including engineering change notes, change requests, and change-propagation transparency (Beibl et al., 2023; ISO/IEC/IEEE 15288, 2023)	3, 6, 15, 19
6) Introduce a dedicated synchronization or integration manager role to coordinate product and production process development (Schuh et al., 2021)	3, 7, 17
7) Define and manage explicit interfaces between product, production system, factory, and spatial planning (Demir and Schmidt, 2026)	3, 16, 17, 19
8) Define synchronization milestones, quality gates, and design freezes between integrated planning strands (Demir and Schmidt, 2026)	3, 7, 14, 16
9) Structure integrated planning through macro- and micro-cycles to enable iterative product and production alignment (Demir and Schmidt, 2026)	3, 7, 11, 15
10) Decompose integrated product–process–space planning hierarchically, functionally, and structurally (Demir and Schmidt, 2025)	1, 2, 3, 19
11) Combine Systems Engineering and production system engineering methods to manage dependencies between products, processes, resources, and production systems (Forschungsbeirat der Plattform Industrie 4.0 and acatech, 2024)	1, 2, 11, 18
12) Introduce systematic value analysis (Jayaram and Vickery, 2000; Molina et al., 2021)	13, 17, 19

Recommendation and supporting sources	Challenges (Table 1)
13) Define a common product and production problem space and integrated product and production profiles early, including constraints, system context, use cases, tact times, safety, reliability, and interdependencies (Albers et al., 2025; Albers et al., 2022)	2, 7, 13, 15, 17
14) Continuously incorporate customer requirements into iterative product and production process development (Francalanza et al., 2018; Schuh et al., 2022)	15, 17
15) Digitally capture, evaluate, and reuse customer and usage feedback after market launch for future product and production planning (Francalanza et al., 2018; Schuh et al., 2021)	8, 15, 16
16) Provide early trade-off decision support for solving conflicts through product, process, or production system adaptation (Albers et al., 2025)	2, 13, 15, 19
17) Define a shared information model and semantic data representation for product and production system information (Gausemeier et al., 2011; Jania and Ulrich, 2008; Tschiltschke et al., 2024)	4, 6, 10, 12
18) Establish an integrated IT toolchain across product and production development, including CAD, PDM/PLM, ERP, and MES (Dogea and Stolt, 2021; Jania and Ulrich, 2008; Säfsen et al., 2022; Tschiltschke et al., 2024)	4, 12, 16
19) Use an ontology for selecting manufacturing processes and considering the possibilities and connections between CAD and CAPP (Cadet et al., 2017; Li et al., 2018; May et al., 2023; Pisarić et al., 2020)	2, 6, 11, 12
20) Model product, process, production system, factory, and simulation subsystems and their interdependencies (Gausemeier et al., 2011; Martin et al., 2024; May et al., 2023)	1, 2, 6, 10
21) Provide a modeling toolbox, including modeling languages, methods, model views, and software tools (Gausemeier et al., 2011; May et al., 2023; Tschiltschke et al., 2024; Martin et al., 2024; Schuh et al., 2021)	10, 11, 14
22) Use digital twins to collect, evaluate, and feed back product and production system data (Dogea and Stolt, 2021; May et al., 2023)	4, 6, 9, 16
23) Use PLM to coordinate product-related information, processes, and methods throughout the entire lifecycle (Dogea and Stolt, 2021; Säfsen et al., 2022)	4, 6, 8, 12, 14
24) Introduce a consistent product and production system architecture and model structure (Gausemeier et al., 2011; Schäfer et al., 2023)	1, 2, 6, 10
25) Standardize data formats and transformation rules to improve interoperability, data migration, and digital continuity (Dogea and Stolt, 2021; Tschiltschke et al., 2024)	4, 6, 12, 16
26) Establish cross-domain consistency management between product and production system models during changes (Albers et al., 2025)	2, 6, 10
27) Use MBSE and configuration methods to derive or configure production system modules and concepts from product, requirement, and production-resource data (Forschungsbeirat der Plattform Industrie 4.0 and acatech, 2024; Gönnheimer et al., 2019; May et al., 2023)	1, 2, 5, 6, 15
28) Use hypotheses and forecasts to handle incomplete product and production system information in early development phases (Schuh et al., 2022; Schuh et al., 2021)	6, 15
29) Introduce software support for continuous analysis and forecasting of product and production system costs (Schuh et al., 2022)	13, 15, 19
30) Analyze change impacts, risk propagation, and dependencies between product, production system, and strategic factors (Demir and Schmidt, 2026; Stürmlinger et al., 2020)	1, 2, 6, 15, 19
31) Assess the maturity of early product information before deriving production system decisions (Sinnwell et al., 2019)	6, 15, 19
32) Evaluate new product variants against factory resources, objects, and capacity limits before introduction (Demir et al., 2025)	9, 15, 19
33) Establish feedback loops to improve interdisciplinary communication, problem consolidation, and organizational learning (Lee, 2020; Roy and Allchurch, 1997; Säfsen et al., 2022; Tschiltschke et al., 2024)	7, 8, 9, 16
34) Early and interdisciplinary use of (digital) prototypes (Albers et al., 2025; May et al., 2023; Schuh et al., 2022; Wlecke et al., 2022)	7, 9, 15, 17
35) Use integrated product and production platforms (Dogea and Stolt, 2021; Säfsen et al., 2022)	5, 14, 15, 19
36) Introduce a flexible production system, e.g., based on the concept of value stream kinematics or modular functional units (Beibl et al., 2023, p. 95; Fleischer et al., 2021)	1, 5, 15, 19
37) Use AI-based assistance systems to extract design knowledge and propose next design steps in product development (Albers et al., 2022; Krahe et al., 2021; Molina et al., 2021)	8, 10, 14

Recommendation and supporting sources	Challenges (Table 1)
38) Standardize procedures, materials, parts, and processes to reduce complexity and cycle time (Bruch and Bellgran, 2014; Jayaram and Vickery, 2000)	14, 15, 17, 19
39) Enable co-location where beneficial and reduce spatial distance; if distributed, compensate through structured communication, shared tools, and clear responsibilities (Held, 2010; Mello et al., 2017; Trolle et al., 2021)	3, 7, 16, 17
40) Systematically formalize, transfer, evaluate, and improve product and production knowledge across departments (Albers et al., 2023; Albers et al., 2022; Hagström and Bergsjö, 2025; Säfsen et al., 2022)	7, 8, 14, 17
41) Involve production planners, manufacturing engineers, and shop-floor experts early and continuously in product development (Albers et al., 2025; Lee, 2020; Säfsen et al., 2022)	7, 9, 17, 18
42) Build project-management, team-management, and method competence through training and dedicated roles (Hagström and Bergsjö, 2025; Lee, 2020)	10, 17, 18

5 Conclusion

The growing complexity of product and production system development necessitates novel approaches that transcend sequential or partially parallelized practices. While the literature clearly argues for the potential advantages of integrative development, widespread application in practice has not yet been achieved. This study addressed this discrepancy by deriving 42 actionable recommendations for improving integrative product and production system development.

The results show that integrative product and production system development requires the deliberate alignment of strategy, people, processes, and technologies. The 42 recommendations reveal eight fields of action: 1) strategic orientation and portfolio alignment, 2) integrated process and interface architecture, 3) shared problem framing, requirements and value transfer, 4) model-based and digital backbone of IPP, 5) analysis, uncertainty handling, and decision support, 6) feedback, validation and lifecycle learning, 7) adaptability, platforms and resource reuse, and 8) cross-domain collaboration, roles and competence development. The findings motivate a shift in the perspective of IPP from isolated methodological tools towards socio-technical integration.

Several limitations must be acknowledged. The review was limited to publications accessible in the selected database, predominantly in English and German, which may have led to the exclusion of relevant perspectives from other regions or languages. Furthermore, the categorization of recommendations is based on qualitative interpretation. The categorizations and the recommendations themselves also have not yet been validated with practitioners. Moreover, the identified recommendations remain relatively generic; their translation into concrete implementation steps, tools, or metrics requires further development.

Therefore, future research should advance IPP across four directions. First, the proposed recommendations must be validated and refined through empirical studies across industries, to ensure their applicability and completeness. Second, quantitative approaches are required to measure the impact of implementing such recommendations on the efficiency, cost, quality and flexibility of integrative product and production system development. Third, future work should explore how emerging topics such as sustainability, circular economy strategies, and digital platform integration can be systematically incorporated into maturity-oriented frameworks. Fourth, the question of how organizations can be guided step by step in applying these recommendations, through roadmaps, best practices and assessment methods, remains open and offers an important area for further investigation.

In summary, this study contributes to a more comprehensive understanding of integrative product and production system development by identifying and structuring recommendations for action. While the results provide a starting point for the systematic improvement of IPP, further research is needed to validate, operationalize and extend these insights to realize the full potential of integrative approaches in industrial practice.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used tools for editorial support and a critical review of the manuscript. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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