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Top Strategic Technology Trends in Industrial Manufacturing for 2024

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Initiatives: Manufacturing and Transportation Sector Dynamics in IT

The industrial manufacturing trends for 2024 accelerate product innovation, operational excellence and sustainability, and the scalability and interoperability of people, assets, products and processes. CIOs should educate leadership about these opportunities while defining digital ambitions.

Overview

Opportunities

- The digitization of industrial manufacturers is capital-intensive, and therefore, a step-by-step, modular implementation of digital technologies is essential. Composable business promotes the willingness of CIOs to invest and get resource commitments from business units.
- Disruptive technologies like generative AI (GenAI) or the industrial metaverse will be accepted and trusted by both IT and business stakeholders if related to a specific use case or business outcome.
- A foundational infrastructure backbone is a key prerequisite to achieving the expected outcomes from technology. Therefore, platform approaches and common data models are required to manage large amounts of data and to ensure the interoperability of products, assets and applications.

Recommendations

Industrial manufacturing CIOs driving digital transformation and innovation should:

- Cultivate composable thinking through education focused on composability concepts, modified key performance indicators (KPIs) for the business and modified job performance metrics that align with composability concepts.

- Establish a pilot program for GenAI applications that evaluates the functionality of the technology, the appropriateness of the use cases and the validity of GenAI output on an ongoing basis.

- Avoid large initial investments in foundational data backbone infrastructure by prioritizing infrastructure implementation partners that offer infrastructure as a service (IaaS) so that the foundational backbone can grow stepwise, with rollouts to additional sites and new functionality being implemented. This will facilitate investment justification and getting buy-in from business stakeholders.

What You Need to Know

The industrial manufacturing sectors differ from other industries due to the complexities of supply chains, the ability to maintain product innovation cycles and the need to periodically optimize production processes while also fulfilling regulations and sustainability KPIs. Industrial manufacturing comprises both process and discrete industries that differ not only due to the different characteristics of the products, but also their operations and business model and digital maturity. But process and discrete industries also have commonalities — the most important one is that both of them are asset-intensive, meaning that they aim to automate production and assembly processes leveraging complex, connected and increasingly software-defined assets.

This results in three basic directions in industrial manufacturing CIO's strategies and visions:

- **Better transparency and predictability** of external influencing factors, such as interrupted supply chains, inflation, and the lack of availability of engineers and other skilled workers, because investments in digital transparency are often long-term.

- **Flexibility to respond to changing customer needs**, while maintaining a high level of standardization in products, assets and production processes. This leads to the need to change operating models on a cultural, organizational and process level, as well as reduce technical debt and improve the interoperability of increasingly software-defined products and assets.

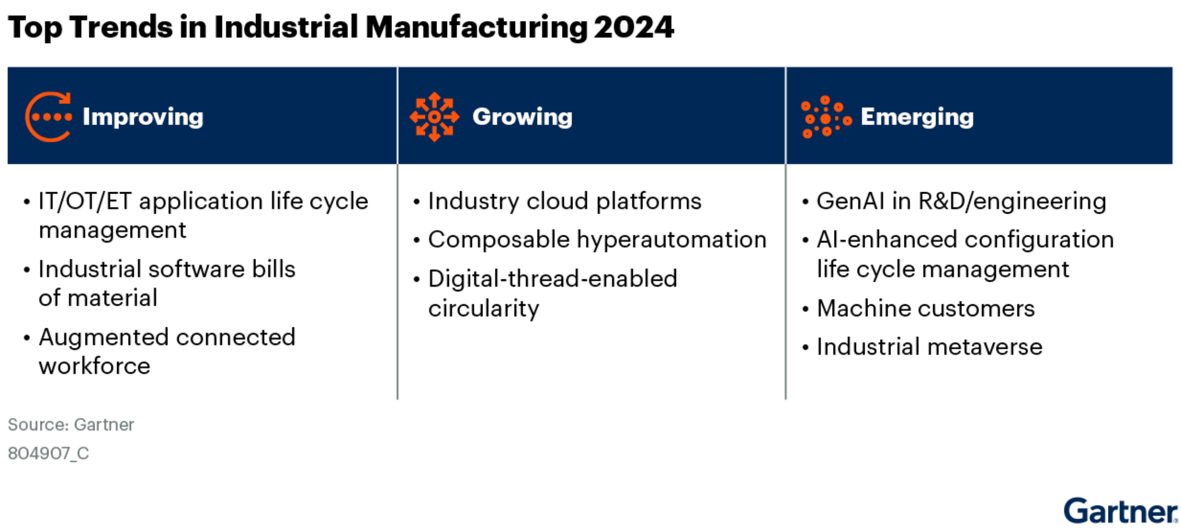
- **Reduction of carbon emissions, as well as using more green energy,** and even producing it themselves to counteract their bad reputation of being high-energy consumers.

This year's industrial manufacturing trends provide CIOs with the opportunity to drive the transformation of operations or even business models in alignment with the visions above. These trends are at different evolutionary stages, with some of them being long-lasting, while others may evolve, change or even become less important over time as they become common practice:

- **IT/OT/ET application life cycle management, industrial bill of material and augmented connected workforce** are trends CIOs already have on their agendas, but there is still much potential for improvement through standards, integration and scalability.
- **Industry cloud platform, composable hyperautomation and digital-thread-enabled circularity** are maturing technologies and concepts. However, they are still in the pilot phase or only basic solutions are available, so the possibilities for functional expansions are far from being exhausted.
- **GenAI in R&D/engineering, AI-enhanced configuration life cycle management, machine customers and the industrial metaverse** are still very visionary trends and require long adaptation times, because they are not only associated with great innovation potential, but also bring with them cultural, process-related and technical challenges.

Figure 1 shows these trends clustered in three categories: improving, growing and emerging.

Figure 1: Top Trends in Industrial Manufacturing 2024



The top strategic technology trends in industrial manufacturing for 2024 are presented in Table 1.

Table 1: Trend Profiles

Improving	Growing	Emerging
IT/OT/ET Application Life Cycle Management	Industry Cloud Platforms	GenAI in R&D/Engineering
Industrial Software Bills of Material	Composable Hyperautomation	AI-Enhanced Configuration Life Cycle Management
Augmented Connected Workforce	Digital Thread- Enabled Circularity	Machine Customers
		Industrial Metaverse

Source: Gartner (January 2024)

Improving

IT/OT/ET Application Life Cycle Management

Analysis by Sudip Pattanayak, Kristian Steenstrup, Marc Halpern

SPA: By 2026, 70% of manufacturers of complex and regulated products will transition to a comprehensive application life cycle management (ALM) platform integrated with requirements management and product life cycle management (PLM) software, up from less than 40% in 2023.

Description:

ALM in manufacturing refers to an integrated system of tools, people and processes that governs developing, testing, deploying, enhancing and upgrading embedded or connected software from product or system concept through end of life. ALM ensures the integrity, quality, functionality and security aligned with the intended software logic, including the alignment of requirements and different parameters of firmware/software.

Why Trending:

- The market demands intelligent manufactured products with growing complexity in embedded and application software. Therefore, it is imperative to manage the complexity of the software life cycle consisting of activities, such as requirements management, planning, collaboration in IT departments and with business during the design and implementation phases, source code management, testing, software deployment and maintenance.
- Manufacturers apply PLM to manage hardware life cycles and integrated bills of materials of mechanical, electrical and electronic components. However, for software, mixed-bag solutions are used, such as stand-alone source code management, version control, test management and general IT workflow solutions, that do not comply with integrated planning, communication and collaboration during the software life cycle. Additionally, it is challenging to keep up with these independent software solutions. ALM provides a robust alternative, and offers off-the-shelf templates to accelerate software development.

- Product servitization models are evolving, with manufacturers generating new revenue streams based on software updates/enhancements. A combination of IT/operational technology (OT)/emerging technology (ET) logic in the software plays an essential role in managing the software updates in a reliable manner. Examples:
  - The OT includes sensors that monitor the performance and health of the product or an asset.
  - The IT processes output from OT and contains the data processing logic to report the operating status of the system or product.
  - ET is the problem-solving technology and business logic that identifies the correction, enhancement and increase of the efficiency of software-operated products.
- An increased number of software elements will pose additional pressure on manufacturers to manage the traceability of source codes, software bills of materials, and changes across the application and product life cycle. A single point of failure in software can lead to a cascading set of issues, with the potential to take a product out of service.

Implications:

- The hardware and software development teams often employ different development methodologies. While hardware usually follows a waterfall method, software is developed using agile development. Manufacturers will need to ensure the integration of the hardware and software components and the corresponding tools, irrespective of the development approaches.
- The complexity of the software needs to be managed by simplifying the regulatory and function safety software elements. ALM solutions will be able to track the requirements, decompose and link the requirements with software modules, and model them as per the functional safety standards across complex and highly regulated industries, such as aerospace and defense, medical devices, automotive, and industrial machinery.
- Manufacturing CIOs and software engineering leaders prefer ALM platforms with modern and adaptive capabilities, such as intuitive user interface, AI and GenAI features; real-time traceability; and test automation, to accelerate new product introductions.

Actions:

- Devise an ALM strategy supported by requirements management to ensure traceability across the application life cycle.
- Plan and implement ALM methodologies and toolsets if you are developing complex, intelligent and/or functional safety-compliant software. In doing so, insist on ALM software that supports industry-vertical-compliant templates and accelerates the adoption of application-life-cycle-based collaboration and communication, including improving the development of complex software across suppliers.
- Justify the investments in ALM as a platform to comply with and support global industry functional safety standards, such as International Organization for Standardization (ISO) 26262 in the automotive domain. When building the investment plan for the ALM platform, consider integration with PLM to optimize the convergence of hardware and software life cycle processes and data, including bill of materials, providing traceability in a digital thread.

Further Reading:

- How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread
- Market Guide for PLM Software in Discrete Manufacturing Industries
- Top BOM Practices for Building Digital Threads in Discrete Manufacturing Industries

Industrial Software Bill of Materials

Analysis by Kristian Steenstrup

SPA: By 2026, at least 50% of organizations procuring mission-critical software solutions, such as OT in industrial equipment, will mandate software bill of materials (SBOM) disclosures in their licenses and support agreements, up from less than 5% in 2023.

Description:

An SBOM is machine-readable metadata that uniquely identifies software and the components used to build it — open source or proprietary. SBOMs are designed to track and share the details of software components and their provenance.

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Why Trending:

- Many manufacturers of complex equipment include software in their products. That software must be documented and managed by the OEM and by the industrial manufacturer that bought the machine. SBOM is a contributor to managing that software life cycle.
- Software as part of manufactured equipment and products adds complexity. Documenting integrated software items in bills of material reduces the risk of equipment defects and increases transparency, auditability and traceability throughout the software supply chain, thus expediting the resolution of security and compliance issues.
- Software security hygiene should extend to external code dependencies and commercial off-the-shelf software, which includes the use of third-party APIs.
- When teams discover flaws or vulnerabilities in a component, they can use SBOMs to quickly identify all software that is affected by the vulnerable component. SBOMs also provide them with information to assess the potential impact and risks introduced by the vulnerable component.
- Regulatory authorities in the U.S. (such as the Food and Drug Administration and Federal Energy Regulatory Commission) and in Europe (for example, The European Union Agency for Cybersecurity) are mandating SBOMs as a prerequisite deliverable for all organizations transacting with government agencies and regulated organizations.

Implications:

- Over the next three years, OEMs who include OT software will be challenged to keep up with the evolution and general direction of SBOM technologies, tools and best practices. They must do this while avoiding or minimizing potential dead ends and missteps.
- The state of the art for SBOM initiatives will evolve and improve continuously through 2026, but the most impactful innovations are unlikely to reach mainstream adoption before 2025.

- While not a complete solution by itself, an SBOM is a critical first step and required element in gaining insight into a complete, accurate and up-to-date inventory of assets that make up a software solution deployment. However, they are only as useful as the processes and tools implemented to process, analyze and leverage the information they contain. Additional tools and techniques, such as software composition analysis and code signing, are also necessary elements of a complete software supply chain management effort.
- The lack of standardized data exchange formats impedes the sharing of SBOMs among teams, partners, suppliers and customers.
- This affects both the supply and demand sides. Manufacturers are also customers of equipment with embedded software, so should manage the SBOM in the equipment they acquire.

Actions:

- To navigate these relationships and dependencies, OEMs and OT software developers should adopt one common industry standard for SBOM formats. There are three SBOM standards: Software Package Data Exchange, Software Identification and CycloneDX.
- Create an SBOM by querying the PLM system to document the software and firmware information used for flashing, coding and parameterizing the software in equipment as it is built. Adopt model-based systems engineering (MBSE) to track and manage the interdependencies between SBOMs and hardware BOMs.Automation of the systematic generation of SBOMs ensures consistency and integrity in case of updates.
- When buying complex products, expedite the resolution of the vulnerabilities in the software supply chain by consuming, verifying and sharing provenance data for all software components and dependencies.

Further Reading:

- Emerging Tech: A Software Bill of Materials Is Critical to Software Supply Chain Management
- Life Cycle Management of Software-Defined Vehicles: Step 1 — Software Bill of Materials

- Innovation Insight for SBOMs
- Innovation Insight: Model-Based Systems Engineering Is Fundamental to Digital Engineering

Augmented Connected Workforce

Analysis by Simon Jacobson and Dana Stiffler

SPA: Through 2027, half of the Fortune 500 manufacturers will create 15% of new positions through innovative engagement models enabled by augmented connected workforce (ACWF) strategies.

Description:

The ACWF drives business results, such as reduced time to competency — the time required after onboarding for an employee to become fully productive — and improved decision making. ACWF is a strategy to optimize the value derived from a human worker by establishing a connective tissue that optimizes the use of intelligent technology, workforce analytics and skill augmentation. I t treats these capabilities as a unified cohesive strategy to accelerate and scale talent. ACWF uses AI , advanced analytics and thoughtfully designed tools providing guidance and support for the workforce's experience, well-being and ability to develop their own skills. These digital initiatives must be bound to a formal workforce and talent strategy spread across knowledge curation, learning and development, and organizational design.

Why Trending:

There is a significant gap in the skills of the workforce today and the rapidly changing needs of organizations. The trend of the augmented connected workforce is driven by six mutually reinforcing themes:

- Technology services, applications and devices have been treated separately, creating silos in the IT organization and friction for the workforce. Additionally, there are ongoing changes to platforms and services, with several solutions being delivered to achieve similar ends.
- There has been an acceleration of new (digital) skills required for work — across all job types.

- An opportunity has arisen for intelligent apps and digital tools to reduce the time to competency for new hires.
- Advancements in workplace automation and AI leave the workforce dealing with ever-more-complex issues.
- New workers may be tech-savvy with newer technology, but they lack subject matter expertise and access to best practices and know-how. Tenured workers have detailed process knowledge and might be digitally savvy outside the work environment, but — even as tools evolve — struggle to fully adopt new technologies in the workplace and use them to change how work gets done.
- Labor shortages are a top challenge for 60% of supply chain organizations. Yet one-third of supply chain organizations lack an effective employee value proposition to attract, retain and engage the needed talent through human-centric work design (see The Future of Supply Chain 2023).

Implications:

ACWF initiatives can reduce the time to competency and increase multiskilling in operations. Broadly, they could also provide more career paths within the organization for entry-level resources to grow without needing to leave and pursue additional schooling or training. Gartner's 2022 Frontline Workers Experience Reinvented survey found that organizations that have increased investment in automation or digitalization saw a significant positive impact in frontline workers progressing to more skilled jobs.

Actions:

- Begin with simplification by taking a phased approach that starts with eliminating offline processes and reducing human error. The measurable returns will stimulate demand for these initiatives and will reveal short-term improvement opportunities, creating the path toward workforce transformation.
- Start a conversation with HR, functional and business leaders about simple ways to launch augmented connected workforce initiatives in your organization. Gain a current understanding of the skills, roles and gaps in your current approach, and stakeholder priorities.
- Begin building a better digital employee experience by using human-centric design disciplines, such as journey mapping and personas, within IT to identify role- and context-specific needs for augmentation at the work-task level.

Further Reading:

- Innovation Insight: Connected Factory Workers Drive Smart Manufacturing
- How to Take a Life Cycle Approach to Developing the Connected Factory
- Worker Quick Answer: How Can I Develop New Factory Workers as the Digital Operating Environment Emerges?
- Industry Insights: Hyperautomation in Manufacturing Will Transform Human Intervention

Growing

Industry Cloud Platforms

Analysis by Alexander Hoeppe, Gregor Petri

SPA: By 2027, more than 60% of large manufacturers will use industry cloud platforms to accelerate their business and product innovation initiatives, up from 37% in 2023.

Description:

Industry cloud platforms (ICPs) address industry-relevant business outcomes by combining software as a service (SaaS), platform as a service (PaaS) and IaaS services into a whole product offering with composable capabilities. These typically include an industry data fabric, a library of packaged business capabilities, composition tools and other platform innovations. Manufacturers can use ICPs to build composable solutions and facilitate the execution of supply chain processes within and beyond their organization's boundaries.

Why Trending:

ICPs leverage underlying SaaS, PaaS and IaaS cloud services to offer industry-relevant packaged business and technical capabilities.ICPs in manufacturing provide services as packaged business capabilities (PBCs) compliant with business processes and technical requirements. PBCs are appealing to manufacturing CIOs and product innovation leads beyond early adopters of cloud infrastructure, because they allow users to get new capabilities without heavy IT development or support efforts. Industrial Internet of Things (IIoT) platform providers and vertical-specific software vendors increasingly enhance their offerings with ICPs for general manufacturing and its subindustries. According to Top Strategic Technology Trends for 2024: Industry Cloud Platforms, manufacturing is the leading vertical for which more than 40 ICPs exist. Some examples include:

- Cloud for Manufacturing, industry solutions for automotive and industry solutions for consumer goods, Microsoft Azure
- Proficy Manufacturing Data Cloud, GE
- IBM Manufacturing Technology Solutions and Cloud Pak for Business Automation, IBM
- Oracle Fusion Cloud, Oracle
- SAP Digital Manufacturing, SAP
- CloudConnect, Siemens
- Manufacturing Cloud, Salesforce

Implications:

The majority of industry cloud platform adopters and those considering adoption, regard high cost and dependency on a single vendor (concentration risk) as the biggest potential future risks associated with ICPs. According to Presentation: Industry Cloud Platform Adoption by Vertical Industry, IT leaders consider industry-specific SaaS applications having API -enabled building blocks, data grids enabling data analysis across platforms, marketplaces and global access to business applications as critical capabilities for adopting ICPs. ICPs need to support composability by providing cloud-native architecture solutions to multiple manufacturing-specific applications, such as PLM, manufacturing execution systems (MESs) and IIoT. As the maturity of these applications grows, the ecosystems of product vendors, business process management and integration platforms will also need to scale their software products and operations in ICPs.

Actions:

- Define a journey to ICPs by creating a team of business stakeholders, chief data officers and enterprise architects who can map the benefits created by adding missing or common capabilities that complement the existing manufacturing-specific application landscape. Prioritize the creation of a compelling business case and a roadmap that allows for stepwise ICP adoption.
- Engage citizen developers or partners to build composable applications that are truly scalable in ICPs, instead of just cloud-hosted solutions, to increase the reusability, maintainability and the accompanying economies of scale in the longer run.
- Select ICP platform solutions and implementation providers that also offer cloud-edge integration capabilities because many use cases require data processing at the edge, while only aggregated data is shared across the organization and beyond with customers, suppliers and partners.

Further Reading:

- What should I know about Industry Cloud Platforms?
- What Manufacturing CIOs Must Know About Industry Cloud Platform Adoption
- Presentation: Industry Cloud Platform Adoption by Vertical Industry

Composable Hyperautomation

Analysis by Alexander Hoeppe

SPA: By 2026, using composition and avoiding diffused (siloed) approaches to hyperautomation initiatives will reduce initiative-specific total cost of ownership by 50%.

Description:

Hyperautomation (HA) requires integration of multiple digital technologies, such as advanced analytics, AI and robotics, with existing IT, OT and ET systems to be able to execute workflows across these organizational, functional and technical silos. The resulting complexity can only be managed with modular, stepwise implementation approaches that can be summarized under the term “composability.” Composable architectures use platform approaches that allow for the deployment of technologies in the form of packaged business capabilities (PBCs) that address not only long-term strategic objectives but also the short-term business needs and challenges of their manufacturing organizations. These PBCs need to be developed and integrated leveraging open standards and standardized APIs. In addition, a scalable foundational data backbone (for example, an industrial cloud platform or an IoT platform) needs to be built up that allows for a best-of-breed approach with regard to the selection providers of PBCs.

HA initiatives are complex and need to be implemented stepwise so that quick-win value can be generated — while not compromising — to achieve a long-term vision of the factory of the future or smart intelligent products. Therefore, not only the solution itself needs to be composable, but also the implementation methodology.

Why Trending:

- Manufacturing organizations struggle with scalability digital solutions and proofs of concept (POCs), not only due to the complexity issues of the solution due to cultural, organizational and process-related challenges and technical debt but also due to budget constraints and investment justification challenges. Therefore, investment in digitization initiatives needs to be subdivided into smaller engagements.
- Large vendors that cover a variety of different technologies are supporting manufacturers by building joint offerings to deliver Industrie 4.0, smart manufacturing or product servitization initiatives end to end.

Implications:

Most manufacturers have spent years prioritizing use cases and implementing POCs to validate to what degree HA technologies help them improve operational or product excellence, customer experience or to better manage risks. The time has not yet come to integrate these POCs. They are often related to business use cases to cross application workflows that can be executed across complex organizations and even beyond manufacturing enterprises' boundaries to facilitate collaboration with customers, suppliers and partners. The rise of ICPs will help build the foundational data backbone, but the standardization of APIs, data models and reference architectures like RAMI 4.0, IIRA or broader concepts like Unified namespace, are also accelerators of HA initiatives. The final vision of a composable HA solution is a network of interconnected PBCs deployed as services on an application composition platform that can be flexibly enhanced or changed. The modular portfolio of use cases, implemented based on a modular, orchestrated approach using SaaS, PaaS and IaaS models, helps replace large initial investments with smaller outcome-driven investments that can be directly related to the business use cases and associated KPIs.

Actions:

- Build up combined business and technology skills by creating fusion teams consisting of IT, OT, ET and other business stakeholders dependent on the scope of use cases and business outcomes to be achieved.
- Ensure that platform providers (such as, IoT, low-code or ICP platforms) or systems integrators who act as your single point of contact or a trusted advisor, not only provide a composable HA portfolio for their own offerings, but also integrate them with their partners' solutions and go-to-market strategies in a composable manner.
- Avoid large initial investments in foundational data backbone infrastructure by prioritizing infrastructure implementation partners that offer IaaS services so that the foundational backbone can grow stepwise with HA rollouts to additional sites and the new functionality being implemented. This will facilitate investment justification and getting buy-in from business stakeholders.

Further Reading:

- Predicts 2023: Composable Applications Accelerate Business Innovation
- Product Leaders Must Deliver Composable, Best-of-Breed Manufacturing Solutions Win
- More Business in Manufacturing With Composable Hyperautomation Capabilities

- 10 Industrie 4.0 Hyperautomation Examples in Life Science Manufacturing

Digital Thread-Enabled Circularity

Analysis by Sohard Aggarwal, Lillian-Oyen Ustad

SPA: By 2027, end-to-end digital thread adoption among manufacturers will nearly double from 12% in 2023, thereby accelerating the shift toward a circular product portfolio.

Description: A digital thread is a connected data-driven framework used to collect, visualize and analyze information and make decisions. I t connects different enterprise systems and applications used across value streams to improve the “why” and “how” of the decisions that are made across a product’s life cycle, including design, production, service and consumption. With access to product usage/service information, manufacturers can not only unlock *n*-tiered traceability (for themselves, regulators and customers), but also improve the prediction of recycling/reharvesting/reuse potential of products for economic benefit, thereby enabling a circular economy.

Why Trending:

- Nearly 80% of a product’s environmental impact is determined during the initial design phase. [1] Manufacturers are increasingly adopting circular economy principles to reduce the intensity of the environmental impact of their operations and address other complex impacts, including Scope 3, biodiversity and circularity. This further accelerates their ability to build products that are sustainably designed, sourced, delivered and recycled.

- In their journey toward sustainable design and circularity, manufacturers are adopting digital threads to connect, trace and visualize product life cycles from cradle to grave. Digital-thread-enabled traceability allows organizations to quickly adapt to meet compliance and regulatory requirements, accelerate customer-centric innovation without compromising product integrity, gather usage information to extend product life and orchestrate ecosystem partnerships.

- Proposed regulations and agreements, [2] including the EU's digital product passport (DPP) initiative, require manufacturers to provide a digital record that shares product information, in particular the traceability of the product and its components across the value chain, including provenance, carbon footprint and end-of-life management. [3] Starting in 2030, all products sold in the EU will be required to have a DPP for the finished goods, inclusive of all individual components. The data stored in the DPP will be updated throughout the product's life, enhancing its usability in circular economy activities, including service and remanufacturing of its materials.

Implications:

- By enabling traceability, manufacturers will gain consistent information across life cycle phases, which can be used to define, track and refine their sustainable product design roadmaps. This will further support them in visualizing complex value chains, delivering data-driven decision intelligence, improving resource efficiency and enabling new business models.
- New projects, such as the EU-funded CircThread, will emerge to focus on data and information management geared toward supporting the circular economy. More specifically, the project supports decision-making processes by promoting access to existing data and sharing information across the products' life cycle. The overall goal is to create data links between the product, value, asset and life cycle chains. To help drive forward this type of approach, the EU is running a project called "A circular view of a product's life cycle" with 36 participants from across the region. [4]
- To implement comprehensive digital threads for sustainability, organizations will need to emphasize product development processes that promote product circularity. This will require manufacturers to leverage technologies, such as PLM and life cycle analysis, to improve design and sourcing decisions that mitigate the environmental impact. The data generated and validated in this process must be shared across OEMs, co-manufacturers, suppliers and customer data ecosystems, which poses a challenge in the adoption of digital threads for product circularity.

Actions:

- Familiarize yourself with the concepts and technologies required to build a digital thread. A digital thread requires multiple applications like PLM, MES or ERP to share product-centric data in a continuous feedback loop.

- Build a comprehensive digital thread adoption strategy by taking into account the organization's sustainability objectives. Take a step-by-step approach, starting with product design, then extend to production, after-sales, service and end-of-life management. If you have already started this process, validate whether this is enabling the organization's sustainability strategy.
- Incorporate circular economy principles in each of the product life cycle phases by formulating the impact on enterprise outcomes related to innovation, sustainability and digital business.

Further Reading:

- Innovation Insight: Implement Digital Threads for Long-Term Flexible Access to Critical Data
- How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread
- Leverage Digital Initiatives to Enable Sustainability in Manufacturing Organizations

Emerging

GenAI in R&D/Engineering

Analysis by Marc Halpern, Sudip Pattanayak, Alexander Hoeppe

SPA: By 2027, GenAI will produce and optimize design contents such as systems, 3D and simulation models for more than 33% of new product and asset designs compared with less than 5% of the content in products and assets designed in 2023.

Description:

Gartner defines GenAI as technologies that "can generate new derived versions of content, strategies, designs and methods by learning from large repositories of original source content" (see Emerging Tech: Generative AI Adoption Trends and Future Opportunities). GenAI has profound impacts on the business, including content discovery, creation, authenticity and regulations; automation of human work; and the customer and employee experience.

In R&D and engineering practice, GenAI combined with product design applications enables automatic creation of designs that advance the development of new products, recipes and formulas, and assets by learning from prior designs. For example, GenAI can produce computer-aided design models of the parts used in consumer and industrial products. Increasingly, GenAI is learning from prototype tests to automate decisions about material selection, part sizing, and the creation of shapes and surfaces. The technology is expected to be applied to generate product and system requirements and specifications.

Why Trending:

- Computational design technology and GenAI knowledge in R&D and engineering have evolved beyond the point where GenAI can be used to deliver commercially viable applications. The success and widespread use of applications such as ChatGPT are well-known examples of commercially viable GenAI in other industry segments and value streams.
- R&D leaders seek the means to increase the productivity of engineers and designers. GenAI provides a means of leveraging the implicit and explicit knowledge locked in existing databases and product-centric applications of design content.
- The growing complexity of product requirements spanning functionality, regulations, safety and cost sensitivity makes product development increasingly time-consuming. At times, the outcomes do not meet the quality standards
- GenAI complements the lack of skills in product development teams at a relatively low cost to employers once GenAI applications have been validated.

Implications:

- Increasingly, GenAI will replace humans to produce design content — particularly if the design content requires optimization-based engineering. Such an optimization process can be time-consuming and may need specialized skills.
- Concerns among designers and design engineers about GenAI replacing their jobs will grow, however. GenAI models will always need adversarial machine learning (ML) frameworks, which can only be sustained with contents generated by human experts.
- GenAI capabilities and safeguards will proliferate and increasingly become important criteria for selecting design and engineering technology partners.

- Risks and accusations of intellectual property (IP) infringement from new designs may increase, since GenAI depends on learning from existing sources of content created from the IP of existing designs.

- The quality of GenAI's R&D and design recommendations will initially be suspect until users gain confidence in GenAI.

Actions:

- Identify which design and engineering activities will be most impacted by GenAI. Determine how R&D and design processes themselves will evolve and impact design and engineering roles and responsibilities. Therefore, define alternative roles and invest in appropriate training for designers and engineers whose jobs are impacted by GenAI in order to retain their knowledge and skills.

- Analyze your existing technology providers, your engineering and design application portfolio, and potential areas where GenAI capabilities can be deployed as a baseline to build out GenAI roadmaps. When selecting GenAI partners, involve legal and regulatory teams to evaluate their AI practices for their ethics, and be aware of usage and exposure to third-party IP that they might use to minimize potential GenAI legal risks.

- Establish a pilot program for GenAI applications that evaluates the functionality of the technology, the appropriateness of the use cases and the validity of GenAI output on an ongoing basis.

Further Reading:

- Innovation Guide for Generative AI Technologies

- Use-Case Prism: Generative AI for Manufacturing

- Hype Cycle for Advanced Technologies for Manufacturers, 2023

AI-Enhanced Configuration Life Cycle Management

Analysis by Christian Hestermann, Alexander Hoeppe

SPA: By 2027, 50% of manufacturers will use AI technologies to make their life cycle management applicable to more than just the product's configuration, up from less than 5% in 2023.

Description:

AI-enhanced configuration life cycle management (AI-CLM) is an evolution from traditional CLM. It comprises a system-of-systems configuration that employs systems engineering techniques to define and execute configurations of products, internal, as well as outsourced manufacturing processes and sales and service options, in connected and orchestrated ways. CLM and PLM are closely related in terms of hardware configuration rules to predefine technically feasible and saleable, but also cost-optimized, products and proposed time-to-customer dates, even for complex variants. Technically feasible variants not only relate to all form-fit function capabilities related to engineering, manufacturing and production BOMs, but also associated software BOMs and ALM that are often tightly coupled with system variants and systems engineering rules.

CLM uses an integrated product architecture with centralized and integrated mechanisms, such as rule engines, and complements them with AI capabilities. AI-CLM enables the configuration of technically feasible and commercially viable product variants and saleable/serviceable variants. It supports and optimizes simulations of production scheduling to predict the time to customer, and controls the joint delivery of products across the entire supply chain and manufacturing process. Especially in early product design activities, GenAI will help to describe and interpret product and variant requirements, and 3D visual configurations.

Why Trending:

Manufacturers are striving to maximize market coverage and customer engagement with products that take optimal advantage of the R&D investments they make and can be produced and serviced cost-efficiently in alignment with the individual needs of customers. It is most relevant to industrial manufacturers in engineer-to-order businesses selling customized machinery. However, managing the exponential growth of variants and the resulting differences in manufacturing processes and sourcing options has been expensive and lengthy. AI- and ML-based mechanisms will be instrumental to master the multiplicity, identify the more-profitable product and production variants, and provide the necessary data and information to internal and external manufacturing facilities. AI-based CLM, therefore, helps industrial engineer-to-order (ETO) manufacturers increase the configure-to-order (CTO) proportion of their products.

A typical motivation to move toward CTO is to improve customer experience. Discrete manufacturers aim to predefine more product variants while they want to maximize the reuse of components and predict the costs and time to the customer, even for complex product variants. Jaguar Land Rover introduced Configit's CLM solution to minimize production risks. [5] Another example is Wärtsilä, a Finnish manufacturer of service power units and other equipment in the marine and energy markets. It has worked on several projects since 2009 with Modular Management to shorten lead times, better fit customer needs and provide high-quality, accurately validated solutions; a faster introduction of new features; and easier upgrades and conversions. [2]

Implications:

Customers in different markets want a common category of product, but configured with different features. CLM satisfies that preference by making complex CTO and ETO businesses more scalable and enhancing the reusability of R&D investments. It enhances R&D leverage through reusability, because it accelerates the standardization of product modules and manufacturing processes, supply chain processes (procurement and logistics), and service operations. These benefits align with the manufacturing trend toward composability and mass customization and enhance customer loyalty.

Traditional CLM approaches still require a high amount of manual work, coordination, data management and alignment among sales, engineering, manufacturing and service. Enhancing CLM by AI tools increases scalability and shortens the time needed from order to delivery. Modularized product architecture based on systems engineering already helps to reduce ETO needs, but AI/ML further reduces the time to delivery for individual customers for products and services. The impact of AI and GenAI, as well as the need to integrate heterogeneous data sources to aggregate siloed data from heterogeneous applications, make it necessary for the CIO to play a coordinating role in the introduction of AI-enhanced CLM. [6]

Actions:

- Organize customers' product requirements from different target markets into a unified structure. The resulting modular, model-based product architecture makes fulfilling customer demand faster and less expensive than designing individual products. Apply MBSE approaches to defining product configurations, and enhance them with GenAI technologies and 3D visual configuration for immediate visualization.

- Build or acquire the necessary skills and resources to effectively apply AI, ML and GenAI technologies to CLM. Partner with internal and external stakeholders, including sales, marketing and manufacturing roles; suppliers; and customers to build the system architecture of product platforms and to define the processes of working with those platforms. Use AI/ML technologies to improve the scalability and performance of these platforms beyond more-traditional collaboration mechanisms.
- Cultivate composable thinking through education focused on composability concepts, modified KPIs for the business and modified job performance metrics that align with composability concepts.

Further Reading:

- Hype Cycle for Advanced Technologies for Manufacturers, 2023
- Market Guide for Composable Product Configurators
- Use-Case Prism: Generative AI for Manufacturing

Machine Customers

Analysis by Jonathan Davenport, Don Scheibenreif

SPA: By 2028, industrial manufacturers that adopt machine customers will utilize these capabilities for 30% of their maintenance and part procurement activities, up from less than 1% in 2023.

Description:

Machine customers are nonhuman economic actors that obtain goods or services in exchange for payment. In the context of industrial manufacturing, machine customers are cloud-based and use data from IoT-enabled factory equipment to autonomously negotiate with external third parties to either place its own orders/service requests or intelligently order the replenishment of consumables and possibly services, such as insurance or repairs.

Why Trending:

- Machine customers provide the potential for condition-based maintenance systems to move to the next level, where the manufacturer can empower the equipment itself to request support — even reaching out to third-party providers to source parts and servicing.
- The capability to positively impact uptime that machine customers bring is important to industrial manufacturers because of the very high cost of stopping operations. For example, when paper pulp production halts, this can cost up to $100,000 per hour, [7] whereas costs for each hour of unplanned downtime can reach $2 million per hour in automotive. [8] The machine customer is taking on the tasks of keeping the line operating — and is not subject to human fatigue or mistakes.
- According to the Gartner IoT forecast, there was an installed base of 380 million connected IoT endpoints at the end of 2023, which will more than double to 783 million by 2028 (see Forecast: Internet of Things, Endpoints and Communications, Worldwide, 2021-2032, 4Q23 Update). Although not all asset types fulfill the technical and economical requirements to become machine customers and this is a disruptive trend that requires a smooth transformation process, the potential to increase productivity and to reduce downtime is huge.

Implications:

For CIOs working for companies that have industrial manufacturing activities, it will be important to be aware that:

- Machine customers represent a natural evolution of existing trends related to predictive and proactive maintenance. But the requirements for an AI-enabled system to analyze data and make informed procurement decisions means that IT will play a central role in enabling outcomes delivered by OT.
- The cloud-based machine customers that manufacturers either build themselves or source from a vendor need to collect IoT data from machines and equipment on the shop floor and interpret the data to make better and faster operational decisions than their human counterparts.
- Machine customers will need to think beyond the needs of a single piece of equipment and weigh up when a maintenance event can be added to a planned maintenance schedule versus when more-urgent repairs need to be scheduled. For machine customers to fully leverage their AI-enabled autonomous decision-making capabilities, enterprise asset management (EAM) and MES will need to be integrated, something that not many companies have been able to achieve.

- The costs of downtime mean that it will be vital for the machine customer to explain the rationale behind its decisions, especially during the early stages of adoption, where some colleagues might be skeptical about the system's capabilities.
- The machine customer will need to be given its own procurement budget/approvals to undertake the negotiation for the parts and maintenance services that its equipment requires.

Italy-based iProd created the Manufacturing Optimization Platform(MOP) — the first platform that can accommodate the requests of machine customers located in a manufacturing environment. The platform allows the machine to automatically purchase what it needs from its manufacturer or the iProd IoT Marketplace. Purchases are based on the production plans assigned to the asset and controlled by the iProd platform, when it is equipped with an electronic system, such as a PLC, CNC or digital sensors, and interconnected to the IoT Tablet. [9]

Actions:

- Build a business case for investment in machine customers by documenting the reduction in operational time and effort required for monitoring the health of production equipment when sourcing the necessary maintenance (including the procurement activity, if appropriate).
- Facilitate the communication between the cloud-based machine customer and other stakeholders (equipment and humans) by building APIs and data platforms to enable the ingestion of data from machines on the shop floor and communication with product and service providers (both internal and external).
- Prove the strength of the machine customer's decision-making process by ensuring that the delivered outcomes are documented in an explainable operational audit of work orders and interruptions.

Further Reading:

- Top Strategic Technology Trends for 2024: Machine Customers
- CIOs Can Maximize Product Lifetime Value by Embracing Machine Customers
- Supply Chain Executive Report: Designing a Digital Supply Chain to Respond to Autonomous Machine Customers
- How the Emergence of Machine Customers Will Impact Your Supply Chain

Industrial Metaverse

Analysis by Sohard Aggarwal, Alexander Hoeppe

SPA: By 2027, about 25% of manufacturing frontline workforce training will be delivered in an industrial metaverse-based environment, up from less than 1% today.

Description: The industrial metaverse is a collective virtual 3D shared space created by the convergence of the physical and digital worlds for industrial applications. People, machines and systems are able to interact with each other to design, validate, simulate, build and optimize processes spanning the manufacturing value chain in an immersive environment.

By leveraging technologies such as augmented reality (AR), virtual reality (VR), digital twins, spatial computing, collaboration tools and many others, it creates a digital representation of the industrial environment, including processes, human-machine interactions, workflows and assets for simulation, analysis and execution to drive operational efficiency.

Why Trending:

The industrial metaverse as a concept is both commonly understood and, at the same time, variously interpreted. However, it is gradually gaining traction in production and supply chain domains, where it simulates the complex processes in production plants and can be useful for testing new products and services, technologies, platforms and upskilling of the industrial workforce. The future vision also comprises interoperability among internal and external entities (business partners and suppliers), which would allow for complex immersive experiences in high-resolution photorealistic 3D representations.

Manufacturers have already invested in building digital ecosystems that can help them monitor processes/assets and enhance collaboration and autonomous manufacturing. But given the heterogeneous and complex nature of the manufacturing industry, those implementations lack a key aspect — interoperability. The industrial metaverse enables interoperability among systems, humans and assets, and allows manufacturers to have workflows transcending organizational silos while creating opportunities for visualization, collaboration and optimization that can be further exploited for economic benefit. Manufacturers can leverage existing tools and technologies while deploying novel ways of production system configuration, advanced simulation and continuous improvement.

Some of the examples include:

- Renault Group is optimizing inventory, reducing lead time and carbon footprint. [10]
- FREYR is scaling battery manufacturing using industrial metaverse. [11]
- BMW Group is improving the speed, precision and efficiency of the planning process. [12]
- Linde Virtual Academy for immersive workforce training. [13]

Implications:

- Design and production engineers are enabled to collaborate immersively in real time, run complex simulations, and preserve engineering knowledge and workflows digitally, thereby reducing development time.
- Data from IT (transactional), OT (sensors and supervisory control and data acquisition [SCADA]) and ET (PLM; product data management; computer-aided design, engineering and manufacturing; and MES) systems can be mined for operational insights, enabling predictive maintenance, process optimization, supply chain collaboration, optimizing and driving new value from physical systems.
- Immersive virtual training can be delivered to improve collaboration and enhance knowledge sharing among hybrid teams.
- Operational safety risks and accidents can be reduced as a result of better incident management strategies that can be refined by simulating complex human-machine interaction scenarios.

- In combination with AI, the industrial metaverse has huge optimization potential across all value-generating processes — such as PLM, CRM, supply chain management or EAM.

Actions:

- Create an enterprise strategy, and ensure that vendors and emergent metaverse technology comply with these ambitions. The vision of a mature and fully interoperable metaverse is more than 10 years out, and it is still too early to determine which investments will pay off. Part of this strategy should be a formal evaluation mechanism to explore opportunities, and rate them on expected business value and feasibility scale.
- Invest in your IT/OT/ET landscape to identify which metaverse-enabling technologies could be leveraged for those outcomes. For example, how the value of AR/VR/extended reality (XR) investments can be enhanced by creating immersive training environments, or how digital twins can be merged with other digital twins or extended to execute real-time workflows.
- Follow a composable — if possible, as-a-service-based — approach, as most of these technologies are still evolving and should, therefore, be implemented step by step with modular use-case-based functional expansion. The industrial metaverse will require the processing of large data volumes, and performance is a critical success factor for end-user acceptance. Investment in hardware and infrastructure (distributed, in-memory, quantum computing and 5G/6G) is a must.

Further Reading:

- Hype Cycle for Advanced Technologies for Manufacturers, 2023
- Cool Vendors in Metaverse and Immersive Experiences
- Quick Answer: What Is a Metaverse?

Evidence

2022 Gartner Frontline Workers Experience Reinvented. This survey was conducted to identify the employee value proposition elements that best attract, support, engage and retain frontline workers. In addition, the survey sought to determine whether they also improve business performance and discover how digitalization and automation efforts at the front line relate to positive outcomes in employee experience and business performance. The survey was conducted online from July through August 2022 among 405 respondents from North America (n = 155 in the U.S. and Canada), Europe (n = 136 in Germany and the U.K.), Latin America (n = 60 in Brazil) and Asia/Pacific (n = 54 in India). Respondents' organizations had $100 million or more in 2021 enterprisewide annual revenue and 1,000 or more employees. Industries surveyed included healthcare providers, high tech (IT), manufacturing, retail, energy, transportation, telecom, utilities, supply chain or distribution, healthcare life sciences, and services.Respondents were required to be first-line managers or higher, with a minimum of six frontline workers directly reporting to them. Managers of teams must be in a specific physical location (on-site) or in field service (proximity to perform their work). Disclaimer: The results of this survey do not represent global findings or the market as a whole, but reflect the sentiments of the respondents and companies surveyed.

[1] An Introduction to Circular Design, Ellen MacArthur Foundation.

[2] Commission Welcomes Provisional Agreement for More Sustainable, Repairable and Circular Products, European Commission.

[3] Circular Economy Action Plan, European Commission, Environment.

[4] Building the Digital Thread for Circular Economy Product, Resource & Service Management, European Commission, Cordis EU Research Results.

[5] Case: Jaguar Land Rover — CLM Helps Jaguar Land Rover Minimize Production Risks - Configit, Alex Crawford, Director of Engineering Operations from Jaguar Land Rover.

[6] Modularisation hand in hand with manufacturability, Wärtsilä.

[7] 5 New Ways to Reduce Costs for Pulp Mills Operations, PaperFirst.

[8] The True Cost of Downtime 2022, Siemens.

[9] We Help Your Company Reduce Costs and Production Process Times, iProd.

[10] Renault Group Launches the First Industrial Metaverse, Renault Group.

[11] FREYR to Scale Battery Cell Gigafactory Production With Siemens Xcelerator, Siemens.

[12] BMW Group and NVIDIA Take Virtual Factory Planning to the Next Level, BMW Group.

[13] The New Digital Transformation Era of Industrial Plants, Linde Virtual Academy.

Document Revision History

Top Strategic Technology Trends in Asset-Intensive Manufacturing for 2023 - 31 March 2023

Table 1: Trend Profiles

Improving	Growing	Emerging
IT/OT/ET Application Life Cycle Management	Industry Cloud Platforms	GenAI in R&D/Engineering
Industrial Software Bills of Material	Composable Hyperautomation	AI-Enhanced Configuration Life Cycle Management
Augmented Connected Workforce	Digital Thread- Enabled Circularity	Machine Customers
		Industrial Metaverse

Source: Gartner (January 2024)

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