Hype Cycle for Advanced Technologies for Manufacturers, 2023

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Initiatives: Manufacturing General IT Initiatives; Supply Chain Technology Strategy and Selection

Manufacturing CIOs have key opportunities to increase productivity, improve quality and drive innovation through evolving IT, thereby gaining competitiveness. This Hype Cycle analyzes the value, maturity and priorities to capitalize on those opportunities.

Analysis

What You Need to Know

This Hype Cycle helps CIOs gather relevant information that supports their intentions to stay at the forefront of product and manufacturing innovation. It merges content from two prior Hype Cycles — the Hype Cycle for Manufacturing Digital Transformation and Innovation and The Hype Cycle for Manufacturing Digital Optimization and Modernization. As manufacturers strive to increase operational excellence and employee productivity, the IT infrastructure advances presented on the prior Hype Cycles are fundamental to the insights, predictive capabilities and productivity enhancements presented on this 2023 Hype Cycle. One-third of the technologies on this Hype Cycle are poised for mainstream adoption over the next two to five years. The remaining two-thirds of innovations will have a high impact, if not transformational impact, on manufacturing over the next 10 years. Manufacturers that are not investing today will be competitively challenged.

The Hype Cycle

Operational excellence, revenue growth, employee productivity and customer experience are among the most common objectives driving technology investments among manufacturing CIOs, according to the 2023 Gartner CIO and Technology Executive Survey. [1] All of the technologies on this Hype Cycle support these objectives. Individual analysis of the innovations describe the drivers and obstacles further.

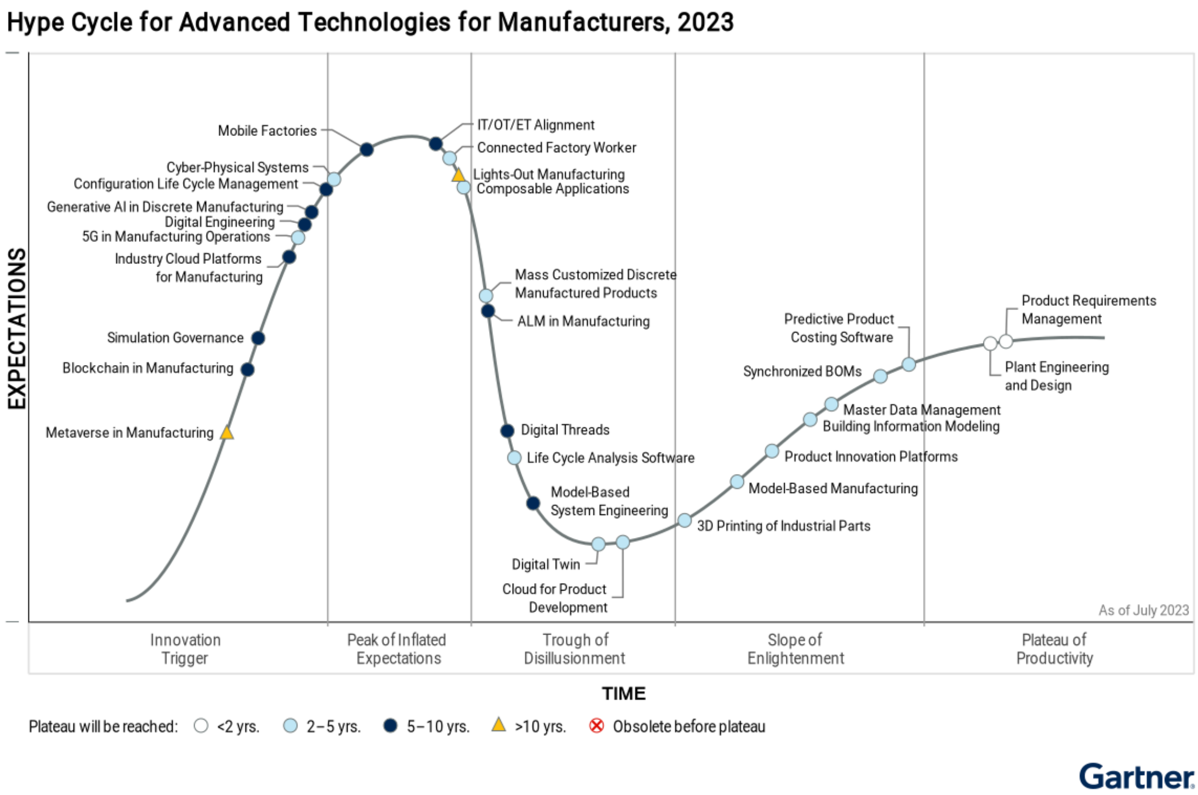
Notably, plant engineering and design, synchronized BOMs, product innovation platforms, and model-based manufacturing will move into the mainstream markets over the next two to five years as adoption continues to grow. Therefore, CIOs have the greatest urgency to adopt these.

Digital twins, model-based system engineering, digital threads, mass customized discrete manufactured products, simulation governance and composable applications significantly enhance all five objectives above. However, CIOs must cultivate partnerships between business leaders and the IT organization to identify best practices to implement these as those practices still evolve.

Major technology trends augment the value of the innovations described above and underpin innovations presented on this Hype Cycle. Although the major trends listed below are not explicitly discussed in this research, the innovations presented in this report would be impossible without these technology trends:

- Rebalancing cloud platforms and edge computing — Innovations such as cloud for product development, industry cloud platforms in manufacturing and 5G in manufacturing operations transform the nature of product development and manufacturing operations software. Cloud platforms enable product innovation platforms, digital threads and digital twins. Cloud platforms also enable connected factory workers.
- Industrial Internet of Things (IIoT) — IIoT and edge computing enable IT/OT/ET alignment, digital twins and digital threads. IIoT and edge computing supported by cloud platforms enable the communication of data from systems, factory equipment and products that enable new business operations.
- Artificial intelligence (AI) — AI (both generative AI and nongenerative AI) contribute to lights-out manufacturing, mobile factories, cyber-physical systems, generative AI in discrete manufacturing and simulation governance.

Figure 1: Hype Cycle for Advanced Technologies for Manufacturers, 2023



The Priority Matrix

The Priority Matrix summarizes business impact versus priority to adopt for opportunities on the Hype Cycle. The opportunities closest to the upper-left corner of the matrix have the highest priority — particularly if competitors have already enabled the opportunity. This Priority Matrix indicates that product requirements management and plant engineering and design have high benefits and less than two years before mainstream adoption. Among these two opportunities, manufacturers have the broadest need for product requirements management, so CIOs should give it the highest priority.

Transformation opportunities going mainstream in two to five years include 5G in manufacturing operations, connected factory worker, cyber-physical systems, digital twin and mass customized discrete manufactured products. Among these opportunities, digital twins have the highest visibility among manufacturing clients based on the number of inquiries with Gartner analysts. Digital threads are also important to enable digital twins. CIOs should begin planning immediately by understanding how digital twins and digital threads can benefit their businesses and by creating a roadmap to implement them.

Cloud continues to advance among manufacturers and have a major impact in product development, becoming mainstream within five years. Industry cloud platforms for manufacturing will have transformational impact and achieve mainstream adoption within 10 years. Therefore, it is imperative for CIOs to be acting on a cloud strategy now.

Table 1: Priority Matrix for Advanced Technologies for Manufacturers, 2023

(Enlarged table in Appendix)

Benefit	*Years to Mainstream Adoption*			
↓	***Less Than 2 Years*** ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
Transformational		5G in Manufacturing Operations Connected Factory Worker Cyber-Physical Systems Digital Twin Mass Customized Discrete Manufactured Products	Blockchain in Manufacturing Configuration Life Cycle Management Digital Engineering Generative AI in Discrete Manufacturing Industry Cloud Platforms for Manufacturing Mobile Factories Model-Based System Engineering	Lights-Out Manufacturing Metaverse in Manufacturing
High	Plant Engineering and Design Product Requirements Management	Building Information Modeling Cloud for Product Development Composable Applications Master Data Management Model-Based Manufacturing Predictive Product Costing Software Product Innovation Platforms Synchronized BOMs	ALM in Manufacturing Digital Threads IT/OT/ET Alignment Simulation Governance	
Moderate		3D Printing of Industrial Parts Life Cycle Analysis Software		
Low				

Source: Gartner (July 2023)

On the Rise

Metaverse in Manufacturing

Analysis By: Sohard Aggarwal

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Embryonic

Definition:

Gartner defines a metaverse as a collective virtual 3D shared space, created by the convergence of virtually enhanced physical and digital reality. A metaverse is persistent, providing enhanced immersive experiences. It will generate multiple opportunities across the manufacturing value chain including new ways of collaboration, productivity, product and service innovation, and hyperpersonal customer experience.

Why This Is Important

Four key innovations driving the development of metaverse in manufacturing are Web3, spatial computing, digital twins (of things and people) and enabling new ways of collaboration and interactions. The convergence of the physical and digital world will allow manufacturers to accelerate innovation, create agile supply chains, improve competitiveness, and deliver products and services that enable new channels of customer engagement, hyperpersonal experiences, and mass customization.

Business Impact

Manufacturers will expand and enhance manufacturing businesses in unprecedented ways, opening up innovative opportunities. Emerging categories of opportunities include:

- Shared experiences to improve employee experience/collaboration productivity and skills.
- Immersive training, remote assistance and product development.
- Customer service and task automation via digital humans.
- Virtual spaces — for live virtual events/product launches.
- Digital revenue through e-commerce and asset tokenization (non-fungible tokens [NFTs]).

Drivers

- **Demand for digital manufacturing operations:** Manufacturers are building digital capabilities to transform their manufacturing operations, product innovation and customer experiences. Immersive technologies such as head-mounted displays, AR/VR/MR and 3D are already reshaping the manufacturing industry and will be an integral part of the future of digital manufacturing.

- **Hybrid workforce enablement**: With the rise of hybrid workforce, manufacturers are seeking digital workspaces that improve employee engagement, productivity and collaboration. Metaverse will enable manufacturers to leverage immersive technologies to achieve this goal, for example, BMW Group and Hyundai Motor. They can even provide employee training and deliver support to remote frontline workers, technicians and field service agents in real time (for example, Jetblue's partnership with Strivr Labs).

- **Immersive customer experience:** Emerging metaverse solutions are making it possible to deliver engaging customer experiences and to earn digital revenue. Gen Z's leverage of gaming, mobile devices and social media is also increasingly shifting behavior toward hyperpersonal immersive digital experiences (examples include Louis Vuitton's LOUIS THE GAME and Gucci Garden).

- **Digital business enablement and revenue creation:** Manufacturers will be able to use metaverse as an additional channel to meet customers' demand from e-commerce and direct-to-consumer (D2C) platforms (examples include United Colors of Benetton and Inditex Group [Pull&Bear]). They can further leverage blockchain-based asset tokenization (NFTs) to drive digital revenue (examples include Mattel [Hot Wheels], McLaren Racing and ASICS).

Obstacles

- **Metaverse is still fragmented and indiscernible:** Emerging solutions provide device-dependent, siloed experiences and limited functionality. Gartner expects that a complete metaverse will take eight to 10 years to emerge. Interoperability, persistence, decentralization and collaborativeness are key attributes of a complete metaverse.

- **Data and cybersecurity risks**: An avalanche of data would require manufacturers to proactively incorporate standards to protect the user information, identify or avoid deepfake/hacked avatars, monitor and report data breaches/cyberattacks, and meet regulatory requirements.

- **Digital maturity:** As manufacturers already manage a complex web of IT, OT and ET technologies, any new technology or solution must integrate with these existing technologies while enabling individual use cases. The subverticals or even individual organizations have different levels of digital maturity which may inhibit adoption.

User Recommendations

- Create a tiger team to identify metaverse-inspired opportunities and build an execution roadmap by evaluating current high-value use cases around digital business or new product/service introduction.
- Evaluate investment in enabling technologies and assess the impact of their deployment on the existing IT/ET/OT ecosystem. Business leaders are advised to proceed with caution since a complete metaverse does not exist yet.
- Since many metaverse-enabling technologies are emerging, creating newer interfaces and need for higher governance develop technology strategies to leverage the built-in infrastructure and participants of the metaverse.
- Build the visibility and interoperability of data and data sources by aggregating data from processes, machines, systems and real-time data sources. Then implement interoperability protocols for connecting, contextualizing and visualizing data across the value streams to support use cases identified earlier.

Sample Vendors

Animoca Brands (The Sandbox); Decentraland; Linden Lab; Meta; Microsoft; NVIDIA; Roblox; Siemens

Gartner Recommended Reading

Quick Answer: What Is a Metaverse?

Top Strategic Technology Trends for 2023: Metaverse

Quick Answer: What Are the Five Essential Attributes of an Emerging Metaverse?

Top Strategic Technology Trends in Consumer Goods Manufacturing for 2023

Blockchain in Manufacturing

Analysis By: Sohard Aggarwal

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Blockchain is a distributed, write-only ledger that consists of cryptographically signed, irrevocable blocks of records (transactions or digital interactions) that can be shared by all participants, like manufacturers, suppliers, customers, service providers, involved in the manufacturing value chain. Each block contains a time stamp and reference links to previous data blocks. Anyone with access rights can historically trace a state change in data or an event belonging to any participant.

Why This Is Important

Value perception of blockchain technology has shifted over the years. Manufacturers are leveraging blockchain to enable transparency, improve trust and generate digital revenue models. Several use cases include:

- Track and trace in the supply chain (auditability of counterfeit parts and goods)
- Tokenized supply chain financing and asset fractionalization
- Managing and executing smart contracts
- Payment or trade finance
- Improvement of warranty management
- Maintenance of records and worker certification

Business Impact

Blockchain brings benefits to manufacturers such as:

- Authenticates product provenance by making traceability in ingredients, parts, labeling, formulas, etc., more transparent.
- Adds a layer of governance, security and process discipline to the end-to-end manufacturing ecosystem.

- Encrypts data to securely automate workflows, such as handling contracts, payments, trading and warranties, and can protect customer information during these exchanges.
- Enables tokenization, digital asset creation and management in web 2.0, 3.0 and metaverse contexts.

Drivers

- **Demand for transparency:** Consumers are increasingly adopting brands that provide transparency in their sourcing, manufacturing practices and environmental impact. Deploying a blockchain-based tracking mechanism increases consumer trust, and simplifies regulatory data capture and independent data sharing to users, increasing trust and confidence. Anheuser-Busch InBev trials blockchain to enable barley to beer traceability for consumers.
- **Adoption of Internet of Things (IoT) and digital twins:** IoT and blockchain configuration can be leveraged to track the origin and physical movement, while digital twins can monitor things and related events, generating new revenue opportunities, cutting costs, and improving trust among participants and customers. For example, Unilever U.K. uses AI, IoT and blockchain to monitor the palm oil supply chain.
- **Automation and Efficiency:** Blockchain-enabled smart contracts create a mechanism for transparency, visibility and consistency. Manufacturers can improve efficiencies by automating the adjudication of preapproved contract terms and reducing transaction times.
- **Protection and management of digital and IP rights:** Create a tamper-proof record of intellectual properties(IPs), patents and trademarks through blockchain to enable the secure exchange of sensitive data with suppliers, contractors and business partners.
- **Sustainability and ESG:** Blockchain offers an opportunity to more effectively measure, track, account for and trade sustainability credits/offsets and greenhouse gas impact to improve governance and access to financing. See more in Infographic: Blockchain Use Case Prism for Sustainability and ESG.
- **Digital business opportunities:** Leverage blockchain to tokenize physical assets or create digital assets in the form of NFTs. They can be sold, bought or traded earning digital revenue for manufacturers while creating new avenues of customer engagement.

For more information, see Blockchain Is Transforming Business — What's Your Strategy?

Obstacles

- Manufacturers share and manage sensitive data from suppliers and customers. Moving over authority from a centrally controlled institution to multiparty consortia can be deeply unsettling, even for organizations that have undergone significant digital transformation.
- The underlying platform required for scalability must evolve to become more efficient while preserving transaction security and data confidentiality.
- Integration with legacy applications and platforms in manufacturing will be difficult due to complexity and lack of blockchain maturity.
- Agreement on data structures and algorithms that can be scaled across heterogenous manufacturing systems and multiple participants is a challenge.

User Recommendations

- Prepare for the blockchain by continuing to tighten up on standards and requirements as they relate to product sourcing, manufacturing, assembly, distribution, storage and payment.
- Identify the unique points of value and risk in your value chain, engage cross-functionally within your organization, and map these points to known industry pilots to assist in building the business case.
- Assess the value and impact by identifying the key cost drivers and the integration of other technologies like IoT sensors, advanced analytics and AI needed to deploy alongside the blockchain technology.
- Leverage blockchain to securely manage and distribute data, use and properly account for product design, and protect intellectual property rights and product specifications.
- Adopt open-source infrastructure technology with multiple independent implementations to minimize any proprietary blockchain infrastructure technology and/or vendor lock-in.

Sample Vendors

Amazon Web Services (AWS); IBM; IOTA Foundation; NTT Data; Fujitsu; Ethereum.org; Avalanche.org; Hyperledger Foundation; Provenance Blockchain Foundation

Gartner Recommended Reading

Guidance for Blockchain Solution Adoption

Improve Sustainability With AI, IoT and Blockchain

How to Choose a Blockchain Consortium for Digital Business Collaboration and Acceleration

How to Leverage Blockchain and Prepare for Data Monetization in Manufacturing

The Future of Blockchain: 8 Scalability Hurdles to Enterprise Adoption

Simulation Governance

Analysis By: Marc Halpern

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Simulation governance is a discipline supported by analytical software that is focused on ensuring that simulation models are built in the best possible way by the right people, using the right tools and processes. The reliability of information generated by simulation activities is interpreted correctly to make valid decisions.

Why This Is Important

Simulation governance seeks to maximize the trustworthiness of simulation models and results as adopting simulation increases. Ambitions for simulation include:

- Replacing more prototype testing with simulation, which can only happen if simulation is trusted more.
- Guiding technical and business decisions with digital twins.
- Capturing lessons learned, and creating and reusing knowledge through simulation.

Business Impact

Simulation governance discipline delivers benefits of simulation more reliably, such as:

- Less time to complete designs due to simulation guidance.
- Fewer physical prototype tests needed because simulation can be trusted more.
- Lower product development costs because simulation reduces physical prototyping and testing.
- Increased capture of design, engineering and manufacturing knowledge for reuse.
- Facilitates transfer of design, engineering and manufacturing knowledge for reuse in future similar work.

Drivers

The need for simulation governance is motivated by:

- Documented costly mistakes in industries, such as automotive and aerospace, which could have been avoided if simulation governance was practiced.
- High expectations that businesses have for simulation, which cannot be achieved unless simulation governance principles and practices are adopted to reduce simulation mishaps.

Proper simulation governance encourages:

- Knowledgeable simulation practitioners to use proper discipline and processes to create models that sufficiently capture the technical and business challenges being studied.
- Correct use, understanding and interpretation of computational methods used to simulate systems.
- Capture of knowledge gained from simulations for continual reuse to improve products, processes, business performance and simulation methodology.
- Increased simulation value when using digital twins.
- More reliable use of simulation data to train GenAI.
- Better use of simulations to reduce or replace physical prototype testing.

- Increased simulation use to certify the safety and performance of large, complex and expensive systems such as aircraft, ships, structures, and industrial equipment.

Obstacles

- Senior-level executives do not understand the strategic importance of simulation governance to fulfill the value of their investments in simulation technology.
- There are relatively few experts in computer-based simulation that can advise on the modeling, simulation techniques, and best practices to build effective and workable simulation governance.
- The experts with requisite simulation governance knowledge often do not understand the intricacies of enabling and managing corporate change.

User Recommendations

- Work with simulation stakeholders to educate senior executives on simulation governance and its value.
- Recruit internal simulation stakeholders and specialty consultants to audit simulation use, and engage with business leaders to assess current simulation value.
- Work with specialty technology providers and internal stakeholders to prepare a business case for simulation governance.
- Work with business leaders to align simulation experts to leaders responsible for prototype testing, product quality management, field service and other business operations where simulation can add value.
- Establish a corporate team responsible for simulation governance.
- Invest in industrial Internet of Things (IIoT) and analytics to collect operational and performance data to compare with simulation results.
- Establish IT, operational technology (OT), and engineering technology (ET) alignment and integration for simulation governance.

Sample Vendors

Engineering Software Research and Development; Predict Change

Gartner Recommended Reading

Top Strategic Technology Trends in Asset-Intensive Manufacturing for 2023

Innovation Insight: Why Engineering Technology, IT and OT Are More Than the Sum of Their Parts

21 Lessons From Successful Digital Twin Implementations for Manufacturing

Industry Cloud Platforms for Manufacturing

Analysis By: Alexander Hoeppe, Marc Halpern

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

Industry cloud platforms (ICPs) address industry-relevant business outcomes by combining SaaS, 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 execution of supply chain processes within and beyond their organization’s boundaries.

Why This Is Important

Cloud, software and service providers are launching ICPs by combining SaaS, PaaS and IaaS offerings with industry-specific functionality and composable capabilities to create compelling propositions for customers. Emerging manufacturing ICPs are using innovative approaches like composable packaged business capabilities (PBCs), digital marketplaces, data grids/DataOps and fusion teams to accommodate IT/OT to faster supply chain integration and platform adaptability due to transforming markets.

Business Impact

Broader cloud adoption within manufacturing will require more comprehensive solutions that follow defined manufacturing scenarios, process models and use cases, rather than technology-oriented solutions that enterprises have to largely configure and integrate themselves. Supply chain disruptions, more regulations, and the potential to servitize products to generate new revenue streams require an ecosystem-based approach based on a common platform to collaborate with suppliers and customers.

Drivers

- As the complexities of both business and technology continue to increase, enterprises are looking for more outcome-based engagements with solution providers. However, ICPs must also be flexible enough to be able to allow users to adapt to the changing boundary conditions.
- To be relevant and be able to resonate with enterprise audiences, such usage of ICPs outcomes must be business relevant, specific, measurable and tangible — a goal that is easier achieved when approached with a clear reference to manufacturing use cases.
- Currently, ICPs for manufacturing are largely being initiated and created by large technology providers, although we see some enterprises considering creating a dedicated ICP such as Catena-X as the basis for a more autonomous industry ecosystem.
- Manufacturing enterprises can gain business value from ICPs through the following: shared best practices; vertically specialized go-to-market (GTM) and implementation teams; compliance of the infrastructure platform with industry-specific regulations, such as General Data Protection Regulation (drafted and passed by the European Union), Center for Internet Security or National Institute of Standards and Technology; analytical capabilities to integrally mine the data from existing and new applications; industry-specific add-on functionality in front- and back-office enterprise applications; and fully vertical-specific solutions, such as digital twins for products, assets, processes, organizations and even supply chain, combined with collections of composable building blocks available in industry cloud marketplaces.
- Providers drive or engage in ecosystems to create comprehensive offerings that cater directly to the established needs of manufacturing enterprises by provision of a composable portfolio of packaged business capabilities. These business capabilities represent use cases like remote predictive maintenance of assets and tracking of products and supplies (location, environmental conditions, carbon footprint, etc.). Thus, ICP also facilitates scalability and tech transfer.

Obstacles

- ICPs for manufacturing are at risk of following the same path as community clouds, where providers added specific vertical functionality. And followed this, by breaking compatibility and upgradability with the parent cloud leaving enterprises on long-term unsupported or unsupportable versions of the cloud.
- ICPs can be overwhelming in terms of the breadth of functionality they cover. Therefore, customers and providers must be disciplined and not burn precious resources on fixing/replacing things that are not broken. Implementing an ICP must be approached as adding an exoskeleton by bringing new and improved capabilities rather than a vital organ transplant, and replacing or repairing functionality that was already present.
- Providers will create their own ICPs that will not adhere to the same standards, so they cannot coexist in one enterprise, resulting in diminished value.

User Recommendations

- Target ICPs to provide the backbone to complement the existing application portfolio by enabling new capabilities that add significant value as an exoskeleton, rather than as full-scale replacements.
- Examine the viability of vendors and their partners regarding technical integration, industry knowledge, and mature GTM strategies and implementation approaches following the best-of-breed principles with minimum risk of lock-in effects.
- Assess the industry-specific features promoted by various cloud providers for the manufacturing industry, and distinguish between real technology/functionality offerings and marketing messages.
- Formulate rules to deploy ICP capabilities as a productive platform for optimization and modernization by improving existing processes and actively recomposing them for more differentiating transformation and innovation initiatives.
- Create a governance and management plan that not only provides a composable management framework for individual cloud adoption in the short term, but also allows for a multicloud governance and management approach as industry clouds mature.

Sample Vendors

Amazon Web Services (AWS); Google; IBM; Infor, Microsoft; Oracle; Salesforce; SAP; Siemens Digital Industries Software; TraceLink

Gartner Recommended Reading

Quick Answer: What Makes Industry Cloud Platforms Different From Traditional Cloud Offerings?

Providers of Cloud Managed Services: Use Composable Industry Platforms to Productize Your Offerings

Changes and Emerging Needs Product Managers Must Address in the CIPS Market

Predicts 2023: The Continuous Rising Tide of Cloud Lifts All Boats

Leverage Gartner's Vertical Strategy Framework for Composable Industry Cloud Offerings

5G in Manufacturing Operations

Analysis By: Alexander Hoeppe

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

5G in manufacturing operations relates to tailored mobile broadband and cellular data services. Increasingly scalable smart factory use cases require more connected assets and systems, but also digital technologies such as AI, or augmented reality/virtual reality (AR/VR) to achieve higher productivity, product quality and flexibility. 5G improves connectivity of data endpoints in factories with higher bandwidth and lower latency, and contributes to faster processing of increasing data volumes.

Why This Is Important

Smart factories require higher degrees of connectivity between a diverse set of equipment which produce higher data volumes and require always-on connections with very low latency and higher security levels. With manufacturing environments needing to process vast amounts of data, 5G combined with edge and distributed computing ecosystems help achieve and improve factory floor flexibility, AR-/VR-based decision-making support, real-time control of connected assets, and in-line quality inspection.

Business Impact

5G for manufacturing operations is in an emerging stage of development for data-intensive use cases like:

- Remote predictive maintenance of production equipment, machine cells and entire production lines leveraging digital twins and advanced analytics
- Worker safety, augmented decision making and collaboration using computer vision, AR/VR and AI
- MV-enabled use cases like tool tracking, AGVs or quality inspection

Yet, the added value for these use cases still has to be proved, so 5G is often still seen as an investment in the future.

Drivers

- Almost all key use cases in manufacturing are expected to be candidates for 5G enablement as scaled implementations require high-performance network infrastructures to manage more data endpoints and to process increasing data volumes (see Market Trend: 5G in Manufacturing Use Cases). But Pure 5G investments will struggle to provide value; unless 5G's strengths are used to enable AR/VR and machine-vision-supported operations, automated guided vehicles (AGVs), manufacturing lab test and demo environments, connected factory floor tools and real-time remote monitoring delivered through a combination of technologies like Internet of Things (IoT), edge compute and cloud.
- Manufacturers that invest in new factories ("greenfield") usually plan for the best possible flexibility and process performance, therefore, selecting state-of-the-art network technologies.
- Innovative organizations perceive early 5G adoption as competitive advantage. Asset-intensive industries are early adopters. Manufacturing and transportation are within the top three planning to invest in 5G within the next 24 months (see Enterprise 5G Opportunity Is Playing Out at a Different Pace in Different Industry Verticals).
- Recent pandemic events have elevated the need for manufacturing operations to consider options for more remote, untethered or virtualized operations. 5G is well-positioned to drive viable manufacturing planning for a new era of remote working and operations through reliability and integrity of data feeds. This could support improvements to worker safety or productivity, remote onboarding, training or certifications with AR/VR, or to help augment traditional operations tools for enhanced process optimization and continuous monitoring of quality and yield.
- 5G enables more flexibility and cost-effective deployments to configure different security paths for different type of devices compared to other wireless technologies like Wi-Fi.

Obstacles

- Speed of which companies can familiarize themselves quickly with many of the new technical concepts and modeling tools presented through 5G.
- Invest in data maturity initiatives to maximize benefit from 5G as it requires adoption of other technologies, such as AR/VR, edge computing, computer vision and digital twin.
- Currently, there are many use cases, especially on the shop floor, that don't require 5G. This makes creation of short-term business cases and investment justification challenging.
- For "brownfield" environments and smaller factories alternative technologies like Wi-Fi 6 or 4G could be more cost-effective than 5G.
- Digital and cybersecurity must be rigorously co-assessed as part of all 5G engagements, especially in its ability to push data out the edges of the enterprise, and for it to shape and influence digitized workspaces.
- The associated programmability of 5G networks due to design principles like network functions virtualization (NFV) and software-defined networking (SDN), and slicing opens up a diverse range of functions, but it entails a lot of operating effort.

User Recommendations

- Analyze your use cases and requirements to determine if there are enough opportunities to generate value with investments in 5G as foundational backbone technology. Only invest if you see strategic advantages for enough business activities.
- Position 5G as a strategic data enabler and opportunity to reassess planned technology infrastructure by ensuring formalized communications and change management processes are phased in parallel in areas, including immersive experience, AI, analytics and specialized IoT applications.
- Work closely with IT colleagues to map early use-case pilots and service propositions paying special attention to the correct frequency spectrum allocations needed. Work with 5G service and infrastructure providers on proof of concepts (POCs) that allow, based on agreed assumptions, to simulate and test the impact of network permanence changes on certain use cases.

Sample Vendors

AT&T; China Telecom; Deutsche Telekom; Ericsson; Huawei; Nokia; Orange Group; Telefónica; Verizon; Vodafone Group

Gartner Recommended Reading

Enterprise 5G Opportunity Is Playing Out at a Different Pace in Different Industry Verticals

Emerging Technologies: 5G Investments Will Increase as Projects Scale — 2021 Adopter Analysis

Market Trend: 5G in Manufacturing Use Cases

Quick Answer: How Should Product Leaders Approach Greenfield and Brownfield Smart Factory Initiatives?

Digital Engineering

Analysis By: Marc Halpern, Sudip Pattanayak, Michael McFerron

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Digital engineering is a platform approach that supports engineering and life cycle activities from conception to decommissioning of digital assets. It connects models and data through model-based system engineering (MBSE) and heterogeneous data pipelines across the entire life cycle of all physical, digital or virtual assets.

Why This Is Important

Digital engineering breaks down barriers between diverse engineering disciplines, promotes collaboration, and reduces integration work and duplication of effort. It involves major changes to IT organizational structure, governance and development methodologies. Digital engineering produces traceability throughout a system's life cycle, better stakeholder alignment, lower costs and faster enhancements.

Business Impact

- Increases visibility into cross-functional engineering disciplines
- Promotes consistency across the entire digital asset life cycle
- Reduces time required for all aspects of engineering, physical, operational and transactional activities
- Improves performance across the entire life cycle of all digital, physical and virtual assets
- Provides a consistent view of models and data across conception, development and production environments to reduce operational delays

Drivers

- Organizations need increasingly large and complex cyber-physical systems, but conventional engineering practices and organizational structures are increasingly unreliable to produce and manage them. Also needed is increased transparency and visibility into and across all engineering life cycles and processes when building cyber-physical systems.
- Organizations need enhanced communication and collaboration from conception to operations of physical, digital and virtual assets for greater flexibility/adaptability in design.
- Organizations need increased efficiencies in engineering practices in defining architectures and configurations of engineered systems, but many lack effective discipline and a platform to enable more efficient engineering practices.
- Organizations need greater interoperability — the ability to manage and exchange standardized data between systems owned by different engineering disciplines. Organizations understand the importance of a fully integrated environment to perform activities, collaborate and communicate across stakeholders.
- Sharing data and information across engineering disciplines is often a downstream task that occurs too late to capture changes early in the development life cycle.
- When dealing with large cyber-physical systems, organizations want greater reliability and productivity in all aspects of their production line and manufacturing process.
- Organizations find it difficult to harmonize architectural patterns from various subdisciplines and to reduce the overlap in system engineering, software engineering and enterprise architecture due to a lack of contextualization of data and models.
- Organizations are increasingly concerned with reproducibility, explainability, audit and governance of digital assets. Siloed engineering efforts make it very difficult to capture changes in design data and other metadata that would enable these efforts.

Obstacles

- Standards for information exchanges are immature and not well adopted. Digital engineering continues to struggle with overcoming proprietary data formats used by industrial manufacturing companies.
- Digital engineering principles are yet to be standardized. Some organizations focus on digital technologies, and others on well-established practices.
- Vendor solutions have not reached the maturity of plug-and-go tools that can be downloaded and easily installed. Some digital engineering offerings require the enterprise to have certain dedicated infrastructure in place and the resources to manage it. In other cases, solution integrators will be heavily involved in the initial setup and in integrating the solutions (MBSE, simulation and digital twin) into the existing technology stack.

User Recommendations

- Deliver a consistent view of engineering content across various stages of a life cycle by storing models in an orchestrated connected environment that is accessible across the entire life cycle of a digital asset.
- Increase the flexibility of data artifacts and model development, deployment and maintenance by providing engineers with an orchestrated and connected infrastructure to support models and tools.
- Shift from managing explicit knowledge and information via documents to managing knowledge and information via object technology and graph models.
- Extend existing data fabric architectures to support data and model exchanges that define standards, data and architectural patterns for all engineering disciplines across the entire life cycle of the digital asset.

Sample Vendors

Aras, Dassault Systèmes; IBM; PTC; Siemens

Gartner Recommended Reading

What Data and Analytics Leaders Need to Know and Do About Digital Twins

Innovation Insight for Model-Based System Engineering

Generative AI in Discrete Manufacturing

Analysis By: Sudip Pattanayak, Marc Halpern

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Generative AI technologies can generate new derived versions of content, strategies, designs and methods by learning from large repositories of original source content. Generative AI has profound business impacts, including on content discovery, creation, authenticity and regulations; automation of human work; and customer and employee experiences.

Why This Is Important

Generative AI will have a direct impact on the manufacturing subindustries such as automotive, aerospace, defense, medical, electronics and energy industries by augmenting core value through generating processes and associated data with AI models. In discrete manufacturing, significant investments are being made in advancing the use of AI as generative capabilities in product engineering, factory operations and aftermarket services to capitalize on the breakthrough of large language models (LLMs).

Business Impact

Generative AI in discrete manufacturing uses AI programs to create new or variations of original content such as product data, designs, images, video, audio, speech and text. When combined with LLMs, it results in improved product designs, supply chain and operational insights, intuitive training modules and better customer experiences by augmenting humanlike interactions with systems, applications and machines.

Drivers

- Business leaders seek to transform to smart manufacturing, providing a new ecosystem of open-source AI models and communities optimizing a variety of use cases. Examples are design optimization, factory and service frontline worker support, and augmentation of supply chain decision making.

- Generative AI can enhance employee and customer experience since it mimics humanlike natural language conversations and contextualizes large volumes of data compiled as language models. An example is interactions of factory workers using generative AI to interact with machines, which generates large data sets that need to be parsed and translated for consumption.

- Generative AI has tremendous potential in copilot support in engineering and smart operations, improving operational excellence and employee productivity. The capability of generative AI to alter and enhance existing content, creating new data elements and novel models of real-world objects, will advance augmented intelligence.

- New criteria-based solutions are being created to solve multiple problems in the real world, advancing the use of existing AI data models. A few examples are LLMs, pretrained transformer models that learn from large volumes of information from the web to create new artifacts and Language Model for Dialogue Applications (LaMDA), a pretrained transformer language model to generate high-quality natural language text to detect nuances in open-ended conversations. Such language models will blend in with the complexity of manufacturing industries, where tasks are still manually coordinated with human interactions.

- The use of OpenAI services will demand the manufacturing companies to set up co-innovation based working models with data and analytics (D&A) and AI vendors to scale use cases such as factory automation, problem reporting, visual quality inspection and predictive maintenance.

Obstacles

- Deepfake products can use generative AI for the material design that could create counterfeits that would pose threats to OEMs.
- Generative AI models that are pretrained and ready to use are becoming increasingly accessible, making the technology available to broad audiences. Along with broader accessibility comes risks, potentially exposing your organization to copyright and intellectual property exposure risks, including technology patents of new products.
- Data quality and reliability is a concern in manufacturing. Bad quality data and lack of evidence will impact the generative AI training data models.
- Manufacturing industries still use legacy systems in all facets of product development and factory operations. The use of generative AI with legacy tools can limit its effectiveness.
- Manufacturing processes and tasks are still human-driven in many value streams. Concerns of generative AI potentially replacing humans will limit the scale of adoption of generative AI across the value chains.
- Regulatory authorities responsible for manufacturing-specific compliance and IP protection might overregulate generative AI due to the lack of predictability of its impact on the industry and society.

User Recommendations

- Determine the business impact (benefits/risks) of generative AI in manufacturing subindustries to avoid legal complications due to misappropriated use.
- CIOs must work with internal and external stakeholders to evaluate generative AI use cases for business opportunities and threats and to assess the technical feasibility, organizational readiness and external factors for adoption or mitigation.
- AI leaders must choose vendors that provide tools for mitigating bias and that provide detailed model cards and transparency in training datasets and functionalities.
- AI and D&A leaders must ensure that good-quality data from the manufacturing value streams is used in your generative AI models to ensure traceability and evidence for validation.
- CXOs must consult with the right partners who can define and develop the use cases of generative AI.
- CIOs and manufacturing operations leaders must avoid overlooking the ethical considerations of the human element by educating the workforce on AI applications as cognitive assistants, not replacements, to humans.

Sample Vendors

Amazon Web Services (AWS); Autodesk; Beckhoff Automation; Dassault Systemes; IBM; Microsoft; NVIDIA; OpenAI; PTC; Siemens Digital Industries Software

Gartner Recommended Reading

Use Generative AI in Applied Innovation to Drive Business Value

Innovation Insight for Generative AI

At the Peak

Configuration Life Cycle Management

Analysis By: Christian Hestermann, Alexander Hoeppe, Marc Halpern

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Configuration life cycle management (CLM) employs system engineering techniques to define and execute configurations of products, manufacturing processes, and sales and service options in connected and orchestrated ways. It comprises a product architecture with centralized and integrated rule engines enabling configuration of variants that are technically and economically feasible as well as saleable and serviceable. CLM also enables production scheduling to predict time to customers.

Why This Is Important

CLM is near the Peak of Inflated Expectations as manufacturers:

- Strive to maximize market coverage by systematically delivering customized products from a common design
- Evolve to more profitable businesses by transforming engineer to order (ETO) businesses into configure to order (CTO) businesses
- Implement CLM across manufacturing industries spanning aerospace and defense, automotive, consumer goods, life sciences, electronics and industrial equipment

Business Impact

System-of-systems CLM:

- Can make complex CTO and ETO business more scalable
- Enables common product modules accelerate manufacturing processes, supply chain processes (logistics) and service operations, making them more predictable and efficient

- Enhances reusability of R&D investments
- Reduces time to delivery for individual customers for products and services
- Enhances customer loyalty given the customization of products and services

Drivers

- Customers in different markets wanting common product categories but needing different features.
- Alignment with the trend toward composability and mass customization.
- Facilitation of customer decision making and the shortening of sales cycles because of fewer limitations on the features the customer wants and the potential for remote selling, even for complex, capital-intensive products.
- The need for cost optimization, given rising costs of parts, raw materials, labor, services, energy and so forth.
- Simplified traceability and decision making.
- Simplified compliance with diverse regulations, such as governance, risk and compliance; sustainability; and environmental, health and safety (EHS).

Obstacles

- Effective communication across R&D, manufacturing operations, marketing, sales, procurement, supply chain operations and service are required.
- Substantial reorganization and investments in process change are required.
- Requirements management is frequently incomplete and incorrect.
- Common standards do not yet exist for moving configurable product models to sales configurators.
- It requires more interfaces across various systems like CRM, ERP, product data management (PDM) and engineering applications.
- Master data quality across heterogeneous system landscapes for product, sales and production is insufficient. This also comprises a lack of standardized rules and processes for bill of materials synchronization, version control, engineering and order change processes.

- Challenges exist in ensuring compatibility of the different combinations of product modules (subsystems).

User Recommendations

- Apply model-based system engineering (MBSE) approaches to defining configurations.
- Think in terms of product platforms, not individual products.
- Rethink and invest in comprehensive requirements management.
- Facilitate communication and collaboration among internal and external stakeholders.
- Create fusion teams consisting of stakeholders from IT and involved business functions.
- Cultivate composable thinking to make existing ETO processes more systematic.
- Prioritize the ability to connect enabling applications by implementing standardized APIs and centralized product platforms.

Sample Vendors

camos; Configit; Modular Management; OpenBOM; PROSTEP

Gartner Recommended Reading

Use Gartner's Reference Model to Deliver Intelligent Composable Business Applications

Product Leader Insight: Enable Digital Threads to Increase Revenue and Customer Loyalty

Magic Quadrant for Configure, Price and Quote Application Suites

Market Guide for Composable Product Configurators

Top BOM Practices for Building Digital Threads in Discrete Manufacturing Industries

Cyber-Physical Systems

Analysis By: Katell Thielemann

Benefit Rating: Transformational

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Cyber-physical systems (CPS) are engineered systems that orchestrate sensing, computation, control, networking and analytics to interact with the physical world (including humans). They control production and mission-critical assets, and underpin all critical infrastructure-related industries.

Why This Is Important

Whether deployed in smart grids, smart buildings or autonomous vehicles, CPS are core to manufacturing, industrial control systems (ICS)/supervisory control and data acquisition (SCADA), operational technology (OT), Internet of Things (IoT), and industrial IoT deployments. They represent the confluence of physical and digital systems to connect people, products, data and processes. Deployments can use sensors, robotics, cloud services, analytics, machine learning and high-speed networks, to orchestrate data and physical processes in real time.

Business Impact

CPS orchestrate data flows and physical processes between previously disconnected systems, automate unstructured processes, shorten cycle times, and improve product and service quality. In industrial environments, CPS replace stand-alone production process control and automation, materials handling systems, and transactional workflow systems to process real-time information. They improve productivity, reduce costs, and enable value creation for all asset-intensive industries.

Drivers

- Customer or citizen demand for faster, cheaper, better and more products/services.
- New digital business models.
- Productivity and maintenance improvements.
- Labor cost reduction made possible by automation provided by robotic CPS.
- CPS-enabled operational excellence and enhanced operational data gathering.
- Improved situational awareness in operations or mission-critical environments.
- The need to keep up with the competitive landscape by automating as many processes as possible.

Obstacles

- Concerns over physical perimeter breaches, jamming, hacking, spoofing, tampering, or command intrusion must be addressed above and beyond cybersecurity considerations.
- Deployment-related obstacles include scale (potentially billions of devices are in scope), complex architectural requirements and design approaches from many disciplines involved, sense and control loops that must be designed to evolve with business needs, the need for significant computational resources, and a variety of sensory input/output devices.
- Many organizations increasingly have a mix of legacy and new systems with proprietary protocols, which creates interoperability challenges. While end users have been seeking better interoperability, common standards are still under development in many industries.
- Many devices lack storage and compute power to facilitate security mechanisms.
- Because CPS are usually highly automated, new skills are needed for operations, security and maintenance.

User Recommendations

- Determine the business value of CPS deployment by weighing benefits against cost, complexity and security.
- Promote the use of standards and interoperability recommendations to manage complexity, enable scalability and extensibility, and ensure focus on security and safety imperatives.
- Make sure that any deployment is negotiated with CPS OEMs to ensure upgrades can be easily incorporated. Emerging technologies, such as cloud computing and 5G, will greatly impact these systems.

Sample Vendors

Honeywell International; Johnson Controls; Medtronic; Siemens; Yokogawa

Gartner Recommended Reading

Predicts 2023: Cyber-Physical Systems Security — Beyond Asset Discovery

CPS Security Governance — Best Practices From the Front Lines

Innovation Insight for Cyber-Physical Systems Protection Platforms

Mobile Factories

Analysis By: Simon Jacobson, Ronak Gohel

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Mobile factories are self-contained production units constructed of ready-for-use modules that can be deployed into markets and assembled at a fraction of the traditional time, cost and risk of conventional capacity.

Why This Is Important

Localizing manufacturing operations raises the importance of operational resilience even as cost efficiencies pressure organizations. Mobile factories are an innovative way to develop highly flexible, fit-for-purpose capacity at less cost and lead time than to stand up a traditional site. Early adopters that have operationalized this strategy often aim to provide greater options to customers and explore demand in uncertain new markets with the intent to scale up, should the market be profitable.

Business Impact

Mobile factories are an innovative approach to leveraging technology and creating resiliency in the network. They offer simplified production setups, improved resource utilization, and significantly lower capital investment and scale-up time — all without risk to competitiveness, flexibility or compliance.

Drivers

- Localizing manufacturing networks and activities to meet personalized demand with minimal risk
- Leverage of competitive ambition, innovation capability and standard processes for deploying modular, flexible and cost-efficient production capacity at a fraction of capital expenditure
- Surging interest in smart factories. Specifically, capacity that utilizes interoperable plug-and-play combinations of new manufacturing techniques and automated systems
- Capitalizing on technologies supporting distributed and localized production, including edge/cloud architectures, digital twins for modeling, simulation and virtual commissioning, and remote monitoring of production assets

Obstacles

- Supply chain as a service (SCaaS) and varied external manufacturing options might be more viable options to lower costs and risk in certain geographies and industries. Current adoption and investigation is from life sciences and consumer products manufacturers.
- Capital planning processes and collaboration are misaligned across supply chain, manufacturing, and engineering.
- Growing product volumes and mixes stretch the limits of fit-for-purpose capacity.
- There is a need for access to infrastructure and resources on a local scale (includes raw materials, skills, and technology).
- Local compliance and environmental regulations are dynamic and uncertain.
- Realizing mobile factories is broader than 3D printing. Coordinating an ecosystem of technology suppliers and OEMs requires significant internal collaboration.

User Recommendations

- Focus on portions of the business where the customer and business requirements are fluid to define design agility for changing the operating model.
- Examine the up-and-downstream network designs during long-term planning. Raw materials order patterns and distribution networks might have to be reconfigured.
- Collaborate with machine builders and technology partners to develop standard configurations for accelerated ramp-up and cost-effective ongoing maintenance.
- Investigate local infrastructure, tax laws and government subsidies, and labor availability to ensure feasibility.
- Embed mobile factories as one kind of capacity orientation within a broader smart factory portfolio.
- Define the sustainability impact of mobile factories, including greenhouse gas and circularity advantages, versus other network solutions.
- Develop a transfer or wind-down strategy. Not all mobile factory deployments will be successful. This requires firm time frames on when to see results by running cost models to evaluate total costs to serve against commercial price points.

Gartner Recommended Reading

Global vs. Regional Supply Chains — Identifying the Right Approach for Your Network

3 Types of Process Agility Enable Supply Chains to Thrive During Change and Uncertainty

Build Segmentation Into Your Manufacturing Strategy to Deliver Business Outcomes

Tool: Evaluating Countries for Manufacturing Site Selection

IT/OT/ET Alignment

Analysis By: Kristian Steenstrup, Marc Halpern

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

IT/OT/ET alignment is the coordination of information technology (IT), operational technology (OT), and engineering technology (ET) through shared standards and governance. Each plays a complementary role to the other two technologies. While IT records transactions and business processes, OT operates and monitors industrial assets, and ET is used to define, design, simulate, analyze, visualize and validate those assets (e.g., GIS, computer-aided design and manufacturing [CAD]/CAM]).

Why This Is Important

For asset-intensive industries, system interoperability is improved when OT, ET and IT systems and processes share infrastructure and planning. This also enhances the agility to change configurations to adapt to market demands, improve product quality and optimize productivity. As a result, organizations seek common architecture plans and standards for the technology acquired, and increasingly look for vendors that support this direction. Most companies are at least beginning this exercise.

Business Impact

The impact of IT/OT/ET alignment is mainly focused on four aspects:

- More efficient use of technology and support resources across IT, OT and ET investments.
- Easier sharing of data from design documents (ET) to operational systems (OT) and business administration, supporting digital threads and digital twins.
- Easier sharing of performance data from OT into the ET process for design and improvement.
- Consistent security and risk management across all technology.

Drivers

- Cost reduction by not duplicating licensing, maintenance and support for common software components.
- Cost optimization by consolidating via cloud, virtualization or colocating servers and back-end hardware in a common data center.
- Agility by being able to start new hybrid IT/OT/ET projects quicker and reacting to changes in a consistent way.
- Risk avoidance by aligning security, patching, disaster recovery and upgrading processes.
- Benefits of using the same support and configuration tools, support contracts, and purchase processes.
- Process and information sharing between domains driving collaboration and cross-pollination of practices and approaches, leading to effective management of digital threads.
- Easier access to ET and OT data for IT analysis such as digital twins, predictive maintenance and production optimization.
- Leveraging OT performance data in product development using ET systems.
- Designing of systems via ET that better cater to OT effectiveness, and future OT system support and data acquisition.

Obstacles

- Coordination between three domains is complex technically and politically. Different cultures and approaches of IT departments, manufacturing/operations and design/engineering need to be reconciled.
- There may be a possible temporary increase in cost on the OT or ET side initially, as technology investments are made to bring software up to the required IT standard/version and to deal with any license compliance gaps.
- The lack of common tools for software asset management (SAM) that caters for IT and OT technology makes centralized control difficult.
- The absence of short-term benefits in terms of cost avoidance make project approval more challenging.
- The entrenched separate positions and practices associated with OT and ET systems, and their criticality, safety and stability, means that realignment takes time.
- Aligning risk appetite and security requirements across three domains with different pedigrees increases the effort needed to identify and manage risk and security.

User Recommendations

- Get agreement on a change imperative, so you have a mandate for change.
- Establish a common governance model across the three domains.
- Evaluate technology management processes to determine how much IT process is applicable to OT and ET, how the unique needs of OT and ET must be recognized and supported, and how to get them aligned and secured by design.
- Incorporate OT and ET requirements in enterprise risk management by adopting an integrated security strategy across IT, OT, ET, physical security and cyber-physical systems (CPS) for greater visibility.
- Create combined hardware platform and architecture policies to ensure compatibility between IT, OT and ET systems by formulating compatible governance for software, communications, and infrastructure.
- Use a responsible, accountable, consulted and informed (RACI) analysis to help manage this transition, and to map out organizational responsibilities for different parts of the technology environment.

Sample Vendors

Bentley Systems; Dassault Systèmes; PTC; Siemens

Gartner Recommended Reading

2022 Strategic Roadmap for IT/OT Alignment

What Should I Know About OT Security?

How IT Standards Can Be Applied to OT

Survey Analysis: IT/OT Alignment and Integration

When Does a CIO Need to Be Involved in OT?

Connected Factory Worker

Analysis By: Simon Jacobson

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Connected factory workers leverage digital tools and data management techniques to improve and integrate their interactions with both physical and virtual surroundings. This improves decision accuracy, proliferates knowledge and reduces variability — improving engagement, satisfaction and retention.

Why This Is Important

Digitization in factories is intensifying while operational know-how fades. Factory workers struggle to embed new technologies into their daily work, negatively impacting the broadening of core skills and building digital fluency eases labor constraints. Manufacturers are investing in their factory workforces. The solution is as much a technology construct that changes how factory workers access information and knowledge to work differently as it's a change management exercise in workforce development, behavioral shifts and integrated continuous improvement.

Business Impact

Frontline workers are indispensable and the convergence of technology innovation and investment in their experience is critical for improving engagement, satisfaction, and retention:

- Increasing operational excellence, flexibility and quality of outputs by continuous learning but also context specific operations to limit deviations from standard procedures.
- Ensuring safe but challenging working conditions to improve work motivation and retention and to open up prospects for career development.
- Extension of standard work procedures for more efficient use of resources, but also appropriate social behavior in communication with colleagues and supervisors.
- Greater, intangible returns appear when initiatives are part of a formal workforce development strategy.

Drivers

- Labor availability and up-to-date skills are constraints. Meanwhile, smart manufacturing is a net job creator and demand for capable frontline workers is soaring. Organizations seek a factory workforce that can seamlessly operate between the virtual and physical worlds.
- Generational gaps in factories can impact technology acceptance. New workers are tech-savvy but lack access to best practices and know-how. Tenured workers have detailed process knowledge and digital savvy as consumers — the tools supporting them on the job have to evolve.
- The nature of work in factories is being (re)designed, digitized and improved, impacting total productivity and peer-to-peer communication — not to mention job families and role profiles.
- Growth in vendor solutions to provide frontline workers the right information available contextualized at the moment of need.

Obstacles

- Accepting operational excellence as “good enough” ROI when the impact and benefits are often intangible.
- Curating relevant datasets across existing technologies, manual and undocumented knowledge, and informal know-how from tenured workers. In parallel, the risk of information overload when moving away from manual tasks could be burdensome versus aiding.
- Involving workers in the solution design and implementation process helps set demand and adoption.
- Learning and development evolution, from classroom and episodic to experiential and continual, is nascent.
- Patience with AI: Although attractive for decision support, curating the knowledge that provides guidance, ensuring IP is protected, and an ethical stance are all critical. Mishaps can impact recommendations, pay or career advancement and lessen trust.
- Underinvesting in governance: Providing workers with tools to build their own experiences or redefine standard work eliminates time and effort. Yet, shadow IT and anarchy arise without dedicated operational excellence/continuous improvement teams to manage common requirements and risks.

User Recommendations

- Strike a balance between digital enablement and cultivating future competencies by framing your initiative as part of a broader manufacturing workforce development program.
- Consider architecture over applications. This will limit point solutions and the complexity of managing multiple vendors. This includes a focus on pulling in data from other transactional systems such as MES as means to link production data with employee-led improvement opportunities.
- Invest in upgrading learning and development (L&D) programs to ensure that skills development matches technology capabilities.
- Make your focus the creation of a “data-driven” culture in manufacturing operations by diligently avoiding a scenario where employee creativity and ingenuity is stifled.
- Prepare to balance governance and flexibility during implementation by having clarity on where enterprise standards must give way to local ways of working.

Sample Vendors

4Industry; Covalent Networks; L2L; Microsoft; Operations1; Poka; QAD Redzone; SAI Global; SwipeGuide; Zaptic

Gartner Recommended Reading

Innovation Insight for the Connected Factory Worker

How to Take a Life Cycle Approach to Developing the Connected Factory Worker

Future of Work Trends: 5 Trends Shaping the Future of Frontline Workers

Supply Chain Executive Report: Developing the Supply Chain Professional of 2025

Composable Applications

Analysis By: Yefim Natis, Anne Thomas, Paul Vincent

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Composable applications are built, in part or in whole, as flexible assemblies (compositions) of software components that represent well-defined business capabilities, packaged for programmatic access. The business-centric modularity of composable applications empowers democratized access to technology and business innovation. Composable applications support faster, safe and efficient digital business innovation. Advanced use of composable applications allows cross-application compositions.

Why This Is Important

Composable applications help support resilience, adaptability and growth of business in the context of increasingly frequent challenges, disruptions and opportunities. They support fast-paced business change while protecting the integrity of the outcomes, and bridge application software and business operations by using coarse-grained business-centric software modularity. Organizations that use composable applications maintain customer loyalty by better tracking their changing needs.

Business Impact

The more composable applications there are in the organization's portfolio, the better the organization is prepared to support changing business requirements through digital innovation. In return, greater confidence in the agility of applications promotes faster business thinking. The improved agility of business technology strengthens the ability of an organization to maintain and grow its business, a high value in the modern context of fast innovation, frequent challenges and opportunities.

Drivers

- In the continuously changing business context, demand for business adaptability directs organizations toward technology architecture that supports fast, safe and efficient application change.
- The demand for active participation of business decision makers in the design of their digital experiences promotes the adoption of technology models that are accessible and useful to business experts in addition to, and in cooperation with, technical professionals.
- The need to reduce the costs of redundancy in software capabilities across applications and business units drives organizations to reusable business modularity and from there to composability.
- The increasing number of vendors offering API-centric SaaS (also known as API products or "headless" SaaS) builds up a portfolio of available business-centric packaged application components — promoting their use as building blocks of composable business applications.
- The emerging architecture of micro front ends and superapps advances the principles of composability to the multifunctional user experience, promoting broader adoption of composability in application design.
- Fast-growing competence in mainstream organizations for the management of broad collections of APIs and event streams creates a technology foundation for safe operation of a composable business technology environment.
- The emerging business model of industry cloud, promotes the architecture of modularity and composition inside and across vertical use cases.

Obstacles

- Limited experience of composable thinking and planning in most software engineering organizations complicates composable design efforts and transition plans.
- Limited practice of business-IT collaboration for application design delays the effective composable design that depends on the complementary expert talents in multidisciplinary fusion teams.
- Most legacy applications can participate in composition via their APIs and/or event streams, but their architecture provides only minimal autonomy, delaying the full positive effect of composable architecture.
- Limited development and platform tools dedicated to composable application architecture limit the early success to advanced design teams capable of adapting precursor technologies to new objectives.
- Insufficient mapping of architectural thinking and models between business and technology planners makes digital representation of business functionality less prepared to track real-world business change.

User Recommendations

- Promote modular thinking as the means to great flexibility in business and software innovation.
- Champion API-first business software design, whether or not the application is also packaging the traditional UI capabilities.
- Build competence in API and event stream management as the precursor to managing composable business software modularity.
- Prioritize the formation of business-IT fusion teams to support faster and more effective adaptive change of business applications.
- Use low-code/no-code technologies to facilitate design collaboration of business and technology experts in fusion teams.
- Build an investment case for composability by highlighting how aging digital assets endanger the future success of the business by forming barriers to innovation, competition and customer satisfaction at the pace of market change.
- Gradually modernize (or replace) existing applications toward an architecture of business-centric modularity.

Sample Vendors

Elastic Path Software; Mambu; Novulo; Olympe; Spryker Systems

Gartner Recommended Reading

Becoming Composable: A Gartner Trend Insight Report

Quick Answer: Who's Who in the Life Cycle of Composable Applications?

Case Study: Composable Platform Strategy to Drive Business Agility (Nike)

Predicts 2023: Composable Applications Accelerate Business Innovation

Use Gartner's Reference Model to Deliver Intelligent Composable Business Applications

Lights-Out Manufacturing

Analysis By: Simon Jacobson, Alexander Hoeppe

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Lights-out manufacturing relates to factories characterized by digitized production processes that adapt with minimal to zero human intervention. It reflects the shift toward hyperautomation — the orchestrated use of multiple technologies, tools or platforms to automate processes and augment humans in factories. It also reflects the growth of autonomous things that can interact with and manipulate different factory environments with various levels of human guidance, autonomy and collaboration.

Why This Is Important

- Ambitions to operate autonomous supply chains supported by smart factories that are heavily automated that can adapt to changing internal and external conditions.
- Market uncertainties such as variable lead times and rising costs, and inconsistent labor inputs make automation an attractive option to maintain service levels or increase competitive stance.
- Ongoing developments in hyperautomation technologies such as robotics, AI/ML, AR/VR, and Internet of Things (IoT) expose the opportunity for factories to create new, virtual production processes and boost cost efficiency,and agility through reliable supply from factories.

Business Impact

The supply chain's demand for factories to flexibly adapt will only increase in the future. Lights-out production offers relief by combining process automation and augmentation to balance cost, compensate for labor gaps and deliver reliable supply.

Drivers

- Increasing localization and shortening of supply chains with different labor, demand and cost profiles reliably balance cost and service fuels interest in automation.
- Counteracting labor shortages by leveraging advances in AI, autonomous things (and other technologies supporting the hyperautomation trend) to remove physically demanding or mundane tasks, executing transactions and provide guidance at the point of decision — without compromise to speed, quality or cost.

Obstacles

- **Finding the starting point**: Different customer demands, labor inputs, utilities and other economic factors between high- and low-cost markets can make lights-out production an expensive ambition versus a cost-efficient reality.
- **Investment approval:** Accessing capital funds and securing funding to overcome expansive collective organizational debt for this expansive initiative might be impeded. Also integration costs of new and existing technologies with existing data, workflows, and decisions carry often under-budgeted-for hidden costs.
- **Complexity:** Decoupling processes and identifying where to augment existing processes with technology and where to apply a lights-out setup is not straightforward. Making trade-offs between agility and flexibility takes time.
- **Technology debt**: Reliance upon a single vendor or technology offers/as the complete solution is short sighted. Upgrades to existing IT and OT could be cost prohibitive.

User Recommendations

- Begin developing new skill sets now to train and maintain algorithms and process improvement.
- Budget extensively to modernize OT (programmable logic controllers, drives and other technologies that control a process) as well as legacy IT systems. Set aside extra funding for integration as its costs are always underestimated.
- Identify process standardization opportunities when differentiating human augmentation from automation. Use the degree of human interaction based on the task or activity as a guide.
- Prioritize cost, risk and technology maturity criteria when deciding what degree to invest in lights-out production by executing a rigorous assessment that examines the cost benefit of fully automating a process.
- Recognize that not all production activities will evolve in a common way and humans will always be needed. Manual processes — either human-driven, or those in isolated and legacy transactional systems — are a sufficient starting point.

Gartner Recommended Reading

Lights-Out Production Will Be a Reality by 2025

From Human Augmentation to Lights-Out Production: How Far to Go With Industrial Automation?

Hyper-Automation Is Changing Factory Workers' Jobs, and IT Will Help With the Transition

Video: DuPont's Journey to Lights-Out Manufacturing

Win More Business in Manufacturing With Composable Hyperautomation Capabilities

Sliding into the Trough

ALM in Manufacturing

Analysis By: Sudip Pattanayak, Marc Halpern

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Application life cycle management (ALM) in manufacturing refers to an integrated system of tools, people and processes that govern developing, testing, deploying, enhancing and upgrading embedded or connected software from product or system concept through end of life.

Why This Is Important

While this innovation is sliding into the trough, interest is growing because:

- The ratio of software in complex and smart products grows and serves critical functions compared to the hardware components.
- Compact product development timelines require reliable software that is compliant with standards such as safety, functionality and usability.
- Software life cycles follow agile methodologies in their own development timelines, yet the outputs must converge with the hardware development milestones.

Business Impact

ALM in manufacturing ensures:

- Accuracy of product's overall functionality concerned with software/systems behavior
- Collaborative closed-loop software development process
- Software test and validation automation to accelerate consistent deliverables
- Regulatory and industry standards compliance

- Linkages from software deliverables to requirement specifications
- Integration of multiple software development tools in a single platform

Drivers

- Software development process/configuration traceability is essential for quality and regulatory business functions to obtain industry and global product compliance certifications.
- Software errors in products result in expensive recalls procedures and efforts to fix them.
- Rapid changes to software, applications and firmware require a software development hub that connects hybrid development tools.
- The complexity of software in products is driving the need for agile and scaled agile framework (SAFe) to develop high-quality software.
- Software deployment methods like over-the-air updates require well-defined software development, configuration management, testing and software in service control methods.
- Products are becoming modular and governed by systems-of-systems principles requiring the software and the hardware to work in a loop. Test and validation of software at the end of development for each system engineering use case are crucial for high-quality products.
- ALM provides automation, configuration management and traceability capabilities to keep pace with increasingly ambitious product and system development timelines.

Obstacles

- The importance of a life-cycle-based software development approach is overlooked due to traditional file-based software deliverable practices.
- Sometimes having ALM processes and tools is perceived to slow down the software development and deployment processes.
- Managing and configuring the ALM tools to meet cross-functional stakeholders' goals can be cumbersome. Some even consider the cost of implementing ALM higher than its benefits.

- ALM adoption is successful only when the hardware and software life cycles and the respective value stream owners are aligned with the overall product development milestones. In some subindustries, the two streams are still disconnected.
- There are not many options for ALM tools in the market. Custom solutions exist, but they do not scale with the growing complexity of products.

User Recommendations

- Adopt SAFe for software development to manage the complexity and quality of software in products.
- Educate cross-functional stakeholders about the need for ALM for efficient and cost-controlled software development practices.
- Converge ALM with product life cycle management (PLM) to align the hardware and software development life cycles. The PLM connects multiple value streams in the overall product's life cycle. ALM and PLM convergence will enable faster product development.
- Implement ALM tools that scale and manage the software development, requirements management, and test and deployment requirements.
- Integrate ALM and model-based system engineering tools to align the system engineering approach with the software modeling and simulation.

Sample Vendors

Atlassian; IBM; JAMA Software; PTC; Siemens Digital Industries Software

Gartner Recommended Reading

Life Cycle Management of Software-Defined Vehicles: Step 2 — Vehicle Software Register

How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread

Mass Customized Discrete Manufactured Products

Analysis By: Marc Halpern, Michelle DeClue, Ivar Berntz

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Mass customization is a design, manufacturing and product delivery approach that allows customers to personalize a product based on selections of predefined features and constraints. This allows for personalization of assembled products without a significant increase in the time or cost to produce.

Why This Is Important

This innovation, moving beyond the Peak of Inflated Expectations, gains considerable attention because:

- Manufacturers seek means to personalize products and software technologies to attract new customers and increase customer loyalty.
- Manufacturers seek to deliver personalized assembled products in an efficient, scalable way using software and technologies such as 3D printing.
- The enabling technologies and processes available to deliver mass customization are sufficiently mature.

Business Impact

The transformational value of this innovation will come from these benefits:

- Mass customization increases profitability.
- Manufacturers operate more efficiently by designing product platforms rather than individual products, reducing workload.
- More agile manufacturing operations produce products with multiple assembled options.
- Online platforms allow customers to easily select combinations of product features.
- Configuration tools raise visibility, providing more comprehensive access to customer-specific product configurations.

Drivers

- Manufacturers recognize that customers increasingly want personalized products within every market.
- Digital technologies enable expanded access to broader markets with more diverse preferences for customized products.
- A great number of commercial technologies for mass customization are available. Therefore, manufacturers want to achieve scalable mass customization before their competitors.
- Manufacturers can improve customer loyalty and brand recognition by providing personalization. Customers are also willing to pay more for customized products, resulting in a significant revenue generation opportunity.
- The customer data can be monetized internally through aggregation and analysis to improve new product ideation and reduce time to market.
- Design and manufacturing marketplaces are further enhancing this capability.

Obstacles

- Product development must be refocused from product design to product platform design, which requires engineering skills.
- Supply chain management becomes more challenging as the demand for parts and materials fluctuates more. Operating lean also becomes more challenging.
- Investments in manufacturing operations must address the need for greater agility. Delivering individualized products for different customers requires rethinking manufacturing operations.
- Mass customization involving 3D printing involves steep learning curves to achieve sufficient quality of printed parts.
- Servicing individualized products becomes more challenging. Service organizations need investment to track configurations and service history of individualized products.
- Manufacturers are reluctant to replace existing product configurators, which contain tacit product knowledge that manufacturers may risk losing if they adopt a new configurator.

User Recommendations

CIOs must work with:

- Data architects to enable data access across product specifications, product configurators, ERP software, product life cycle management applications, manufacturing execution system software and supply chain applications.
- Business leaders to coordinate workflow across R&D, regulatory and supply chains to ensure compliance with regional government regulatory issues, including documenting and labeling individual products.
- R&D leaders to ensure designers and engineers have the software and training to design product platforms.
- Business leaders across product development, sourcing, manufacturing and service to revise how bills of materials are defined and managed.
- Service leaders to ensure that field organizations have information to service individualized products.

Sample Vendors

Configit; Dopple; Epicor; Modular Management; Tacton; Valtech; ZeroLight

Gartner Recommended Reading

How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread

CG Manufacturing CIOs Must Enable Organizations to Deliver Personalized Products at Scale

Top Strategic Technology Trends in Asset-Intensive Manufacturing for 2023

Top Strategic Technology Trends in Manufacturing and Transportation for 2023

Digital Threads

Analysis By: Christian Hestermann, Marc Halpern, Rick Franzosa, Sudip Pattanayak

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

A digital thread is a framework of roles, processes and tools that enable the collection, organization and presentation of data for multiple factors that influence a product or process and their evolutions over their respective life cycles. The integration and organization of data and information enable multiple users to access, integrate, organize, trace and transform disparate technical and knowledge-based data from multiple operational and enterprise-level systems.

Why This Is Important

Digital thread is a fundamental concept of digital manufacturing. The digital thread supports digital twins by connecting multiple data and information sources across design, manufacturing, supply chain systems, processes, and other aspects of business with interdependencies and traceable history. It can connect the evolution of design requirements through production, delivery and service and then retirement or reuse to ensure a compliant and quality product is delivered to the customer.

Business Impact

Digital threads improve the efficiency and agility of decision making on cost, quality, traceability, sustainability and regulatory compliance of design, production, use and service of products. They provide insights on variations in cost and quality metrics impacted by changes to product designs and configurations. Their dynamic nature can streamline execution of standard work, improve suppliers' engagement, help organizations determine the most beneficial investments in the evolution of a product and its digital twin.

Drivers

- A broad vision of product life cycle management (PLM) encourages digital thread investments. Digital threads encompass a wide time horizon, and provide history and context specific to a product's or a process's life cycle.
- Technology advances and growing experience at governing data are enabling digital threads. Growing volumes of data come from a rising number of connected products supported by IoT platforms, edge devices and sensors. New technologies and tools (cloud services, industrial IoT platforms, and automated data synchronization and validation) can access, verify, validate and synchronize data — as well as offer analytics for simulation and pattern analysis. This is more than core manufacturing execution systems (MES), PLM and ERP systems can provide when used in isolation.
- Manufacturers across multiple industries understand digital threads' criticality to mitigate the complexities and risks associated with new configurations (and product-specific variants) or rising customer demand for smaller order quantities.
- Compliance with regulations, such as those of the U.S. Food and Drug Administration (FDA) and International Traffic in Arms Regulations (ITAR), will be more transparent and efficient.
- Mature management of bills of materials (BOMs) from engineering (eBOM) through manufacturing (mBOM) and service (sBOM) is a challenge, which digital threads can address.
- Cost optimization and time savings come from shortened decision cycles and improved agility on both global and local bases. Accelerating innovation and bringing products to market faster are also important values gained from digital threads.
- The growing demand for various environmental, social and governance (ESG) initiatives are well supported by digital threads.

Obstacles

- **Intellectual property protection concerns and cyber risks:** These can dissuade members of value chains from participating in digital thread initiatives.
- **Difficulty achieving consensus on architecture and scope:** Different roles in value chains have a stake in digital threads. Each of these roles has different priorities, different content needs and different ways of interacting with data. Satisfying each role causes delays, and increases scope, cost and the risk of failure when implementing digital threads.
- **Vendor lock-in:** Manufacturers that rely on a few vendors to deliver large "chunks" of digital threads will likely become increasingly dependent on that vendor, particularly as the content and workflows added to a digital thread increase over time.
- **Technology obsolescence:** Technology advances rapidly expand the possibilities of digital thread architectures. However, the risk of obsolescence derives from committing to digital thread technologies that become obsolete before the intended life span of the digital thread.

User Recommendations

Supply chain leaders and CIOs looking to invest in and manage the digital thread should:

- Focus on building the digital thread as a representation of a product and all the processes that evolve over the product's life cycles, instead of confining it to engineering and production.
- Use the digital thread as a tool for improving efficient decision making, cost, quality, traceability and regulatory compliance in product design, manufacturing and service.
- Adopt an industry data governance strategy for a digital thread by including members of the value network in planning for data oversight, data orchestration, data curation and data management.
- Overcome the absence of a complete data model by investing in standards to capture, connect and normalize data from different systems.
- Include open standards as much as possible in the digital thread roadmap.

Sample Vendors

Anark; Aras; Schneider Electric (AVEVA); Dassault Systèmes; Exentra; Hexagon; iBase-t; Microsoft; PTC; Siemens Digital Industries Software

Gartner Recommended Reading

Innovation Insight: Implement Digital Threads for Long-Term Flexible Access to Critical Data

Top BOM Practices for Building Digital Threads in Discrete Manufacturing Industries

How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread

Implementing the Technical Architecture for Master Data Management

Quick Answer: 4 Technical Prerequisites for Successful Digital Twins Implementation in Manufacturing

Life Cycle Analysis Software

Analysis By: Lindsay Azim

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

Life cycle analysis (LCA) is a methodology that enables the end-to-end assessment of environmental impacts of products, assets or services. LCA requires complex data analysis to establish product carbon footprints, identify resource-intensive processes and prioritize product design changes to reduce environmental impacts. LCA software reduces the complexities of collecting data and completing the analysis, enabling organizations to assess trade-offs and make quicker strategic decisions.

Why This Is Important

LCA provides data-driven insight into where enterprises can make improvements across life cycle stages, including design, material inputs and resource-intensive processes, to reduce environmental impact. LCA software enables faster and more accurate data analysis needed for organizations to make trade-off decisions between environmental impact categories, differentiate themselves with customers, meet industry standards, and engage with suppliers on improvement activities.

Business Impact

Visibility of environmental impacts through LCA enables targeted improvements to meet reduction targets. LCA data verified by a third party is used to substantiate consumer-product claims to limit potential accusations of greenwashing. Additionally, requests for cradle-to-gate LCAs from suppliers help track and uncover hot spots for Scope 3 emissions reduction. The time required to collect data and perform a complex impact assessment necessitates the use of LCA software.

Drivers

- Pressure for increased transparency through product carbon footprint data is accelerating. There is a need to reduce cost, cycle times and complexity in establishing product carbon footprints.
- There is increased scrutiny of environmental claims and concerns of greenwashing by advertising regulators and NGOs, in addition to the stakeholder pressure to report the environmental impacts of products and services.
- Flexibility is needed to perform varying levels of analysis depending on the business need. This spans from full LCAs, which require significant budget and time investment, to an LCA “lite,” which is faster, able to be completed by nonspecialized staff, and suitable to inform internal decisions on strategic focus and new product development.
- Organizations need to interpret results and make quicker decisions on the environmental trade-offs between alternatives. LCA software makes it easier to perform a side-by-side comparison of one, or more, products and raw material inputs for product development.

Obstacles

- LCA software provides a modeled view of environmental impact, and the reliability depends on the quality of source data. A mix of primary and modeled data is collected and the level of uncertainty is often unknown. Supplier data (Scope 3) requires additional resources to review data quality.
- Full LCAs are no small feat and come with a significant price tag. In addition to software, outside experts and specialized skills are needed to complete this analysis. Additional costs are required for third-party verification if results are published.
- LCA software is a mix of generic, industry-specific or niche product tools (such as packaging), and it is difficult to select the most appropriate software to meet enterprise needs.
- There are a number of LCA standards (ISO 14040, 14044) in addition to country guidelines, such as PAS 2050 Carbon Footprint (U.K.) and International Life Cycle Data System (ILCD) on Life Cycle Assessment (EU). The variance in approach is a limitation to data comparability that makes using software more complex.

User Recommendations

- Assess the business need prior to selecting an LCA software. LCA software can speed up high-level assessments and decision making. However, in addition to software investments, full LCAs require additional data collection and external collaboration with industry experts.
- Determine the availability of data, including supplier (Scope 3) data, and understand how boundary conditions and assumptions will impact assessment uncertainty.
- Assess how the results from the LCA will be used, and integrate into process, design and strategic decision making.
- Determine what additional skills are needed internally to utilize software and complete an LCA. Budget for collaboration with external experts and third-party verification if necessary.

Sample Vendors

iPoint; One Click LCA; openLCA; SimaPro; Sphera; Trayak

Gartner Recommended Reading

Quick Answer: How Does Life Cycle Analysis Advance Sustainability?

How to Create Product Carbon Labels

Emerging Technologies and Trends Impact Radar: Environmental Sustainability

Model-Based System Engineering

Analysis By: Marc Halpern, Sudip Pattanayak

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Model-based system engineering (MBSE) is a digital approach to creating models that capture and simulate behaviors of systems and systems of systems. In this case, a system refers to an assemblage of items that function together to deliver intended value. The models identify the relationships among key variables within the systems and across systems. They also seek to determine the environmental or operating conditions that influence behaviors, in order to understand and improve those behaviors.

Why This Is Important

MBSE is descending into the Trough of Disillusionment despite gaining more importance and interest in many industries because products, infrastructures, processes and organizations have become complex and interdependent, elevating the need for improved systems modeling. Also, many organizations are realizing that enabling MBSE goes beyond just technology adoption and requires changing processes and culture.

Business Impact

Model-based system engineering:

- Replaces document-centric work environments with models.
- Facilitates communication and collaboration of product and systems stakeholders.
- Improves the organizational structure in digital enterprises.
- Cultivates better, more disciplined and cost-effective problem solving and decision making.

- Streamlines creation of product variants.
- Supports the planning and implementation of digital threads and digital twins.

Drivers

- The need for MBSE among manufacturers has been heightened by the increased use of software as a part of physical systems.
- Organizations facing increasing organizational, process and product complexity believe MBSE helps them manage the complexity better.
- Manufacturers seek to design and deliver individualized products more efficiently by designing product platforms instead of products.
- MBSE is core to modeling relationships across critical factors that enable digital threads and digital twins. Digital threads and digital twins are central to digital business strategies among manufacturers.

Obstacles

- The time and cost to produce trustworthy models with sufficient fidelity to real-world systems.
- Challenges in transferring the knowledge of best MBSE practices from a small knowledgeable community of experts to a broader market.
- Lack of standardized integration of systems that contain all the fragmented data needed to make MBSE executable.
- Poor adoption of standards that would make long-term use and reuse of the models more efficient.
- Difficulty in changing the behaviors of organizations in ways that would make MBSE practice more productive.
- The view of MBSE as an academic, formalized approach that mainly attracts asset-intensive industrial discrete manufacturers, undermining its adoption in companies other than asset-intensive manufacturers.

User Recommendations

- Gain support of the leadership team by estimating the ROI MBSE can deliver. This involves estimating the cost, benefits and time needed to break even.
- Start with a modest MBSE program with an intended business outcome, challenge or use case to get business decision makers involved and convinced of MBSE's value.
- Apply MBSE lessons learned to new MBSE initiatives.
- Recognize that systems improved through MBSE can affect the performance of other parts of a business that the system impacts. For example, changes to manufacturing operations will likely affect supply chain operations.
- Ensure integration of MBSE with IT platforms and other applications provides mapping between the requirements of the system being modeled and the technical specifications that meet those requirements.
- Plan for change management, including changes to organizations, roles, processes and practices, with experts in multidisciplinary roles and a focus on systems thinking.

Sample Vendors

Ansys; CIL4Sys Engineering; Dassault Systèmes; IBM; Intercax; Maplesoft; MathWorks; Modelon; Siemens; Sparx Systems

Gartner Recommended Reading

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

Innovation Insight: Why Engineering Technology, IT and OT Are More Than the Sum of Their Parts

Digital Twin

Analysis By: Alfonso Velosa, Marc Halpern, Scot Kim

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

A digital twin is a software-enabled proxy that mirrors the state of a thing, such as an asset, person, organization or process to meet business outcomes. There are three types of digital twins: discrete, composite and organizational. Digital twin elements include a model, data, a one-to-one association and monitorability. Digital twins are built into a range of software: analytics, 3D models, CRM and IoT. Data on the state of the thing must be sourced via telemetry or application state changes.

Why This Is Important

Enterprises are using digital twins to create virtual representations of previously opaque or time-lagged things. Digital twins can help meet business outcomes such as process optimization, improved visibility or new business models. Specific examples include improving supply chain decisions via better supply and demand visibility, and reducing downtime by monitoring equipment state. Tech providers are increasing value by building domain-specific templates and integration to data sources.

Business Impact

Enterprises are implementing digital twins to:

- Gain visibility into things such as equipment or customer state that enable people to make better maintenance or marketing decisions.
- Assess, simulate and reduce the complexities of designing and developing innovative products and new service models.
- Improve patient outcomes, employee safety and customer transactions by using digital twins of people.
- Drive new data monetization models and contribute to product-as-a-service business approaches.

Drivers

- Enterprises are accelerating their adoption of digital twins to support a broad variety of business outcomes. These business outcomes include reducing the cost structure through improved monitoring of assets and optimizing equipment and processes by aligning asset digital twins into a range of solutions, such as predictive analytics and field service management. They also include product differentiation by engaging consumers and controlling assets, and integrating data silos into one central visualization.
- Asset-intensive sectors — for example, oil and gas, transportation, manufacturing and buildings — are leading in using digital twins to optimize business processes such as product development, supply chain and operations.
- Leading OEMs are exploring how digital twins can help add long-term annuity streams to their regular revenue.
- Leading-edge enterprises are implementing digital twins to model book-to-bill status, foreign exchange risk and supply chain processes. They do so to optimize costs and improve processes.
- Technology providers — from large cloud vendors to startups — are identifying potential ways to serve and charge customers using digital-twin-enabling product portfolios. In particular, they are developing template libraries to demonstrate domain knowledge and to shorten time to value for enterprise customers.
- Standards organizations such as IEEE, Eclipse, ITU and consortia (including the Digital Twin Consortium) contribute to establishing digital twin standards, architectures, ontologies and improving visibility.

Obstacles

- Few enterprises understand what they are trying to achieve, let alone the metrics for digital-twin-based projects. This lack of vision limits project scope and investment into new business processes that can take advantage of digital twins.
- Few enterprises have the cross-functional fusion teams — across business, finance, operations and IT — that are required to achieve business outcomes powered by digital twins.
- Digital twins present a technical challenge for most enterprises due to the blend of operational and information technologies required to develop and maintain them.
- Pricing remains an art, and most vendors focus on their technology differentiation, even though customer organizations are looking for business value outcomes when purchasing digital twin offerings.
- Standards bodies remain emergent. Most vendors use proprietary formats. There is a lack of standards for a broad range of digital twin technical areas such as data source and model integration and metadata management.

User Recommendations

- Co-create the digital twin strategy with the enterprise business unit to identify opportunities and challenges and establish clear success metrics. Further, the business must select sponsors and super users, create a budget and build a roadmap that starts small and scales up.
- Avoid digital twin projects that lack a business sponsor as this is key to success. Lack of internal sponsorship will waste IT resources.
- Identify IT organization technology, governance and skills gaps and build a plan to resolve them.
- Protect intellectual property by working with procurement to ensure that digital twin data and custom models belong to the enterprise.
- Develop an architectural, security and governance framework to manage large numbers of discrete digital twins, as well as composite and organizational digital twins.
- Select vendors not just for their technology portfolio, but more importantly, for the intellectual property (IP) they have in your vertical market. The IP should be demonstrated in libraries of prebuilt digital twin precursor models.

Sample Vendors

Akselos; Esri; GBTEC Group; Mavim; Nstream; Sight Machine; Toshiba; TwinThread; Vanti; visCo

Gartner Recommended Reading

Quick Answer: What Is a Digital Twin?

Emerging Tech: Tool — Digital Twin Business Value Calculator

Life Cycle Management of Software-Defined Vehicles: Step 3 — Vehicle Digital Twin 2.0

Quick Answer: Privacy Basics for a Digital Twin of a Customer

Emerging Tech: Tech Innovators for Digital Twins — Digital Business Units

Cloud for Product Development

Analysis By: Sudip Pattanayak, Christian Hestermann

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Cloud for product development refers to all facets of product design, engineering and data management, performed on a cloud platform. Cloud is used as an infrastructure for high-performance computing, scalability and as-a-service platform to increase collaboration, break the traditional application silos in manufacturing, enable business automation and improve application user experience.

Why This Is Important

Using a cloud-first approach improves manufacturers' agility in product design and enhances collaboration and support throughout product life cycles. Industry-specific, cloud-based product development applications, such as computer-aided applications (CAx) and product life cycle management (PLM) software, can scale and leverage API-enabled building blocks to develop composable architectures. Product development in the cloud is accelerating the adoption of technologies such as digital threads.

Business Impact

Cloud for product development has the following business impacts:

- It accelerates new product development by making collaboration easier through the engagement of online engineering communities (mechanical, software and system architecture) across geographic locations.
- It enables faster adoption of new business features in product development software like PLM, with DevOps and DataOps practices.
- It entails lesser total cost of ownership (TCO) than on-premises solutions, when the cloud-based solution's capabilities are aligned with enterprise needs.

Drivers

- The prevalence of SaaS for other business software is encouraging the shift of engineering and product data management solutions to the cloud.
- Today's hybrid work environments are driving the need for a well-performing product development software suite accessible from anywhere using the internet.
- Enterprise applications, including product development solutions, are required to comply with global IT technology and security standards. Cloud-based software allows standardization of application software development, deployment and security measures.
- Cloud-based low-code applications enabling rapid business automation capabilities are now mainstream across all enterprise applications. Product development applications such as PLM use low-code platforms to improve end-user experience.
- Manufacturers are seeking means to improve collaboration across partners, suppliers and customers, which cloud-native applications and business models enable.
- Cloud platforms are accelerating the benefits of data-driven frameworks such as digital threads, by leveraging cloud-based integration, data intelligence and advanced AI/ML technologies.

Obstacles

- There are concerns about dependency on a single application vendor offering product development solutions in the cloud, inadvertently blocking the selection of the best-of-breed software.
- Adopting cloud-based engineering and data management solutions involves business process reengineering efforts for optimal outcomes. However, this step is ignored as it feels cumbersome and unnecessary, which undermines the benefits of cloud.
- The license models and yearly cost impacts of cloud software of applications, such as CAD or PLM, are not well-explained, raising concerns about the cost benefits of migration to the cloud.
- Cloud product development applications must interface with other software and require seamless data exchange. However, the interoperability of product development solutions operating in specific cloud platforms can be restricted due to architectural limitations.
- Large product data file transactions, especially design and simulation, between cloud and on-premises applications can cause significant performance challenges.

User Recommendations

- Develop a robust transition plan from on-premises to the cloud by considering the benefits and risks of cloud product development applications.
- Engage stakeholders from different value streams and use cloud adoption guidelines to evaluate the technical and business process feasibility, software selection/upgrade, and deployment tasks. This includes understanding the cloud-based license models to optimize the cost of adopting cloud-based solutions.
- Align with cloud licensing models that offer flexibility and the ability to optimize TCO over fixed contract periods.
- Design an interoperability framework across applications by ensuring your enterprise architecture harmonizes with other solutions and allows data orchestration and integration.
- Adopt cloud product development software that aligns with your customization and performance requirements as well as your intellectual property protection needs.

Sample Vendors

Altair; Aras; Dassault Systèmes; Infor; Propel Software; PTC; Siemens

Gartner Recommended Reading

How to Plan for a Successful Adoption of SaaS PLM

Presentation: Industry Cloud Platform Adoption by Vertical Industry

What Manufacturing CIOs Must Know About Industry Cloud Platform Adoption

Climbing the Slope

3D Printing of Industrial Parts

Analysis By: Ivar Berntz, Marc Halpern

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

3D printing (3DP) of industrial parts refers to the use of 3DP to produce a finished item, subassembly or intermediate product. It can also be used to print tools, jigs, fixtures, dies and molds that would be used during the production of finished goods. This applies to OEMs and their suppliers, which can produce items on an assembly line or in a machining, casting or forming line using 3DP.

Why This Is Important

Manufacturers continue to use 3DP, for its perceived cost and time advantages, to produce customized complex products just in time (JIT) and simplify supply chain logistics and manufacturing operations. CIOs must become familiar with 3DP because it is an operational technology (OT) enabled by engineering technology (ET), but depends on IT to operate efficiently and effectively.

Business Impact

3DP for industrial parts is being used to eliminate bottlenecks in manufacturing and supply chain operations and enhance business resiliency. It reduces the inventory required for spare parts and tools and can quickly produce customized products with new material combinations and complex geometries. It transforms manufacturing operations and service with its ability to produce industrial parts JIT instead of purchasing them or using a service bureau.

Drivers

- 3DP advances the popular goal of lean manufacturing for industrial, asset-intensive organizations and offers shorter lead times, since inventories of spare parts can be reduced and supply chain operations streamlined.

- 3DP helps in improved cost position, higher design reuse, faster product launch and introduction and better aftermarket services for industrial manufacturers, resulting in improved competitive value.
- 3DP directly uses 3D data from geometric design models, either created from scratch or scanned from existing products. 3DP eliminates the additional work needed to translate 3D data into execution instructions for mainstream manufacturing operations.
- 3DP offers design and structural freedom, leading to the development of in-house capabilities such as prototyping and design verification. Since it is an additive procedure, expensive raw material and resources are not wasted.
- The technology advances the ability to increase the energy efficiency and durability of products, especially across the aerospace, defense and automotive industries. It can produce products with complex shapes, and high strength and weight resistance, that cannot be produced with traditional manufacturing techniques.
- Consumers increasingly demand personalized products, which can be delivered more rapidly through 3DP. These individualized products are also more scalable and less costly than other manufacturing approaches, where the major cost arises from the molding process for low-volume products.
- 3DP is part of a technology convergence trend that stimulates innovation where there are advances in material science and the ability to embed technologies (e.g., sensors, actuators, computer chips) in larger 3D-printed industrial parts through nano 3DP.

Obstacles

- 3DP's investment cost and production time continue to be a major challenge for producing industrial parts. This can be overcome by planning the technology's adoption roadmap and leveraging service bureaus to scale production.
- The multiple parties involved in the 3DP process lead to siloed adoption. This results in poor integration between 3D printers and designing software (the OT and ET components), and workflow software such as manufacturing execution systems (MES), ERP and SCM (the IT component).

- Owing to limited materials available for industrial parts production, there are concerns around the reliability and performance of these products, especially under adverse environmental conditions of high temperature, resistance and chemical exposure.
- Insufficient training, education and awareness to use 3DP technologies and materials efficiently is decreasing the technology's uptake.
- IP related to industrial products' ideas and design must be safeguarded, or it will be subject to financial losses and lost growth opportunities.

User Recommendations

- Partner with the decision-making teams in the organization (finance, engineering and operations) to validate the viability of 3DP technologies by building an investment case.
- Align the involved parties to create a connected workflow to create an IT-ET-OT alignment.
- Audit and invest in IT components needed to connect 3D printers with workflow and design applications such as CAD, PDM, ERP and MES that capture content needed for 3DP operation.
- Augment the production of tools and fixtures by encouraging the use of 3DP. This will result in a shorter lead time and pay for the initial cost and time investment.
- Work with supply chain leaders to assess the potential impact of 3DP on your extended supply chain across activities such as sourcing of parts, maintenance, overhaul and repair.
- Monitor the advances in 3DP and materials technology and discuss with decision makers to evaluate the benefits to manufacturing and supply chain operations.

Sample Vendors

3D Systems; Desktop Metal; EOS; Fictiv; GE Additive; Markforged; Materialise; Protolabs; Stratasys; Xometry

Gartner Recommended Reading

IT/OT/ET Alignment With 3D Printing Enhances Scalability

3D Printing Will Accelerate Design and Product Innovation in Existing Manufacturing Setups

The Manufacturing CIO's Role in Adopting and Scaling 3D Printing

Market Guide for 3D Printer Manufacturers

Quick Answer: Mapping Design for Additive Manufacturing Tools to 3D Printing Use Cases

Model-Based Manufacturing

Analysis By: Marc Halpern, Rick Franzosa

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Model-based manufacturing (MbM) refers to the use of digital models of factories, assets, resources and processes rather than document-based content and physical models to plan, validate and monitor the manufacturing of products.

Why This Is Important

MbM, moving up the slope, is core to digital manufacturing, MbM:

- Is key to digitalizing manufacturing businesses.
- Reduces manufacturing costs because factory layout, movement of materials, and factory operations are tested with computer models before committing to capital investments.
- Saves time and money by leveraging the manufacturing models to program, simulate and validate manufacturing processes.
- Is needed to create digital twins and digital threads of factories and operations.

Business Impact

MbM cuts iterations out of activities such as defining manufacturing facilities, processes and programming factory automation. Users identify bottlenecks and programming issues by simulating factory operations before commencing or changing/enhancing their factory operations. MbM saves substantial time and money in automation corrections and reduces scrap resulting from faulty manufacturing ramp-up. Some users reported 20% to 30% cost reductions during scale-up to production.

Drivers

- Manufacturing strategists believe that MbM saves considerable cost and time by reducing the number of iterations necessary to start manufacturing ramp-up.
- The technology enablers, such as Internet of Things, machine learning, modeling tools, simulation tools and remote access, continue to advance — building increased confidence in MbM.
- MbM has a very strong linkage to digital twins and digital threads, which are high in digitalization hype.
- MbM success stories are growing in number, with savings that are compelling enough to minimize initial cost concerns.

Obstacles

- MbM requires substantial planning and investment to build the technology platform. It involves the orchestration of engineering technology, information technology and operational technology.
- Interfaces must be built between ERP, MES/MoM, PLM, CAD and CAE. Interfaces are also needed for remodeling and simulation tools addressing factory layout, workcell layout, manufacturing operations, part and materials movements, machining operations and workflow.
- The cost and complexity of orchestrating these technologies can be an inhibitor.
- MbM requires training and experience to build skills and confidence. Engineering operations typically have deeply ingrained culture, practices and processes. Discomfort with making these changes can be an obstacle.
- The creation and validation of complex process simulation models requires skill sets that may not be readily available in manufacturing.

User Recommendations

- Plan for MbM by encouraging the creation of an integrated architecture for MbM and a roadmap to accomplish that architecture.
- Manage risk and complexity associated with MbM infrastructure by adopting model-based system engineering approaches to design and validate that the architecture brings together the ET, IT and OT elements.
- Continually nurture, maintain, improve and update MbM as manufacturing knowledge evolves.
- Set expectations properly by explaining to business stakeholders that MbM will require significant initial and ongoing configuration effort.
- Advise engineering and manufacturing leaders to adjust job training and performance metrics in ways that encourage MbM adoption, and cultivate collaboration with R&D and engineering to ensure that efforts are aligned.

Sample Vendors

AspenTech; AUCOTEC; Autodesk; AVEVA; Dassault Systèmes; iBase-t; PTC; Rockwell Automation; Siemens Digital Industries Software

Gartner Recommended Reading

Top Strategic Technology Trends in Asset-Intensive Manufacturing for 2023

Product Innovation Platforms

Analysis By: Marc Halpern

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

A product innovation platform is a cloud-native IT infrastructure that cultivates and supports continuous creativity through collaboration and enriched design functions.

Why This Is Important

Product innovation platforms are moving toward the Plateau of Productivity. Demand is high because:

- Manufacturers want to deliver innovative products faster.
- Increased cloud maturity makes highly functional product innovation platforms possible.
- They allow designers and engineers at different sites to work together more effectively, shortening design time.
- CIOs seek platform as a service, such as product innovation platforms, to reduce the IT costs of maintaining applications used to design new products.

Business Impact

The business impacts of product innovation platforms include:

- Manufacturers having greater agility in developing new products with product development team members working in different locations globally and in navigating changing requirements and market conditions.
- Advances in social networking enabling a greater infusion of new ideas, mashups and domain expertise.
- Eliminating product data management tasks such as version control and design history, leaving more time for users to focus on creativity.

Drivers

- Product development applications, used for decades, are becoming obsolete. Manufacturers seek to modernize IT and applications used for new product development.
- Supply chains and customers are increasingly involved in new product development. Manufacturers, suppliers and customers need a common IT platform that makes communication for product development more efficient.
- Manufacturers seek ways to shorten product development times and reduce costs. They see product innovation platforms as a means to accomplish that.
- Product development team members working from remote locations need a platform with rich collaboration capabilities that also includes requisite design and engineering functionality.
- IT organizations, in an effort to offload technical management of product development applications that demand high-performance computing, seek SaaS and managed services from external partners.

Obstacles

- Product innovation platforms are insufficiently open to working easily and reliably across diverse third-party applications and their data.
- Manufacturers are so deeply invested in their current product development and product life cycle (PLM) environments that it is difficult for engineers and designers to adapt to the new ways of working that product innovation platforms require.
- Manufacturers find it daunting to cleanse legacy data and enable new data architectures to work efficiently and effectively with product innovation platforms.
- Culturally, designers and engineers feel more comfortable with design content residing on their own hard drives.
- Designers and engineers occasionally report that the performance and functionality of product innovation platforms do not yet match the performance and functionality of legacy on-premises applications.

User Recommendations

- Enable CIOs and IT leaders to keep abreast of product innovation platforms, as these platforms continue to evolve and are adopted to enhance product design, manufacturing activities and product services.
- Acknowledge that these are conceived to run in the cloud and that performance will be a priority, particularly for graphics-intensive visualization, modeling and simulation activities.
- Be acutely aware of software architecture when judging the level of performance running in the cloud and at what cost.
- Make open architecture a priority when selecting these platforms to ensure that they work with complementary applications such as CRM, ERP and MES.
- Take caution to ensure that the platform meets cybersecurity needs.
- Ensure IT organizations use product innovation platform adoption as an opportunity to update product development data and product data architectures.
- Ensure that value networks establish guidelines for sharing and protecting intellectual property.

Sample Vendors

Aras; Autodesk; Dassault Systèmes; Eurostep; Onshape; PTC; SAP; Siemens

Gartner Recommended Reading

2023 CIO and Technology Executive Agenda: An Asset-Intensive Manufacturing Perspective

Building Information Modeling

Analysis By: Marc Halpern, Bettina Tratz-Ryan

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Building information modeling (BIM) is the discipline supported by software to capture, organize and manage information needed to design, create, monitor, repair, evolve and operate facilities from earliest conception to demolition.

Why This Is Important

Increases in regulations governing design, construction, operations and maintenance of facilities compounded by the number of roles involved in these activities require better means of managing and accessing information. So, organizations in many industry sectors including construction, government, manufacturing and retail need better means of organizing and accessing content about their facilities to streamline facilities design, construction, management, operations, modernization and demolition.

Business Impact

BIM delivers the following benefits:

- Reduces lost time and unnecessary costs associated with using wrong or out-of-date content throughout the life cycles of facilities.
- Improves ability to find and access content to support any activity such as facilities design, construction, operation, upgrade, maintenance and demolition of facilities.
- Improves collaboration across many roles responsible for the life cycles of facilities.
- Enhances sustainability and circularity over the life cycles of facilities.

Drivers

- As the costs of constructing and operating facilities continue to rise, facility owners, construction firms and operators seek means to increase efficiency of life cycle activities by reducing cost and time.
- Product development team members working from remote locations, instead of at a central location, need a platform with rich collaboration capabilities that also includes requisite design and engineering functionality.
- Technology advances and growing experience with BIM encourages more companies to adopt it.
- Prevalence of SaaS for other business software encourages cloud-native BIM.
- Manufacturers, utilities and architectural engineering and construction firms seek better means of complying to a growing number of regulations (such as those here in Six construction regulatory issues looming in 2020 by Construction Management) that they believe BIM will support more efficiently.
- Stakeholders in facilities seek to reduce costly mistakes with BIM by enabling better access to more timely and accurate information.
- BIM enables improved collaboration across roles participating in life cycle activities from remote locations.

Obstacles

- Engineers and contractors are deeply invested in their current culture and processes, making it difficult to adapt to new ways of working that BIM requires.
- Reaching consensus on BIM priorities and architecture proves challenging given the number of involved roles both inside and outside an enterprise.
- There will be a need for a champion investor.
- The lack of digitized data, especially among constructors, poses challenges to BIM adoption.
- BIM champions struggle to make compelling business cases for the investment.
- Building BIM content in proprietary design software formats will decrease its utility over time, cause vendor lock-in and increase the cost to maintain BIM.
- BIM projects will fail if scope creep creates higher-than-expected costs and lower-than-expected ROI. Insufficient supplier, partner and customer participation in BIM initiatives can lead to gaps in key content.
- Inflexible or incorrect BIM model design undermines future usefulness or possibly makes it obsolete before the end of a facility's service life.

User Recommendations

- Reduce the risk of failed BIM implementations by phasing the implementations into smaller, focused projects that build upon each other.
- Structure BIM initiative using governance or maturity models. Use both the BSI Levels 0 through Level 4, and incorporate 2D BIM to 7D BIM (as explained by NBS in BIM Levels explained) categories of data as the company moves from one level of BIM maturity to the next.
- Address BIM data architecture challenges by assigning IT architects to work with key BIM stakeholders.
- Encourage BIM adoption by redefining job performance metrics that encourage potential users to adopt BIM.
- Assign a BIM lead to run a project defining corporate standards for creating and modifying BIM models, and establish a training program to educate the user community.

Sample Vendors

Asite; Autodesk; Bentley Systems; Hexagon; Nemetschek Group; RIB Software; Trimble

Gartner Recommended Reading

Innovation Insight for Building Information Modeling

Creating Sustainable and Innovative Smart Buildings Through Data

Master Data Management

Analysis By: Sally Parker

Benefit Rating: High

Market Penetration: More than 50% of target audience

Maturity: Mature mainstream

Definition:

Master data management (MDM) is a technology-enabled business discipline in which business and IT work together to ensure the uniformity, accuracy, stewardship, governance, semantic consistency and accountability of the enterprise's official shared master data assets. Master data is the least number of consistent and uniform sets of identifiers and extended attributes that describe the core entities of an enterprise.

Why This Is Important

MDM is a cross-organizational collaborative effort that focuses on the consistency, quality and ongoing stewardship of master data. Master data is the subset of data that describes the core entities an organization requires to function — customers, citizens, products, suppliers, assets and sites. Master data sits at the heart of the most important business decisions, driving a need for a consistent view across business silos.

Business Impact

MDM initiatives are progressing as a foundational component of digital transformation. Leading organizations draw a causal link between their master data (parties, things and places) and the business outcomes it supports, including customer retention, supply chain optimization, and risk and regulatory compliance.

Interest in MDM extends to a broad range of vested-interest stakeholders, including finance, marketing and supply chain. MDM is now mainstream. Organizations seeking a single view of their master data recognize it as a necessity.

Drivers

- MDM is not a new concept, but adoption varies across geographic regions, with North America the most mature region, followed by Western Europe. The rest of the world is earlier in the maturity cycle and representative of markets primed for growth.
- Business process integrity eludes organizations with complex or heterogeneous application and data landscapes. Such organizations can suffer from inconsistent master data and/or a lack of trust in their master data. Organizations are increasingly recognizing the direct and causal link between this data and business outcomes, which MDM is designed to address.
- Rapidly evolving business needs, particularly in uncertain times, translate into greater demand for the benefits afforded by MDM — notability agility. The COVID-19 pandemic, which initially stalled projects, ultimately served to fast-track a broader realization of the causal link between trusted and connected master data and business resilience.
- Interest levels are increasing across a broader range of stakeholders (beyond technology), in both private and public sectors.
- A prior hesitance to embark upon MDM initiatives, due to complexity and cost, is easing.
- The barrier to entry has dropped significantly over the past two years with the broader availability of cloud-based and subscription-based MDM vendor offerings, which are now the most dominant offerings for net new clients. This lowering of the barrier to entry renders MDM viable for a broader target audience that comprises small and midsize organizations.
- A shift in mindset toward a more granular and business-outcome-led MDM program is reflected in the MDM vendors' "land and expand" strategies, where clients start small and progress toward incremental mastery of use cases and domains.
- Digital transformation requirements are forcing organizations to either start or modernize their MDM programs to leverage more recent cloud-based offerings and new augmented MDM capabilities.

Obstacles

- **Lack of consistent vendor presence:** Coverage is weaker outside North America and Europe.
- **Technology blinkers:** The prevailing pitfall remains the instinct to treat MDM as a technology initiative in isolation. Technology alone won't solve a challenge that traverses people, processes and technology.
- **Human factors:** Organizations that fail to proactively engage business stakeholders in scoping struggle to meet expectations of value and to establish an operational governance structure in service of MDM.
- **Goals:** MDM is still too often seen as an IT project. When MDM is a data or IT project that doesn't align to business outcomes, it fails.
- **Perceived complexity:** The MDM solutions market only recently shifted toward subscription pricing, cloud-based offerings and simpler products, which contribute to more approachable solutions and shorter deployment times.
- **Skills:** Successful MDM implementations require business acumen, technology and governance capabilities. Finding the right balance and availability of these skill sets remains problematic and is driving a need for third-party services as the norm.

User Recommendations

- Use business outcomes to identify the least amount of data with the greatest business impact.
- Approach MDM as a technology-enabled business-led initiative.
- Secure executive sponsorship to facilitate cross-organizational collaboration.
- Ensure that the causal link between the MDM initiative and the business outcomes it supports is clearly understood and articulated.
- Keep your master data attributes lean and focused.
- Leverage third-party services to fast-track time to value. The majority of organizations leverage external support with their MDM strategy and/or implementation. Third parties offering industry expertise and accelerators can greatly impact time to value.

Gartner Recommended Reading

3 Essentials for Starting and Supporting Master Data Management

Create a Master Data Roadmap With Gartner's MDM Maturity Model

Data and Analytics Essentials: Master Data Management — Presentation Materials

Synchronized BOMs

Analysis By: Christian Hestermann, Marc Halpern, Alexander Hoeppe

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Practices and technologies for synchronized bills of materials (BOMs) associate and update equivalent items from different BOMs, such as engineering, manufacturing, sales and marketing, and service. At the same time, they enable each of the items in the BOMs to be labeled and structured differently.

Why This Is Important

Synchronized BOMs are in early mainstream in maturity and remain important because they:

- Reduce errors in product data to facilitate the integrated engineering change process (including version control)
- Enable central management of BOM synchronization and configuration rules
- Streamline design-to-manufacturing-to-service-to-retire workflows
- Shorten the time from design completion to product manufacturing
- Reduce scrap, rework and inventory shortages
- Increase flexibility to deliver individualized products
- Make replacement parts easier to identify

Business Impact

Successfully synchronizing BOMs:

- Saves time and the cost of updating and validating BOMs by automating manual and error-prone activities.
- Avoids the risks of wrong orders shipped from suppliers and to customers, since BOM changes are automatically translated to BOM item identifiers recognizable to the recipients.
- Makes tracking and tracing the origins and sourcing of BOM items more efficient to improve product quality and deliver more-reliable product service.
- Enables reliable and consistent decision making on configurations, prices and product status.

Drivers

- Manufacturers must digitalize to remain competitive, and BOM synchronization is an important element of any manufacturing digitalization initiative. Synchronized BOMs are an essential component of digital thread initiatives.
- In industries such as aerospace and defense and life sciences, traceability is key for regulatory compliance. BOM synchronization is a key enabler for traceability.
- Supply chain efficiency improves cost and time to market. Synchronizing BOMs improves that efficiency, because it lessens the ambiguity about which parts the BOM items refer to.
- Enhancing product quality and improving customer experience requires synchronizing BOMs to support engineering change control by which valuable product enhancements flow back from manufacturing or service activities into the product design.
- Environmental, social and governance ambitions (ESG) mandate longer lifetimes for a variety of products by servicing and repairing them instead of replacing them. Service and repair activities, whether executed by the original manufacturer or by third-party service partners, are enabled by intracompany and intercompany BOM synchronization.
- Scalable mass customization and product servitization business models elevate the importance of BOM synchronization in reducing the risk that wrong parts and features will be added to customer-specific products.
- Product and system structures become more complex as more software components are added. This elevates the priority of BOM synchronization as more BOM types and more-complex configurations of product and system content are introduced.

Obstacles

- BOMs impact many roles in an enterprise (and supply chain) with different priorities. The differences in priorities make it difficult to reach consensus on how to synchronize BOMs.
- Often, there is contention about who (and which system) owns BOMs. That responsibility needs to be resolved across multiple roles.
- The automation that synchronizes BOMs can cause errors. It takes time to determine the extent to which the automation is feasible and to build confidence in the automation programmed.
- BOM information and sync rules are hidden in siloed applications (like product life cycle management [PLM], ERP, manufacturing operations management [MOM] or simply Microsoft Excel) and point-to-point interfaces. This makes it difficult to manage engineering and order changes.
- Replacing OEM parts with substitutes during service life may require changes to BOM structures. This complicates BOM synchronization and management of the life cycle of digital twins.

User Recommendations

CIOs responsible for IT that supports BOMs must:

- Reduce conflicts over BOMs by encouraging engineering, manufacturing, procurement and service owners to plan BOM synchronization strategies.
- Improve the ability to identify the parts and materials in BOMs reliably by working with BOM stakeholders to plan the use of “nonintelligent” and “intelligent” naming for BOM items.
- Improve the efficiency of BOM use across supply chains by structuring BOMs with as few levels of hierarchy as practicable.
- Reduce the complexity of managing BOM data by modularizing and standardizing BOMs, based on customer-specific features of the final product to the extent possible.
- Identify technologies that support and automate synchronized BOMs across applications.

- Improve the transparency of BOM content by adopting search and reporting functionality to analyze BOM item usage.
- Rightsize the investment in synchronizing BOMs by studying data architecture, master data management techniques, training and talent to implement it.

Sample Vendors

Aras; Arena; Dassault Systèmes; iBASEt; OpenBOM; Proplanner; PTC; Siemens

Gartner Recommended Reading

2023 CIO and Technology Executive Agenda: An Asset-Intensive Manufacturing Perspective

Innovation Insight: Implement Digital Threads for Long-Term Flexible Access to Critical Data

The State of Master Data Management

Top BOM Practices for Building Digital Threads in Discrete Manufacturing Industries

How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread

Predictive Product Costing Software

Analysis By: Marc Halpern

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Mature mainstream

Definition:

Predictive product costing software predicts, captures and manages product costs over product life cycles. Besides the enabling technology, this innovation includes the discipline, organizational factors and processes to continually improve product costing competency.

Why This Is Important

This innovation is in the mature mainstream, as the growing complexity of products and markets is compelling manufacturers to use software to manage product costs. It enables designers and engineers to more easily factor life cycle costs into their design decisions, reducing life cycle costs. For example, products in fast-moving consumer goods have short life cycles, and buyers are extremely price-sensitive; so small design changes can mean big cost savings.

Business Impact

Businesses can improve ROI with predictive product costing software, as:

- Predictions guide reductions in manufacturing, sourcing and warranty costs.
- Predicted costs guide negotiations with suppliers and outsourced manufacturing services.
- Analytics generated offer insights into how costs can be reduced with minimal impact on product performance throughout product life cycles.
- Costing provides insight into target pricing that will deliver profits.

Drivers

- As IT becomes increasingly important to business performance and business leaders involve CIOs more in business strategy, CIOs can add business value by enabling greater product cost savings without compromising product quality.
- Globally, manufacturing is becoming increasingly cost-competitive. Initiatives such as product cost management improve competitiveness.
- Digital methods of managing product costs align with digital business as a top initiative among manufacturers.
- Variation in cost of parts, raw materials and energy is encouraging more disciplined cost management practices supported by software.
- Increasing need for best sustainability practices has implications for product costs that must be managed.
- The enabling software applications have become increasingly mature due to enrichment with advanced analytics capabilities and deeper integration with core business applications such as product data management (PDM), manufacturing execution system (MES) and ERP, giving manufacturers more confidence to adopt them.

Obstacles

- Adopters need more reliable methods and data to predict the cost of materials, parts, services and processes to build greater confidence in product cost management.
- Product development teams must be more conscious of cost impacts when designing. Designing for function and reliability has traditionally been a higher priority. Cost as a priority must be elevated.
- In some manufacturing verticals, particularly durable goods industries, product costing professionals are not adequately connected to product development teams organizationally. This is challenging because cost estimators may not have the latest design changes that can impact costs.
- Poor data quality across different systems creating, sharing and updating product master data undermines confidence in cost management software.
- Product costing involves analysis of activities as well as material costs. This demands challenging integration of applications such as ERP, product life cycle management (PLM) and project management applications.

User Recommendations

- Find the best software fit for your company by investigating cost management software options. Consider the trade-offs of product cost management "add-ons" to ERP and PLM software and specialty software.
- Help the business build confidence in costing software by encouraging business units to calibrate the predictive cost models, leveraging historical data and generative artificial intelligence
- Contribute to the culture and practice of product cost management by working with business leaders to identify subject matter experts and creating a central group that provides ongoing oversight and governance of costing activities.
- Ensure product master data quality by creating common data models for product and product-related data, which need to be updated continuously during the course of regular master data governance processes.

Sample Vendors

3C Software; aPriori; Boothroyd Dewhurst; Cognition; FOG Software Group; Oracle; pVelocity; SAP; Saphirion; Siemens Digital Industries Software

Gartner Recommended Reading

Top BOM Practices for Building Digital Threads in Discrete Manufacturing Industries

Innovation Insight: Implement Digital Threads for Long-Term Flexible Access to Critical Data

Top Strategic Technology Trends in Manufacturing and Transportation for 2023

Top Strategic Technology Trends in Manufacturing and Transportation for 2023 — Presentation Materials

Entering the Plateau

Plant Engineering and Design

Analysis By: Marc Halpern

Benefit Rating: High

Market Penetration: More than 50% of target audience

Maturity: Mature mainstream

Definition:

Plant engineering and design refers to a suite of factory layout and design capabilities involving 3D modeling, drawing and simulation software. The software is used to conceptualize, define, document and evaluate a plant that will be newly built or is being upgraded. It includes mathematical tools for simulating part and material flows, chemical processes and worker safety, and analyzing life cycle costs, efficiency and sustainability.

Why This Is Important

Plant engineering and design is important because it accelerates digitalization of plants, minimizing the risk of faulty factory design. It also shortens the time to create factory digital twins that can reduce factory operating costs.

Business Impact

Cost and time savings and better factory efficiency come from:

- Identifying problems in factory design and planned construction before committing to construction and modernization
- Aligning product engineering with factory and process planning
- Improving factory operational efficiency and sustainability
- Improving manufacturing agility
- Reducing factory planning errors
- Using the virtual models as the basis of factory digital twins and virtual commissioning

Drivers

- Manufacturers report that reducing costs and improving employee and equipment productivity is a top priority. They perceive that factory digitalization streamlines activities by making factory content more accessible.
- Interest in the use of simulation technologies to streamline factory activities and processes is also growing, buttressed by improvements in the simulation technology capabilities, ease of use and performance.
- Industrie 4.0 thinking extends factory reach to include external partners and even customers. This encourages manufacturers to rethink the factory itself and the nature of the software needed to plan, design and construct, and share manufacturing facilities in virtual environments.
- The concept of “virtual commissioning” or running a physical plant from a virtual model or “digital twin” is gaining mind share. This software helps create those virtual models.

Obstacles

- Although some interfaces and standards exist for sharing data, they are not yet sufficient to easily build models using multiple software applications.
- Since the costs and time to build such models are high, making the business case for this level of investment can prove challenging.
- The majority of such software is not built to run on the cloud and will take years to rewrite for optimal performance and sufficient functionality on the cloud.
- Deciding on the level of fidelity of the virtual models to the actual plant can be challenging. Insufficient fidelity will not deliver business benefits. Very high fidelity can be costly to produce without providing additional business benefit.
- It is difficult to keep the models updated.
- Since most factories are unique, it is difficult, if not impossible, to create templates that can automate the engineering and design effort across multiple factories.

User Recommendations

CIOs responsible for enabling plant engineering and factoring must:

- Involve factory design specialists, manufacturing/industrial engineers and plant maintenance engineers in selecting such software.
- Orchestrate all of the key stakeholders. CIOs must be the drivers for alignment and collaboration for the IT-related issues when creating the original models and updates to models.
- Assign a team to orchestrate IT, engineering technology and operational technology.

Implementers responsible for converting 3D plant designs and existing plants into digital twins must:

- Enable the digital twins by adopting a combination of 3D modeling software, scanning technologies and simulation technologies, as appropriate.
- Validate the reliability of importing geometric data and nongeometric data into the chosen factory modeling software by comparing imported data to the actual factory. Then compare measurements on the virtual model to measurements in the actual factory.

Sample Vendors

AspenTech; Autodesk; AUCOTEC; AVEVA; Bentley Systems; Dassault Systèmes; Hexagon; PTC; Siemens

Gartner Recommended Reading

Quick Answer: 4 Technical Prerequisites for Successful Digital Twins Implementation in Manufacturing

Innovation Insight: Why Engineering Technology, IT and OT Are More Than the Sum of Their Parts

Product Requirements Management

Analysis By: Marc Halpern, Sudip Pattanayak

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Product requirements management (PRM) captures customer and market needs ranging from subtle preferences to specific technical necessities. The technical necessities can span mechanical, electrical, chemical, material and software dimensions.

Why This Is Important

PRM is in early mainstream adoption and remains valuable because:

- Understanding what customers, markets and regulatory authorities require from products is fundamental to delivering products and product platforms that are successful.
- As customers demand more customized products, capturing and organizing product requirements is a need that software can address.
- Where software is part of physical products, reporting requirements changes in real time is key to successful product delivery.

Business Impact

PRM:

- Helps capture and manage what customers and regulators expect from products.
- Shortens the time needed to verify design objectives and regulations such as those addressing sustainability and safety.
- Notifies product development teams when product requirements change.
- Increases the confidence that designs meet objectives when delivered.
- Reduces reworks of designs and products (avoiding delays), lowers life cycle costs, and enhances product and project successes.

Drivers

- Product and project stakeholders must capture, organize, track and evolve requirements at all stages of a product life cycle: design, manufacturing, service life, product discontinuation and disposal.
- Manufacturers feel increased pressure to deliver products that satisfy fast-changing customer and market needs.
- Manufacturers seek to extend traceability of products back to requirements.
- As markets continuously move toward customer-specific products, manufacturers need better means of tracking product requirements for each category of customers in different markets.
- Software requirements are hard to manage, and they change fast. IT enables real-time notification for changes to requirements.
- Product development teams are becoming distributed more globally, and a growing number of product developers work from remote locations. Therefore, it becomes increasingly difficult for them to have a common understanding of product requirements as they attempt to work collaboratively. Enterprise PRM software addresses that need.
- Product requirements become more complex as markets become more global. Increasingly, manufacturers need enterprisewide management software to keep track of different requirements for different markets as the combinations of requirements become more complex.
- Global regulations addressing issues such as sustainability, safety and localized preferences complicate requirements management, so PRM is needed.

Obstacles

- The culture of capturing, classifying, prioritizing and reusing product requirements in office applications, and even more informally via instant messages and emails, is deeply ingrained. These approaches cause errors due to incomplete communications and late updates. It is challenging to win acceptance of enterprisewide PRM because it requires more discipline and structure.
- Enabling enterprise PRM software requires the import of requirements from many different sources that have different formats and different semantics. Manufacturers struggle with enabling a common format and semantics to import requirements in a common format usable in the PRM application.
- Different categories of requirements across mechanical, electronics, software, system design, government regulations and others need different representations yet must be related since they are interdependent. PRM adopters struggle to find comprehensive approaches to capturing the categories of requirements in a harmonized way.

User Recommendations

- Adopt enterprisewide PRM to replace the informal use of office tools, emails and messaging for requirements that need to be shared.
- Ensure that enterprise PRM offerings are best-in-class solutions that are integrated or interfaced with relevant software categories, such as product development applications, product life cycle management (PLM), quality management (QM), cost management applications, CRM and ERP.
- Identify and validate the methods of importing requirements from external sources in formats that are compatible with the candidate PRM software.
- Apply model-based system engineering techniques to harmonize and relate different categories of requirements for use within PRM software.
- Define guidelines for the use of tools other than PRM software to informally develop requirements, and then formally document the requirements in the enterprise PRM software.
- Adopt job performance metrics and KPIs that encourage using enterprise PRM.

Sample Vendors

BigLever; Dassault Systèmes; IBM; Jama Software; PTC; Siemens

Gartner Recommended Reading

Innovation Insight: Model-Based System Engineering Is Fundamental to Digital Engineering

Top BOM Practices for Building Digital Threads in Discrete Manufacturing Industries

Appendixes

See the previous Hype Cycle: Hype Cycle for Manufacturing Digital Transformation and Innovation, 2022

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 2: Hype Cycle Phases

(Enlarged table in Appendix)

Phase ↓	*Definition* ↓
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant media and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the innovation is pushed to its limits. The only enterprises making money are conference organizers and content publishers.
Trough of Disillusionment	Because the innovation does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the innovation's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the innovation are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the innovation to reach the Plateau of Productivity.

Source: Gartner (July 2023)

Table 3: Benefit Ratings

Benefit Rating	*Definition*
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2023)

Table 4: Maturity Levels

(Enlarged table in Appendix)

Maturity Levels ↓	*Status* ↓	*Products/Vendors* ↓
Embryonic	In labs	None
Emerging	Commercialization by vendors Pilots and deployments by industry leaders	First generation High price Much customization
Adolescent	Maturing technology capabilities and process understanding Uptake beyond early adopters	Second generation Less customization
Early mainstream	Proven technology Vendors, technology and adoption rapidly evolving	Third generation More out-of-box methodologies
Mature mainstream	Robust technology Not much evolution in vendors or technology	Several dominant vendors
Legacy	Not appropriate for new developments Cost of migration constraints replacement	Maintenance revenue focus
Obsolete	Rarely used	Used/resale market only

Source: Gartner (July 2023)

Evidence

[1] **2023 Gartner CIO and Technology Executive Survey.** This survey was conducted to help CIOs and technology executives overcome digital execution gaps by empowering and enabling an ecosystem of internal and external digital technology producers. It was conducted online from 2 May through 25 June 2022 among Gartner Executive Programs members and other CIOs. Qualified respondents are each the most senior IT leader (such as the CIO) for their overall organization or some part of their organization (for example, a business unit or region). The total sample is 2,203 respondents, with representation from all geographies and industry sectors (public and private), including 499 from manufacturing companies. Disclaimer: 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.

Document Revision History

Hype Cycle for Manufacturing Digital Transformation and Innovation, 2022 - 4 August 2022

Hype Cycle for Manufacturing Digital Transformation and Innovation, 2021 - 23 July 2021

Hype Cycle for Innovation in Manufacturing Industries, 2019 - 29 July 2019

Hype Cycle for Innovation in Manufacturing Industries, 2018 - 26 July 2018

Hype Cycle for Process Manufacturing and PLM, 2017 - 19 July 2017

Hype Cycle for Process Manufacturing and PLM, 2016 - 18 July 2016

Hype Cycle for Process Manufacturing and PLM, 2015 - 24 July 2015

Hype Cycle for Process Manufacturing and PLM, 2014 - 15 July 2014

Hype Cycle for Process Manufacturing and PLM, 2013 - 31 July 2013

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Some documents may not be available as part of your current Gartner subscription.

Understanding Gartner's Hype Cycles

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Top Strategic Technology Trends in Manufacturing and Transportation for 2023

Top Strategic Technology Trends in Asset-Intensive Manufacturing for 2023

Top Strategic Technology Trends in Consumer Goods Manufacturing for 2023

Top Automotive Trends for 2023

How to Plan for a Successful Adoption of SaaS PLM

How CIOs Can Use PLM to Optimize the Adoption and Value of a Digital Thread

Innovation Insight: Implement Digital Threads for Long-Term Flexible Access to Critical Data

2023 CIO and Technology Executive Agenda: An Asset-Intensive Manufacturing Perspective

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Table 1: Priority Matrix for Advanced Technologies for Manufacturers, 2023

Benefit	*Years to Mainstream Adoption*			
↓	***Less Than 2 Years*** ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
Transformational		5G in Manufacturing Operations Connected Factory Worker Cyber-Physical Systems Digital Twin Mass Customized Discrete Manufactured Products	Blockchain in Manufacturing Configuration Life Cycle Management Digital Engineering Generative AI in Discrete Manufacturing Industry Cloud Platforms for Manufacturing Mobile Factories Model-Based System Engineering	Lights-Out Manufacturing Metaverse in Manufacturing

Benefit	*Years to Mainstream Adoption*			
↓	***Less Than 2 Years*** ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
High	Plant Engineering and Design Product Requirements Management	Building Information Modeling Cloud for Product Development Composable Applications Master Data Management Model-Based Manufacturing Predictive Product Costing Software Product Innovation Platforms Synchronized BOMs	ALM in Manufacturing Digital Threads IT/OT/ET Alignment Simulation Governance	
Moderate		3D Printing of Industrial Parts Life Cycle Analysis Software		
Low				

Source: Gartner (July 2023)

Table 2: Hype Cycle Phases

Phase	*Definition*
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant media and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the innovation is pushed to its limits. The only enterprises making money are conference organizers and content publishers.
Trough of Disillusionment	Because the innovation does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the innovation's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the innovation are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the innovation to reach the Plateau of Productivity.

Phase ↓	*Definition* ↓

Source: Gartner (July 2023)

Table 3: Benefit Ratings

Benefit Rating ↓	*Definition* ↓
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2023)

Table 4: Maturity Levels

Maturity Levels	*Status*	*Products/Vendors*
Embryonic	In labs	None
Emerging	Commercialization by vendors Pilots and deployments by industry leaders	First generation High price Much customization
Adolescent	Maturing technology capabilities and process understanding Uptake beyond early adopters	Second generation Less customization
Early mainstream	Proven technology Vendors, technology and adoption rapidly evolving	Third generation More out-of-box methodologies
Mature mainstream	Robust technology Not much evolution in vendors or technology	Several dominant vendors
Legacy	Not appropriate for new developments Cost of migration constraints replacement	Maintenance revenue focus
Obsolete	Rarely used	Used/resale market only

Source: Gartner (July 2023)