Hype Cycle for Manufacturing Operations Strategy, 2023

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Initiatives: Manufacturing Operations

Scaling digital capabilities and navigating the risky environment are driving manufacturing operations leaders to readjust priorities. This Hype Cycle supports strategic planning with key technologies and management disciplines for calibrating roadmaps, aligning investments and engaging peers.

More on This Topic

This is part of an in-depth collection of research. See the collection:

- 2023 Hype Cycles: Deglobalization, AI at the Cusp and Operational Sustainability

Analysis

What You Need to Know

Already challenged by navigating economic headwinds and ongoing disruptions across supply chains and labor markets, manufacturing operations leaders must cut through the uncertainty. They also need to set a balanced strategy to explore, implement and scale new concepts and technologies to make data-driven, informed decisions while delivering reliable supply from efficient operations.

This Hype Cycle provides a holistic view of innovative concepts, maturing and emerging technologies, and organizational constructs. It illustrates varying levels of maturity, business impact, market adoption and obstacles for consideration when plotting current and long-term manufacturing strategies. This Hype Cycle helps manufacturing operations leaders make informed decisions that balance risk mitigation, cost pressures, capability building and continuous improvement, and digital transformation.

The Hype Cycle

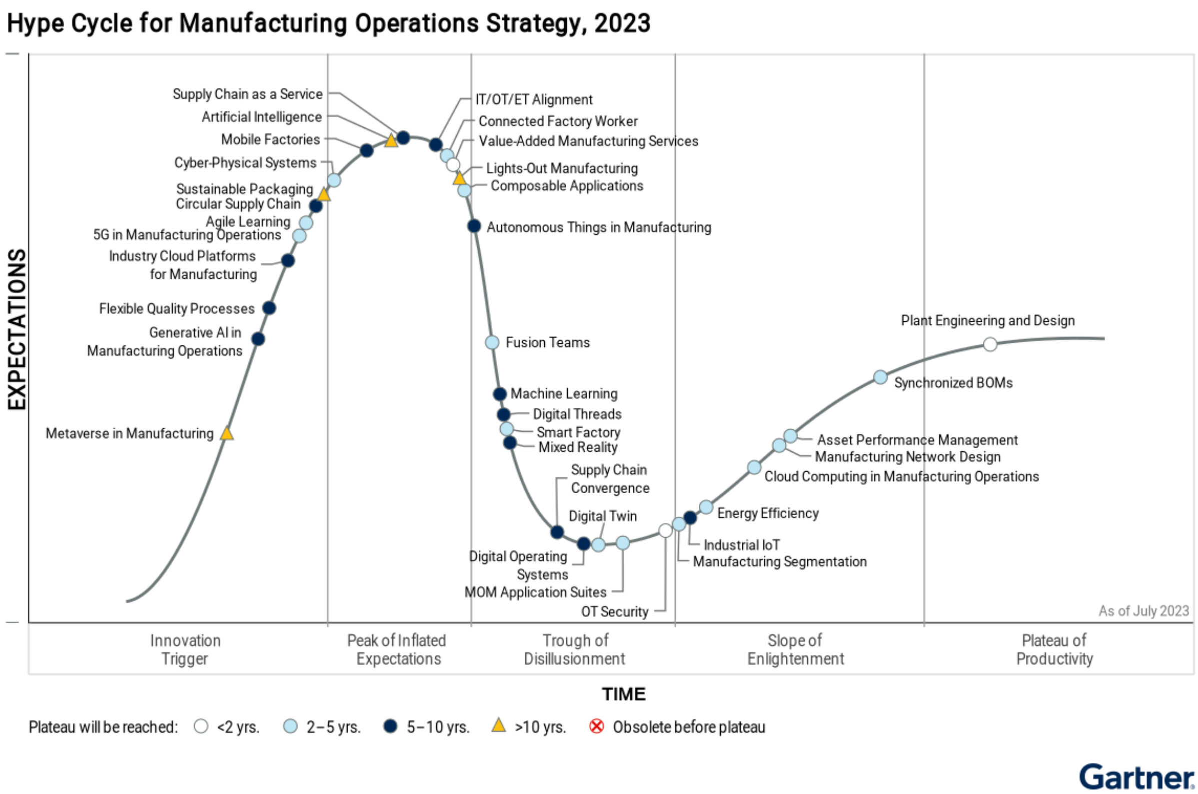
This Hype Cycle features several profiles that illustrate an ongoing pipeline of manufacturing concepts, management disciplines and technologies to explore and exploit. The landscape has shifted this year as manufacturers respond to changing market conditions by prioritizing agility, sustainability and digitization. Specifically, they have increased their focus on:

- Meeting dynamic customer preferences requires composability and process agility that supply chain as a service and value-added manufacturing services can deliver.
- A wide spectrum of profiles, including circular supply chain, mobile factories, sustainable packaging and energy efficiency, demonstrate sustainability's importance across the continuum.
- Leveraging production data more efficiently shines light on artificial intelligence (AI), machine learning and, more recently, generative AI (GenAI) to improve decision accuracy.
- Smart factories have moved closer to the trough, which reflects scalability beyond lead plants — yet still elevates several profiles, including digital twins, 5G, OT security, and plant engineering and design.
- Increased demand for automation to mitigate risk and labor costs bolsters the interests in AI, cyber-physical systems, lights-out manufacturing and autonomous things.
- Connected factory workers need both agile learning and mixed reality to improve training — and exposure to new technologies — GenAI for example — to improve efficiency and execution of work. Additionally, fusion teams and IT/OT/ET alignment are larger organizational constructs that foster collaboration and capability building at scale — and across diverse stakeholders.
- The big advances across the continuum for cloud computing and composable applications — plus the introduction of industry cloud platforms — reflect organizations building capabilities to support fast-paced business change, while protecting the integrity of the outcomes.

The profiles in the Trough of Disillusionment are a concern. While manufacturing operations management (MOM) application suites and industrial IoT gain momentum toward the Plateau of Productivity, digital operating systems and supply chain convergence remain in the trough. Attention to both is critical to connecting manufacturing operations with the rest of the business in a systematized manner.

Broadly avoiding a “capability building” bottleneck in the trough and accelerating movement toward the Plateau of Productivity means investing with a broad view and accounting for upgrades, infrastructure, integration, new specializations and process reengineering. All of these accelerate blurring boundaries between IT and the rest of the business. The resultant appetite from lines of business for planning, running and managing their own digital initiatives only adds an imperative that designs for resilience and agility extend into technology delivery so scale can happen.

Figure 1: Hype Cycle for Manufacturing Operations Strategy, 2023



The Priority Matrix

The Priority Matrix illustrates the immediate and future opportunities for different profiles based on their potential impact and maturity. Do not be misled by the large number of innovations that will enter the Plateau of Productivity in five to 10 years; it doesn't imply that organizations cannot reap some benefits in shorter time frames. It highlights the importance of simplifying current processes for long-term agility, identifying a portfolio of projects with predictable outcomes, constantly scanning the market for talent that can seamlessly operate in the physical and digital worlds, extending agility to how initiatives are funded, and identifying a suitable level of risk appetite.

- Disruptions and economic pressures will continue, raising the importance of reliable output from factories and sustained continuous improvement.
- Prepare to test your organization's risk appetite and innovation capability. Organizations with lesser risk appetites and no "first mover" culture should plan to be "fast followers."
- Eliminate Isolated site projects in favor of an enterprise roadmap focused on concurrently accelerating capability building and digitization. This will limit competition for resources, safeguard initiative predictability and create a path to scale that eliminates isolated site projects with well-designed pilots with limited scope that will ultimately accelerate, not delay, technology deployment and the time to benefit.
- Reframe site-level planning to invest differently, adjusting the ratios between capex and opex to simplify funding and accelerate adoption.

Table 1: Priority Matrix for Manufacturing Operations Strategy, 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 Fusion Teams Smart Factory	Circular Supply Chain Digital Operating Systems Flexible Quality Processes Generative AI in Manufacturing Operations Industry Cloud Platforms for Manufacturing Mobile Factories Supply Chain Convergence	Artificial Intelligence Lights-Out Manufacturing Metaverse in Manufacturing
High	OT Security Plant Engineering and Design Value-Added Manufacturing Services	Agile Learning Asset Performance Management Cloud Computing in Manufacturing Operations Composable Applications Energy Efficiency Manufacturing Network Design Manufacturing Segmentation MOM Application Suites Synchronized BOMs	Autonomous Things in Manufacturing Digital Threads Industrial IoT IT/OT/ET Alignment Machine Learning Mixed Reality Supply Chain as a Service	
Moderate				
Low				Sustainable Packaging

Source: Gartner (July 2023)

Off the Hype Cycle

- Immersive experience in manufacturing operations has been replaced with mixed reality.

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

Generative AI in Manufacturing Operations

Analysis By: Simon Jacobson

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. GenAI in manufacturing operations can improve performance and frontline worker productivity with intuitive interfaces with complex technology.

Why This Is Important

Generative AI (GenAI) exploration is accelerating, thanks to the fast evolution of large language models (LLMs) and mass popularity of services like ChatGPT. GenAI has the potential to fundamentally change a broad spectrum of production activities, improving reliable supply from efficient operations. GenAI can:

- Improve the worker experience with more intuitive guidance and recommendations.
- Provide additional synthetic data for model training, and then generate and consider novel scenarios and workflows for solving complex problems, to improve flow and manage change.
- Generative code development lessens the cost and time for automation programming or developing completely new manufacturing applications where the codebase is not built on proprietary low-code/no-code platforms.

Business Impact

GenAI will have a profound impact on:

- Frontline productivity by simplifying interfaces and providing chatbot-driven ask-and-answer support, while providing new opportunities for upskilling labor.
- Lessening variability and improving performance across core operational excellence and sustainability objectives.

- Faster change management where generative code development is paired with software-defined approach to automating production. This will improve commercial scale up from R&D and product changeovers, improving flexibility.

Yet, intellectual property (IP) protection will be needed. Responsible AI, trust and security will be necessary for safe exploitation of GenAI.

Drivers

- The hype around and interest in GenAI in our personal lives has accelerated the desire for organizations to understand its potential impact on their different factories.
- GenAI is forcing manufacturing organizations to accelerate their exploration of the potential applications of AI on a broad scale.
- Synthetic data draws enterprises' attention by helping to augment scarce data, mitigate bias or preserve data privacy. These capabilities can be well utilized to predict demand and supply patterns in complex supply networks.
- GenAI can automate up to 30% of the programmers' work.

Obstacles

- Not all of GenAI is based on LLMs. There are many ongoing pilots in manufacturing that seek to leverage variational autoencoders for time series data. However, multisite scale coupled with technical debt, systems upgrades and integration, as well as data quality concerns and low-analytics maturity can limit adoption.
- The most suitable deployment model for GenAI is unclear. Directly using public services (like OpenAI) is a risk, leveraging foundational models from technology providers or building custom models in-house remains nascent, and efficacy is unproven.
- GenAI uncovers new ethical and societal concerns. Mitigating risk and threats requires a staunch focus on ethics and collaboration with unions and workers councils.
- Low awareness of GenAI among security professionals could undermine GenAI adoption.
- Depending on the model chosen for fine-tuning, the compute resources for training foundation models are heavy and not affordable to most enterprises. Impact sustainability concerns about high-energy consumption for training generative models are rising.

User Recommendations

- Assess your organization's current technical maturity level and cultural appetite for GenAI. Third-party managed services are a growing alternative to operationalizing and managing corporate foundation models.
- Identify initial use cases where you can improve your solutions with GenAI by relying on purchased capabilities or partnering with specialists. Consult vendor roadmaps to avoid developing similar solutions in-house.
- Understand and communicate expected ROI and intangible benefits of GenAI pilots, ranging from better understanding of the potential and challenges of deploying the technology to quantifiable financial and productivity improvements.
- Track GenAI use cases from other enterprise functions that are farther ahead of their understanding and adoption of GenAI. This will help identify what use cases make sense for manufacturing and when.
- Quantify the advantages and limitations of GenAI. Supply GenAI guidelines as it requires skills, funds and caution. Weigh technical capabilities with ethical factors.
- Mitigate GenAI risks by working with legal, security and fraud experts. Technical, institutional and political interventions will be necessary to fight AI's adversarial impacts. Start with data security guidelines.
- Optimize the cost and efficiency of GenAI solutions by combining GenAI with other AI techniques and technologies (e.g., 5G, IoT) and manufacturing systems.

Gartner Recommended Reading

Innovation Insight for Generative AI

Quick Answer: What CSCOs Should Know About ChatGPT's Capabilities and Pitfalls

Emerging Tech: Generative AI Needs Focus on Accuracy and Veracity to Ensure Widespread B2B Adoption

ChatGPT Research Highlights

Use-Case Prism: Generative AI for Manufacturing

Flexible Quality Processes

Analysis By: Kate Wagner

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Embryonic

Definition:

Flexible quality processes are defined by these four characteristics — adaptable, customizable, judgment-driven and embedded in business processes. Flexible quality processes reduce end-user circumvention and significantly improve a company's ability to respond to market changes and unanticipated disruptions.

Why This Is Important

To cope with increased unpredictability, shorter business cycles and disruptions, companies are prioritizing speed, innovation and customer alignment. Traditional quality processes defined by consistency, scale and operational efficiency can't keep pace. Flexible quality processes are a new approach to maintaining quality standards while being adaptable, customizable, judgment-driven and embedded in business processes.

Business Impact

By designing processes that are adaptable and empower employee judgment, quality leaders ensure that the processes remain relevant and add value during disruptions. Flexible processes are designed in a way that ensures quality and business requirements are met without unnecessary constraints. This decreases end-user frustration around usability and the inevitable need to change processes in response. As a result, practitioners view quality processes as critical to success rather than a barrier.

Drivers

- The proliferation of information and communication technologies, the widespread adoption of automation, and the massive increases in unplanned events make the corporate climate far more unpredictable and unstable. At the same time, customer preferences are quicker to change and more divergent than ever, forcing businesses to constantly reevaluate their offerings to ensure they keep up with increasing demands for personalization and novelty.
- To better meet these priorities, companies are fundamentally transforming their ways of working — moving to agile methodologies and iterative testing. Business leaders and customers are expecting the same from quality processes. It's no longer enough that quality processes, like change control, inspections and supplier qualifications, manage risk or prevent errors. They have to achieve the same thing with greater speed and flexibility.
- The additional shift in expecting frontline employees to own more processes and to make independent, real-time process decisions requires the quality processes to not only be seamlessly embedded in the business but also equip employees with judgment-driven decision criteria.
- Legacy quality processes were designed to meet outdated needs and priorities, which, in modern times, fail to contribute to enabling business success and are viewed as barriers to achieving key goals such as on-time product launches and expanded product personalization.

Obstacles

- Flexible processes represent a dramatic shift from how most quality processes were traditionally designed. And, these traditional processes were designed in a particular way to meet regulations, industry standards and customer expectations for consistency — all needs that still need to be met.
- As with any fundamental shift in design principles, teams need to acknowledge and overcome any unconscious biases that may exist when designing the new processes based on assumed requirements from the legacy processes.
- Teams default to commonly used approaches of streamlining and rebuilding from scratch that have limited success. Our research shows that the gap between existing process capabilities and flexibility needs is too great to close through incremental streamlining while rebuilding does not guarantee improvement either.

User Recommendations

To ensure effective quality processes in the digital age, leaders must:

- Discuss and explain the meaning, rationale, and process of designing flexible processes to the leadership and process execution teams.
- Determine processes to focus on by assessing which existing quality processes are likely to inhibit business success if left unchanged and are commonly the root cause of errors due to process circumvention by employees.
- Resist settling for incremental improvements or streamlining processes alone. This approach rarely results in the flexibility that the business needs.
- Run process assumption-busting sprints prior to redesign initiatives to enable staff to break away from a status quo mindset.
- Establish expectations for process redesign initiatives so that project teams reinvent processes by starting from scratch, challenging all requirements, using available technology and leaving room for employee judgment.

Gartner Recommended Reading

Presentation: Quality Management in 2025: Predictive, Connected, Flexible and Embedded

Reimagining Quality Processes for the Digital Era

Case Study: Process Requirement Assumption-Busting Sprints (Pharmavite)

Case Study: Process Redesign Business Teams (Harman International)

Toolkit: Quality Process Reinvention Prioritization Matrix

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?

Agile Learning

Analysis By: Jose Ramirez, Graham Waller

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Agile learning is a mindset and method of skills development, via iterative short bursts, applied in the flow of achieving outcomes that can dynamically adjust with changing needs.

Why This Is Important

Today's hypercompetitive labor market has increased the talent demand, heightening the need for the rapid upskilling of employees. Additionally, the future of work trends, including hyperautomation and artificial intelligence (AI)-driven applications, are accelerating skills shifts, particularly digital skills, through all roles. These trends are shortening the half-life of skills demanding agile learning to future-proof employees. Unfortunately, traditional training is often too time consuming and slow to respond to these changes and trends.

Business Impact

Agile learning connects learning curves with earning curves. For employees, learning advances their career, future-proofs them against change and increases their value. For an enterprise, learning fills the pipeline of dynamic skills critical to executing the organization's mission.

Agile learning helps enterprises to:

- Positively impact business outcomes
- Adapt rapidly to changing business needs
- Effectively upskill and reskill employees
- Provide a clear plan to fulfill skill needs

Drivers

- Agile learning summarizes a set of principles and practices that have been emerging and coalescing in the market. Gartner research indicates that 27% of enterprises have adopted agile learning principles to achieve superior talent and business outcomes from their training investments. Agile learning organizations reported remarkable improvements over their peers in Gartner's 2020 agile learning survey. Agile learning is an imperative for organizations since the total number of skills required for a single job is increasing by 5.4% year over year.
- Agile learning enterprises embed learning continuously into the flow of work, resulting in 9.9 times the impact of achieving learning outcomes, the highest impact ratio of any driver.
- Agile learning enterprises devote double the time to both training and learning as nonagile organizations. Giving employees the time to learn has a 7.2 times impact on achieving outcomes.
- Agile learning enterprises promote learning communities, which spread knowledge and skills more effectively than individual learning. Social learning has a 4.3 times impact on achieving outcomes.
- Agile learning enterprises harness data-driven learning techniques 64% more than nonagile learning peers and report roughly twice the confidence in the effectiveness of learning measurement.

Obstacles

- Many leaders are unaware of the agile learning approaches that are now possible. Although learning occurs daily in organizations, it's seldom intentional, siloed or fragmented. Leaders often view learning as time away from employees' work versus being integral to highly productive work. Providing employees the time to learn can feel ambiguous, and leaders are skeptical that employees will use the time effectively. Leaders also believe they can hire new talent to fill skills gaps rather than foster a culture of learning with current employees.

- Enterprises reported that "lack of employee motivation" (where employees feel that the learning is low priority in their work) and "time constraint" (where employees are not given the time to acquire that learning) are the top barriers preventing harnessing modern learning techniques. "Can't find time to learn" prevented employees from embracing agile learning in 51% of nonagile enterprises compared to only 31% reported by agile learning enterprises.

User Recommendations

- Reframe learning as central to everyone's job, not time away from the job. Embed learning into the flow of activities that employees perform to deliver their outcomes.

- Factor the hybrid work environment into the design of your learning program. For example, make learning content available regardless of where and how employees are working.

- Share the agile learning manifesto with the enterprise to champion agile learning. Shape a culture that connects learning and earning curves by using its four values and eight principles.

- Engage in frequent microlearning, applied as a part of your daily work, toward achieving an important outcome. Role model agile learning for your organization.

- Integrate agile learning immediately by starting small, i.e., select a single skill to develop or a small team so that iterative changes can be made along the way.

Gartner Recommended Reading

Agile Learning Manifesto

Future of Work Trends: The Agile Learning Imperative

An Executive Leader's Guide to Agile Learning

Foster a Culture of Agile Learning to Upskill IT Employees Faster

Circular Supply Chain

Analysis By: Laura Rainier, Sarah Watt

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Circular supply chain is the application of circular economy principles to the end-to-end supply chain. A circular supply chain decouples consumption from growth using three principles: design out waste, keep material in use at the highest quality for as long as possible and return materials to the environment to have a positive impact. Benefits of the circular supply chain include enhanced customer engagement, raw material security and containment of inflationary-driven costs.

Why This Is Important

A circular supply chain decouples resource consumption from growth, enabling leaders to maintain business competitiveness while reducing environmental impact. According to the 2022 Gartner Future of Supply Chain Survey, engaging in circular economy activities is important to 75% of supply chain leaders. Additionally, 92% of high-performing supply chain leaders expect to have sufficient capabilities to enable circular economy benefits in three to five years.

Business Impact

A circular supply chain uses resources more efficiently by designing waste out of products, packaging and processes, and better-leveraging materials through product take-back, refurbishment, product life extension and other means. The approach shifts economic incentives toward durability and material efficiency and provides a hedge for materials volatility. Digital technology allows for product orchestration while also gathering insights into customer use, which is fed back into product design.

Drivers

- Legislative drivers: Various regulatory requirements are emerging to drive enhanced circularity. For example, the “right to repair” requires access to spare parts and technical information to enable products to be kept in use for as long as possible. EU waste policy aims to ensure that high-quality resources are not lost from the economic system. Concerningly, 60% of EU household waste still goes to landfill.

- Supply chain resilience: Circular supply chains enable the organization to meet customer demand amid disruption through second-life products or by reclaiming raw materials for manufacturing new products.

- Impact on climate change and biodiversity: A circular approach has the potential to reduce climate change impacts, as product embodied energy (and emissions) is used more efficiently. By slowing the rate of consumption, the circular supply chain reduces its reliance on the extraction/production of new raw materials and their associated emissions. Enterprises must undertake life cycle analysis to review the environmental impacts of end-of-life options, enabling trade-off decisions to be made.

- Enhanced value: The circular economy enables enterprises to access new markets, offer new business models and products, and build a differentiated sustainability narrative.

- Innovation: The circular economy is a catalyst for innovation. Examples include design for reuse and longevity, innovative business models and design for disassembly.

- Customer expectations: According to the 2022 Gartner Circular Economy Survey, customer demand for circular products is the biggest driver of changes to the physical supply chain network to enable circular economy outcomes.

Obstacles

- Metrics: Traditional ROI metrics do not effectively capture the benefits of the circular supply chain due to short-term focus, siloed thinking and a transactional approach. Circular strategies capture more value from materials, over a longer period of time.
- Stakeholder engagement: Scaling the circular supply chain relies on engaging with partners across the organization and ecosystem. Partnership is required to enable product return flows, materials recovery, industrial symbiosis between organizations and additional customer value offerings. Convening external stakeholders and sharing relevant data with the ecosystem is a key barrier.
- Execution: Take-back models enable remanufacturing and reuse, but the supply chain has less control over what is returned. This can create excess inventory without a productive next use.
- Impact: Standards are emerging to measure the impact of circular initiatives, but accurate assessment of environmental and other trade-offs is complex.

User Recommendations

- Prioritize products: Select the products best positioned for the circular strategy by assessing which products deliver the most financial and nonfinancial benefits, evaluating the customer appetite for circular products and assessing the feasibility of circular models.
- Enable: Apply circular design guidelines (for example, modularity, durability), craft circular business models (for example, reuse, product as a service), and implement processes that enable material loops (for example, reverse logistics, reverse planning).
- Pilot: Demonstrate how to overcome common leadership concerns, such as the cannibalization of market share.
- Digitalize: Leverage digital technology for product use insights, and to improve the speed, rate and quality of second-life products. Formulate performance scorecards to aggregate data from multiple parts of the organization.
- Organize: Organization structure is a key enabler in advancing circular economy strategy. Use centers of excellence to embed circular economy into operating models.

Gartner Recommended Reading

3 Criteria to Select "Winning" Circular Economy Products to Enable Growth

3 Accelerators to Advance the Circular Economy in Supply Chain

Use Circular Economy to Mitigate Inflation, Drive Growth and Deliver Value Amid Economic Uncertainty

Craft a Reverse Supply Chain Strategy to Enable Circular Economy at Scale

How to Structure Your Organization to Drive Circular Economy Integration

Sustainable Packaging

Analysis By: John Blake

Benefit Rating: Low

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Sustainable packaging is the development and use of packaging that results in improved utilization of materials, and decreases the negative impact of packaging on the environment. It can include recycling, recycled content, reuse, material substitution and reduction in the carbon footprint of packaging.

Why This Is Important

Sustainable packaging has become a core aspect of sustainability commitments as packaging and plastics have been deemed major contributors to pollution and greenhouse gas (GHG) emissions. Organizations need to address packaging to meet their environmental, social and governance (ESG) goals and the expectations of customers and consumers in order to protect their brand's reputation. In addition, the rapid advancement of global packaging legislation is heightening the urgency to adopt sustainable packaging practices.

Business Impact

Consumer and customer sentiment drove voluntary sustainable packaging goals, but now there is a rise in packaging legislation globally that will mandate changes in how packaging is designed and utilized. Sustainable packaging is complicated and can be costly to implement. It's estimated that many 2025 commitments will be missed, risking brand reputation. Significant levels of innovation and investments may be required to meet voluntary and mandated targets.

Drivers

- **Consumer/customer pressure:** There is an awareness of the harm that products and packaging have on the environment and this is driving purchase decisions. Brand reputation, waste and the contribution to Scope 3 emissions are being scrutinized.
- **Legislation:** 2022 marked not only the first of its kind — a Plastic Packaging Tax implemented in the U.K. — but it also marked California becoming the fourth state in the U.S. to pass Packaging Extended Producer Responsibility (EPR) legislation. Meanwhile, 2023 ushered in new packaging taxes in Spain and there are (at the time of publication) over 10 states in the U.S. with proposed packaging EPR legislation. These are just a few of the examples of global packaging legislation.
- **ESG strategy:** As the value of having a clear and actionable ESG strategy becomes clear, organizations are moving beyond focus on Scopes 1 and 2 emissions and are increasingly setting their attention to Scope 3, which includes packaging. Further, boards are increasingly stepping up their oversight of ESG, as they recognize its necessity for long-term resilience and the very visible nature of packaging and packaging waste.
- **The war on plastic:** As awareness of the impact of plastics and plastic packaging on the environment increases, organizations need to develop a position regarding its use. There is a desire to replace plastics, drive a circular economy through recycling, eliminate or minimize use of virgin or petroleum-based polymers and move from single use to reusable packaging.
- **Costs:** The overuse or misuse of packaging has cost implications as well as sustainability implications. Another cost risk is the growth in legislation. Organizations will be penalized for the quantity and types of packaging they produce. However, reducing or optimizing packaging through the lens of sustainability can also reduce packaging costs.

Obstacles

- **Complexity:** Visions of fully recyclable, reusable and plastic-free are harder to implement than anticipated, due to financial and technical feasibility (such as product protection, costs, recycling infrastructure and sourcing limitations).
- **Data maturity:** Packaging specification data practices are at a low maturity level. Common challenges include insufficient processes and systems of record, as well as accuracy/completeness of data. Software for packaging specification management is an emerging market.
- **Infrastructure:** Investments in recycling infrastructure and by packaging suppliers has not kept up with the promises or needs of brand owners.
- **Costs:** Material shortages, reusable packaging supply chain and manufacturing assets are driving cost pressures.
- **Collaboration:** Packaging's impact is cross-functional, requiring stakeholder support to navigate change management challenges.
- **Greenwashing:** Overpromising, under delivering or misleading consumers poses risks of legal or consumer backlash.

User Recommendations

- **Data:** Establish the baseline for any sustainable packaging strategy by capturing data on current packaging consumption.
- **Upstream innovation:** Optimize products and packaging through the lens of sustainability and consumer needs.
- **Feasibility:** Assess the business impact and feasibility of sustainable packaging by engaging cross-functional teams in the process of setting or resetting packaging goals. Key considerations include sourcing and quality of packaging, material and capital costs as well as operational changes.
- **Stakeholders:** Engage stakeholders to support necessary changes and investments. Sustainable packaging often involves development, financial commitments and change management to advance beyond pilots.
- **Investment:** Determine where investments are needed to support sustainable packaging by starting with specification data visibility. This will prove critical as legislation evolves. Map required investments in manufacturing assets, as well opportunities for strategic investments with packaging suppliers.

Gartner Recommended Reading

Quick Answer: How to Create a Sustainable Packaging Strategy

Quick Answer: How to Advance Sustainable Packaging Goals

Quick Answer: How to Comply With Sustainable Packaging Legislation

Market Guide for Packaging and Product Specification Management

At the Peak

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

Artificial Intelligence

Analysis By: Noha Tohamy

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Artificial intelligence (AI) applies advanced analysis and logic-based techniques, such as machine learning, deep learning, regression analysis and prescriptive analytics, to identify and predict patterns, self-learn, and make and execute decisions. AI augments human decision making or automates routine and nonroutine tasks.

Why This Is Important

AI has the potential to transform supply chains. It significantly augments humans' ability to make decisions, by identifying patterns and making actionable recommendations.

With AI, organizations can automate decision making and execution. This is critical for dynamic supply chain processes that require analyzing large sets of data and real-time response. For example, AI can automate order promising, production scheduling and product testing. AI can support overall digital transformation.

Business Impact

Leveraging AI in decision automation allows supply chains to dynamically react to changing supply and demand patterns. AI closes the gap between planning and execution, ensuring that the factors driving decisions are still valid at execution.

AI has a profound impact on talent, freeing up staff from non-to-low value-add tasks. This allows them to pursue more fulfilling, higher value-add priorities, such as internal and external collaboration and scenario planning.

Drivers

- Continued interest in AI from supply chain leaders looking to alleviate supply chain talent shortages.
- Ability of supply chain technology providers to embed AI capabilities for identifying patterns and predicting, making and executing decisions into their existing solutions.
- More best-of-breed, AI-oriented supply chain technology vendors that position their solution as a complementary intelligence layer to augment current supply chain solutions.
- Identifying more use cases for AI within individual functions such as planning, sourcing and manufacturing.
- Interest in using AI to augment decision making with better actionable recommendations.
- A better articulated vision for automating supply chain decision making, beyond initial use cases like demand forecasting and demand sensing.
- Emphasis on supply chain agility as organizations cope with significant spikes in demand and supply variability, inflationary pressures, and continuously changing business conditions.

Obstacles

- Continued challenges with the availability and quality of data that can accurately represent a supply chain process.
- Limited data required to effectively train AI algorithms and generate accurate recommendations.
- Shortage in data science talent attracted to supply chain organizations due to organizations' technical immaturity and lack of attractive career paths.
- Lack of organizational readiness to adopt complex AI solutions and rely on them in mission-critical decisions.
- AI initiatives are mostly pilots, with few deployments — at scale — that have demonstrated technology maturity and ability to support supply chain objectives.
- Lack of transparency in AI technology, further challenging the willingness of users to trust their output.

User Recommendations

- Experiment with AI in lower-order supply chain processes such as improving data quality and data harmonization.
- Align supply chain AI strategy with overall enterprise AI strategy to leverage enterprisewide technology and talent resources.
- Beyond pilots, prioritize solution scalability and reusability when choosing AI technology vendors to support broad AI adoption.
- Focus on specific use cases where you believe AI presents the highest potential, and embark on small pilots to gauge potential benefits and challenges to success.
- Ensure the availability of data science resources, internally or from service providers, to build and maintain AI solutions.
- Focus on cultural changes to ensure that the organization is in step with the AI vision. This includes training supply chain users on incorporating AI into their decision-making process.
- Define new career opportunities for supply chain users to pursue, once their nonroutine tasks are automated with AI.

Gartner Recommended Reading

Use-Case Prism: Artificial Intelligence for Supply Chain

Top Trends in Strategic Supply Chain Technology 2023

Supply Chain as a Service

Analysis By: Michael Dominy

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Supply chain as a service (SCaaS) is the ongoing management of one or more supply chain functions for other enterprises. SCaaS is a revenue-generating, digitally enabled service that taps into the business process or operational capabilities of an enterprise.

Why This Is Important

SCaaS is an opportunity to directly grow revenue by using existing or new capabilities to perform a supply chain activity for another company. There are two primary types of SCaaS: Operations as a service, which involves contracting out physical operations. Business process as a service which involves performing a nonphysical operational activity for another enterprise.

Business Impact

- Increased revenue for manufacturers, retailers, distributors or healthcare providers with factories, private fleets, warehouses, stores or other leverageable physical assets with operational capacity or business process capabilities to deliver physical or digital SCaaS to organizations.
- Reduced cost by better utilization of supply chain assets from physical assets such as warehouses and trucks to business process and technology assets such as supply chain planning.
- Expanded relationships with existing customers by offering additional services.

Drivers

- **Capabilities and capacity.** Operational capability, capacity or availability of supply chain business and technology expertise present opportunities for organizations with advanced supply chain capabilities to directly deliver revenue to their organizations by monetizing their supply chain through services provided to other enterprises.

- **Cloud platforms and applications.** Cost-effective availability of cloud computing infrastructure services, multitenant SaaS applications, open-source software and analytics tools have enabled service providers and some enterprises to create, launch and sustain supply chain business process services.

- **Connected and intelligent things.** Lower technology costs and increased connectivity with products changes what the supply chain function must do. In the past, the supply chain managed products. Today, intelligent connected things are starting to manage the supply chain, essentially turning the supply chain organization into a service provider for the physical object. For example, a piece of equipment or appliance that is tracking inventory or activity on its own can order replacement inventory or create a service order.

Obstacles

- **Identifying and selling physical operational SCaaS.** Most buyer and provider matchmaking in physical operations has been between companies and providers versus company to company.

- **Onboarding SCaaS customers.** Whether it is physical operations as a service or business process services, integrating systems and defining roles, responsibilities and required activities are complex and time-consuming.

- **Differing commercial arrangements.** Instead of an order-to-cash process, with invoicing and collections triggered by a shipment, a contract with service agreements governs payments.

- **Transforming talent**. SCaaS requires new ways of working. Supply chain professionals must switch from an internal orientation to an external client mindset. Not all individuals are comfortable and skilled to do so. Because all SCaaS involve digital skills, individuals in the supply chain organization will need to develop or expand digital competencies.

User Recommendations

Enterprises such as retailers or manufacturers contemplating offering SCaaS should:

- Determine physical asset SCaaS opportunities by analyzing capex and capacity forecasts.
- Evaluate which processes can technically support multitenancy and scalability requirements by reviewing IT architecture.
- Assess competitiveness by benchmarking an offering against existing providers including 3PLs, contract manufacturers and BPO providers.
- Create customer journey maps by documenting physical and digital flows from customers back through the supply chain.

Enterprises considering contracting for SCaaS should:

- Target lower-performing supply chain activities by using maturity assessment and benchmarking.
- Audit and monitor areas of higher risk, such as global trade management, by asking how systems such as denied-party lists are updated.
- Assess SCaaS for specialized purposes, such as network design or inventory optimization, by assessing skills of those in the supply chain organization.

Sample Vendors

Amazon; Arrow Electronics; Avnet; Cardinal Health; Lenovo; Mayo Clinic; Primary Connect; Quiet Platforms; Target

Gartner Recommended Reading

Take Four Steps to Develop Your Supply-Chain-as-a-Service Strategy

Operationalize and Scale SCaaS Through Multienterprise Organization, Governance and Talent Capabilities

Supply Chain as a Service Converges Physical and Digital Supply Chain to Deliver Revenue

Market Guide for Supply Chain Strategy, Planning and Operations Consulting

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

Value-Added Manufacturing Services

Analysis By: Sam New

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Value-added manufacturing services are more nascent and less mature than traditional offerings. Also known as “contract manufacturers,” “co-manufacturers,” “third-party manufacturers,” or “CMOs,” they offer services beyond traditional manufacturing activities. Services include product development, standard production, final assembly, test, and pack (FATP), and the like.

Why This Is Important

Relationships between brand owners and external manufacturers are generally mature. Historically, external manufacturing was driven by tactical pressures including cost, capacity, reduction of fixed assets and risk exposure. Maturity of approach to manufacturing services still varies significantly by industry. Gaining an understanding of service offerings will enable manufacturers to think strategically about the ability to offload broad supply chain scope in addition to traditional manufacturing.

Business Impact

Using adjacent external manufacturing services can support:

- Cost optimization
- Risk management
- ESG goals
- Business continuity management
- New product introduction and development
- Supply chain network resiliency/contingency planning
- Decreasing time to market and time to volume

Service providers may be engaged for additional benefits, including:

- Acquisition of specialized knowledge, skill sets or technology
- Returning in-house focus to core/specialized activities
- Network optimization enhancement

Drivers

- Brand owners, the buyers of third-party manufacturing services, outsource both manufacturing activities, and other supply chain services, including planning, sourcing, etc.
- Buying organizations reexamine the scope and scale of the activities that they outsource as business models, enterprise-level goals and exogenous circumstances change.
- A brand owner can reduce costs, save time and increase agility by using many of the available services in the external manufacturing marketplace, but this is not guaranteed.
- The key to unlocking and sustaining competitive value involves delineating core and noncore activities, and the governance and supplier relationship management skills of the brand owner.

Obstacles

- Intellectual property risk may arise, enabling competition from partners themselves.
- Various software products may need to be integrated to promote partnership collaboration and supply chain visibility.
- Workforce and headcount may be impacted if outsourcing is new to an organization.
- Geopolitics and economics may impact service provider/site selection.
- Specialized talent is required to manage strategic partnerships, and cross-functional approaches are essential.
- Multiple processes change when outsourcing. S&OP and new product introduction must include the outsource provider. Supply planning, sourcing and procurement, quality, and logistics often require adjustments to comply with service agreements or contract terms and conditions.

User Recommendations

- Define requirements and services sought, and encourage manufacturing service providers to propose adjacent activities as optional line items in proposals. Be cautious about new services. Insist that they provide customer references and speak with them before engaging.
- Use cross-functional teams, including supply chain, finance, and commercial, for holistic and diverse decision making around outsourcing.
- Use partners to support growth opportunities, gain access to scarce commodities through supplier relationships, and provide expertise and shared investments to speed up new product introduction or support after-sales services.
- Examine the expertise and proprietary tools that external manufacturers offer for risk mitigation and business continuity. Use this assessment as a component of the service provider selection process for evaluation for longer-term partnerships.

Sample Vendors

Catalent; Celestica; Flex; Hon Hai Technology Group (Foxconn); Jabil; Plexus; Thermo Fisher Scientific (Patheon)

Gartner Recommended Reading

Market Guide for Electronics External Manufacturing Services

Strategic Considerations in Manufacturing Make-Versus-Buy Decisions

Build Supply Chain Talent and Competencies to Optimize External Manufacturing Partnerships

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

Autonomous Things in Manufacturing

Analysis By: Jonathan Davenport

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Autonomous things in manufacturing like mobile robots, drones or industrial equipment can operate in the real world without human interaction. They can work across many environments, with varying levels of capability, coordination and intelligence. The devices use AI to augment or automate tasks and processes, and are one of the three foundational building blocks for smart factories.

Why This Is Important

Autonomous things are foundational to smart factories. They can assist or redeploy human workers, enabling cost optimization with improved production cycle times and product quality. This creates high, and occasionally transformational, business benefits. While there are successful use cases of "cobots" working alongside humans, the more sophisticated applications that autonomous things can handle changes the nature of human-machine collaboration, impacting operational decisions.

Business Impact

Technology advancements are spurring demand for speed and throughput without any disruption to factory overhead and ongoing costs. This is attractive, but requires sizable investments in factory IT and operational technology (OT) infrastructure and change management initiatives. It also requires the adoption of Internet of Things (IoT) combined with the maturation of AI to drive adoption and deliver sustained value. More-intelligent environments translate to machines and humans working together in a precise, safe and collaborative fashion.

Drivers

Discussions on automation at functional and corporate levels are increasing:

- There is growing interest in exploring how to enhance different combinations of physical and virtual objects, and manipulate different factory environments with various levels of human guidance, autonomy and collaboration.
- Evolving capabilities of various individual technologies (e.g., IoT, AI, edge computing and 5G).
- Formal smart factory strategies that support various styles of automation (that is, lights-out processes).
- Aging economies combined with a lack of appropriate talent and skills leading to labor shortages in many industrialized nations, especially in Europe and Japan. These labor availability risks are driving interest in automation or remote management of site activities.
- Internal business requirements combined with competitive pressures drive a need for higher levels of repetitive quality, responsiveness, efficiency and sustainability objectives.
- Autonomous thing implementations' ability to reduce cost or reliance on legacy systems and to improve human working conditions and safety, while delivering improved productivity and speed.
- Macro environmental factors like supply chain constraints, labor shortages and inflation make productivity improvements of both human workers and machines, and the support of remote and flexible working even more important. In turn, this also helps diversify factory workers and broaden their skill set so that they can move to supervisory tasks beyond siloed tasks and contribute to continuous process improvement.
- Emergence of automated things orchestration platforms which act as an intelligent middleware that integrates and orchestrates work between various business applications, heterogenous fleets of operational robots and other automated agents like doors or elevators. This middleware layer helps reduce integration costs to enterprise IT systems such as ERP or warehouse management system.
- Autonomous things can often be utilized based on a service-based subscription, cutting down on barriers to adoption. The operational expenditure links costs directly to the benefits that autonomous things deliver.

Obstacles

- This technology is not solely a physical form factor. Autonomous things cannot match the human brain's breadth of intelligence and dynamic general-purpose learning, meaning they are not well suited to nonrepetitive tasks. Essentially, the more complex a task is (e.g., complex assembly) the more costly it is to replace a human worker.
- Demand outstrips supply for new skills requirements altogether in manufacturing. The wide talent pool needed to meet the complex programming, analytical, technical and engineering skills (OT) is lacking.
- The costs and complexities of managing growing data volumes, assessing use cases and processes, and testing and learning about different technologies might put autonomous things out of direct reach for now.
- In countries with low labor cost and high labor availability, the business case turns out in favor of the people and not the machines.

User Recommendations

- Avoid the perception of job elimination, at a time when factory staffing levels are in flux, by introducing autonomous things with acute clarity and clear communication.
- Manage the accelerated pace of behavioral change between humans and machines by reshaping continuous improvement and operating systems to incorporate standard work, new metrics and defined decision rights.
- Evaluate autonomous things as both substitutes for and complementary to your existing workforce and automation layouts. Map methods and procedures with the right concepts for autonomous things by understanding labor versus automation trade-offs.

Gartner Recommended Reading

Lessons From Mining: 4 Autonomous Thing Benefit Zones for Manufacturers

Autonomous Things Deployment: 5 Best-Practice Stages That Require Manufacturing CIO Leadership

Top Strategic Technology Trends in Asset-Intensive Manufacturing for 2023

Quick Answer: Manufacturing CIOs Are Using Intralogistics Smart Robots to Proliferate Smart Factories

Fusion Teams

Analysis By: Jason Wong

Benefit Rating: Transformational

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

A fusion team is a multidisciplinary team that blends technology or analytics and business domain expertise, and shares accountability for business and technology outcomes. Instead of organizing work by functions or technologies, fusion teams are typically organized by the cross-cutting business capabilities, business outcomes or customer outcomes they support.

Why This Is Important

More software development will be done outside of IT as business users become more digitally dexterous. Business units building digital business capabilities want full control of all the people critical to that business, and closer collaboration between business and IT professionals.

Business Impact

The ongoing democratization of digital delivery is an effort to increase the realized value of digital initiatives, and drive speed and agility. This involves placing the design, delivery and management of digital capabilities where that value is created: with the people and teams closest to the customer, products or business operations. In this context, “democratization” speaks to making the creation and management of information and technology accessible to everyone.

Drivers

- According to the 2022 Gartner Digital Worker Survey, 48% of non-IT workers customize or build tools from technology provided by IT or from tools they acquire on their own. This is in line with Gartner's prior surveys showing that, on average, 41% of employees are business technologists.
- Development of digital products for use by external customers drives fusion teams.
- Business units need control of all the resources for delivering a product, including control of the professional software engineering teams.
- Mixed teams of business people and software engineers allow for tight collaboration on the details of a product, which often leads to more effective delivery and outcomes.
- Making software development an integral part of product development allows software engineers to inject innovative ideas for the product.

Obstacles

- Organizations that do not orchestrate the democratization of digital delivery may end up with misaligned or duplicative initiatives and capabilities; inconsistent customer experiences; inefficiencies; and compliance, privacy or security issues.
- Business leaders often find themselves unprepared to take on technology leadership responsibilities because they may have limited visibility into what this means for their own roles and their ways of working.
- Business leaders outside IT may not have adequate experiences, skills and competencies to lead their own fusion teams.

User Recommendations

- Update your division-of-labor practices for application governance. IT and business should share responsibility for portfolio strategy, roadmap planning, vendor product release planning and application project/sprint delivery.
- Encourage acceptance of fusion teams that do technology work outside of IT — the business units may need to have full control of the resources to deliver their product or service.
- Ensure that the CIO and other business leaders work together to build agile and effective governance frameworks for the work that the fusion teams do. With control comes responsibility.
- Focus on the human side of managing digital business risk and foster "digital judgment" in fusion team leaders. Digital judgment is the set of beliefs, mindsets and behaviors that lead to sound risk management among frontline technology decision makers throughout the enterprise.

Gartner Recommended Reading

Quick Answer: How Can Digital Workplace Leaders Support Business Technologists?

Quick Answer: What Types of Fusion Teams Do Business Technologists Lead?

Video: What Are Fusion Teams and Why Do CIOs Need Them?

Video: What CIOs Need to Know About Governing Business Technologist-Led Fusion Teams

Business-Led Cloud Enterprise Application Portfolios Produce Higher Business Value

Machine Learning

Analysis By: Simon Jacobson, Scot Kim

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Emerging

Definition:

Machine learning (ML) is an AI discipline that uses statistical models to identify predicted insights and logical patterns based on the analysis of large sets of data. Three major subdisciplines are related to the types of observation provided: supervised learning (observations contain input/output pairs [aka labeled data]), unsupervised learning (labels are omitted) and reinforcement learning (evaluations are given of how good or bad a situation is).

Why This Is Important

ML takes advantage of large amounts of structured data (text), unstructured data (videos, images and other data to identify patterns) and industrial data (asset machine data) to generate insights and predict outcomes. In manufacturing operations, ML is an essential enabler of smart manufacturing. It can improve different facets of maintenance and quality, identify variability and improve operations.

Business Impact

ML algorithms identify undetected patterns across data that users typically would not find. ML algorithms rely on data to identify patterns to generate insights and predict trends. These insights improve over time, as algorithms self-learn/retune from prior performance. ML, however, is not a panacea. Successfully cultivated strategies are built on common workstreams and digital roadmaps that promote scalability so maximum value is gleaned.

Drivers

- Algorithms are not new in manufacturing, yet the adoption of modern tools lags behind other supply chain functions, such as planning. In the past year, pilots have increased as companies became more bullish on automation as a way to efficiently run shifts and maximize the value of production data. Typical use cases include eliminating unplanned downtime and stoppages, increasing yield optimization, reducing energy usage, improving product quality or stabilizing production processes.
- Competitive advantage — objectives to identify trends and plan resources and capacity more effectively — is driving the ML hype. Providers, in an effort to modernize incumbent systems, are simplifying their tools to develop algorithms. However, this needs time to evolve and mature (especially for advanced techniques such as unsupervised learning).
- Increased leverage of edge computing is expanding the interest in ML. As edge computing becomes pervasive among manufacturers, ML adoption will follow suit due to the added intelligence embedded within the edge computing construct.

Obstacles

- **Data complexity** — Having the right data in the right formats, managing the relationships between different data and then training models takes time. The following examples provide different kinds of data: IT and OT across legacy data sources, vision systems, edge devices and transactional systems.
- **Lack of industrial data management framework** — Curated ML data is required for AI models to properly contextualize industrial assets into valuable insights for decision makers, enabling them to make the right business decision at scale.
- **Heterogeneous systems and data sources** — ML is an integral part of provider offerings spanning industrial IoT platforms, hyperscalers, OT providers and multiple point or niche solutions. This creates selection and integration challenges.
- **Skills** — There is high demand and insufficient supply within the current manufacturing workforce for data science, engineering and infrastructure talent to develop, test, train and maintain algorithms.
- **Bias** — Lack of algorithmic trust, and concerns over job loss and upskilling requirements can limit maximizing ML value.

User Recommendations

- Assess the speed of response and frequency of prediction needed. In many instances, traditional analytics techniques, such as descriptive and diagnostic analytics, can be more effective.
- Quantify the technical resources and skills development required for process engineers, data scientists and other production workers to build and train ML models, and interpret the signals.
- Ensure the availability, readiness and context of the data that will be used by ML algorithms. Given the diverse use cases, and that ML relies on training datasets to identify patterns and relationships, having the right data is essential.
- Capture governance parameters properly across the different sources to ensure the algorithms work. Ensure that all data sources are aligned to the overall data schema to dictate common parameters.

Sample Vendors

Amazon Web Services; Braincube; Cognite; Drishti; HighByte; Mareana; Microsoft; Sight Machine

Gartner Recommended Reading

How to Improve the Performance of AI Projects

Infographic: Common Layers of Data Science and Machine Learning Activity

Use Gartner's MLOps Framework to Operationalize Machine Learning Projects

Tool: Vendor Identification for Data Science and Machine Learning Platforms

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

Mixed Reality

Analysis By: Tuong Nguyen, Marty Resnick

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Definition:

Mixed reality (MR) is the merging of real and virtual worlds, where physical and graphical objects appear to interact and integrate naturally. MR, in concept, is a single technology. However, MR includes an underlying group of technologies encompassing the spectrum of immersive displays and interactive systems that spans from the digitization of real environments to augmented reality (AR) and virtual reality (VR).

Why This Is Important

MR enhances the user's surroundings with real-time, relevant, interesting and/or actionable information, but adds a layer of sophistication through advanced, contextual understanding of the scene and situation. This makes MR (as a digital filter) more dynamic, relevant and immersive, creating a more seamless experience or interface between the digital and physical world. For example, an AI Avatar walking around furniture rather than through furniture or walls.

Business Impact

Today, MR capabilities focus on optimizing “hands busy” work environments, such as maintenance and repair. Over time, MR will expand to include experiences that can visually enhance everyday objects. New business models will emerge, which will change how customers buy products using MR or how they conduct operations by visually connecting the user’s view of the real world with their data-driven virtual world counterparts. For example, rapid prototyping and testing of products and marketing

Drivers

- Growth and maturity of underlying technologies, such as computer vision, scanning technologies, geopose, AR Cloud, mapping, modeling, head-mounted displays, edge processing and high-bandwidth, low-latency networks, and generative AI, are making MR experiences more viable.
- Metaverse hype (especially for the spatial computing aspects) has also provided positive momentum on MR.
- Cross-pollination benefits digital twins for support, design and collaboration purposes, and MR as a 3D visualization and interaction tool.

Obstacles

- **Content:** Digitization efforts have seeded the market with some content, but will need to be increased by orders of magnitude to make MR useful for the mass market.
- **Control:** MR adds a layer of control complexity over AR because it moves beyond a simple digital overlay. It includes active interaction with and of the digital aspects of a physical scene. For example, “touching” and “feeling” a digital object, or hearing a digital object coming from a distance or overhead. This also requires systems that are sufficiently sophisticated to understand the environment, context and the processes of a scene/situation.
- **Convenience:** Head-mounted displays (HMDs) are the primary device for MR experiences. They are both high priced and purpose built. Until there is better access to form factors that make these experiences seamless and valuable, this will be a hindrance. For example, handheld devices deliver a poor user experience for extended MR usage, and HMDs are both high priced and purpose built.

User Recommendations

- Apply MR technology to enable new types of experiences and interactions involving 3D visualization and manipulation of digital objects in the real world. Use cases such as just-in-time checklists and remote support with simple telestration are better served with AR.
- Assess the tactical value of MR. While it may be the culmination of AR and VR technologies, MR will demonstrate more value in scenarios which benefit from physical interaction and manipulation where digital are aware of or need to interact with the physical environment. For example, fitting new surgical equipment into dimensional constraints of an operating room, or redesigning a public space.
- Evaluate ROI potential by focusing on a small number of pilots benchmarked against traditional, non-MR experiences as well as AR and VR experiences.
- Build in-house expertise for MR experiences by hiring developers with immersive skills (such as gaming engine, 3D modeling and UI design).

Sample Vendors

Google; Magic Leap; Microsoft; Nreal; ThirdEye Gen; Viewpointsystem

Gartner Recommended Reading

Emerging Technologies: Tech Innovators in Augmented Reality — Spatial Web

Emerging Technologies: Tech Innovators in Augmented Reality — AR Cloud

Emerging Technologies: Find Success With Head-Mounted Displays Despite Modest Market Growth Expectations

Emerging Tech: Venture Capital Growth Insights for Head-Mounted Display Technologies

Emerging Technologies: The Future of the Metaverse

Smart Factory

Analysis By: Simon Jacobson, Alexander Hoeppe

Benefit Rating: Transformational

Market Penetration: 20% to 50% of target audience

Maturity: Adolescent

Definition:

Smart factory is a concept used to describe the application of different combinations of modern technologies with standard work to create a hyperflexible, self-adapting manufacturing capability.

Why This Is Important

Smart factories combine modern technologies and standard work to innovate how factories operate. Smart factories are an underlying capability of smart manufacturing and broader digital supply chain and Industrie 4.0 initiatives, providing an environment where frontline workers and technology interact in an open, connected and coordinated fashion.

Business Impact

Smart factory value creation and benefits happen across a wide spectrum, leveraging a vast array of technology combinations and use cases that will differ by industry, kind of supply chain supported and manufacturing style. The initial benefits are broadly rooted in improving site operations. Over time — as smart factories are synchronized with how the business works — improvements in flow, customer service, sustainability, agility and profitability are possible.

Drivers

- Industrie 4.0, smart manufacturing initiatives (including resiliency, automation and optimization), new value chain requirements and evolving operating model shifts are driving interest in smart factories.
- Competitive pressure is driving the innovation of production management by digitizing existing processes to improve data-driven decisions by workers.
- Improving operational resilience means sites can take on more orders, meet market changes faster, improve sustainability, or deliver newer and more complex products.
- Users are becoming dissatisfied with the value, scalability and cybersecurity risk inherent in legacy manufacturing technology (such as MES, ERP, OT).

Obstacles

- Outside-in designs for smart factories and the role they play in the network require aligning culture and individual job roles/responsibilities on a local basis.
- The majority of smart factory initiatives are upgrades of existing facilities. Complexity of integrating different modern technologies such as industrial Internet of Things (IIoT), AI or digital twins with existing information technology/operational technology (IT/OT) investments can be costly and time consuming.
- Belief that a single-vendor solution exists. Not one specific technology or vendor can deliver a smart factory.
- Funding models to overcome extensive backlogs of IT and operational technology (OT) upgrades, integration, and other technical debt are challenging to create.
- The emphasis of tactical wins at sites that are not synchronized with product supply strategy thereby create the risk of excess costs and constraints elsewhere in the business.
- The urgency of aligning and converging IT/OT and engineering technology (ET) is easily overlooked.
- There is a failure to acknowledge and adequately prepare for the cultural and change management impacts that come with process design or redesign, and new ways of working.

User Recommendations

- Avoid isolated technology projects by promoting the smart factory concept as part of an agile system designed to service demand. This keeps the focus on enabling profitable agility across the supply chain.
- Design for scalability by identifying capabilities first and applying a composable (i.e., modular) step-by-step approach. Then introduce standard use cases combining workflow, data processing, technology and user experience.
- Prioritize use cases based on site maturity and objectives.
- Utilize real-time factory data to improve decisions and mitigate risks in the supply chain.
- Include your workforce — people are your critical assets. Redefine learning and development (L&D) to give factory workers the digital dexterity to interact with new processes and technologies around them.

Gartner Recommended Reading

Innovation Insight for Smart Factory

Quick Answer: What Are the Differences Between Industrie 4.0, Smart Manufacturing and Smart Factory?

Video: DuPont's Journey to Lights-Out Manufacturing

Quick Answer: Differences Among Industrie 4.0, Smart Manufacturing and Smart Factory

Predicts 2023: The "Triple Squeeze" Will Require Manufacturing CIOs to Gain Visibility by 2026

Supply Chain Convergence

Analysis By: Dwight Klappich

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Supply chain convergence is where supply chain functional silos are broken down and end-to-end (E2E) business processes span, synchronize and optimize across traditional functional domains.

Why This Is Important

To get beyond Stage 3 maturity, supply chain organizations must embrace convergence as both a business and an IT vision and strategy. Companies continue struggling to systematically integrate E2E business processes in the fragmented supply chain functional and IT environments prevalent in most organizations. Coordinating, let alone optimizing, E2E processes across application silos remains elusive, but with the emergence of composable application architectures, this is becoming more attainable.

Business Impact

Supply chain maturity and supply chain convergence attainment are closely aligned, wherein higher-maturity organizations are more likely to address the cultural and operational issues necessary to reach higher levels of convergence. Breaking down the functional silos by leveraging technology to assemble composite processes across domains addresses the urgency to pursue convergence as companies seek higher maturity, and as new business models (like digital) drive transformational change.

Drivers

- E2E processes are horizontal and often span multiple functional organizations and systems, and increasingly span enterprises. Most organizations are organized by functional silos, but once a company makes the commitment to think horizontally, aligning processes will become a necessity.
- New process improvement will require organizations to adapt their cultures and operational environments to coordinate and synchronize E2E processes, such as selling, buying or making. This will require supply chain capabilities and systems to converge across and between traditional supply chain management functional silos. However, until recently, technology was a barrier, but with the emergence of composable application platforms, this is potentially technically feasible.
- While for years companies have recognized the need to better orchestrate E2E processes, it is only recently that technology, notably microservice-based API-centric architectures, is making this possible.
- With the emergence of composable microservice-based technical architectures, in some cases, companies can soon assemble packaged business capabilities (PBCs), irrespective of the functional domain the services typically belong to, which will lay the foundation for Stage 3 and beyond convergence.
- Convergence is needed to support the next wave of business value, because it's better at orchestrating E2E processes. But as they mature, companies will increasingly apply optimization capabilities to these E2E processes to allow them to perform better.
- Initially, convergence strategies will be focused inside-out within the enterprise, but to mature further, companies must shift their focus to an outside-in perspective. Companies must consider the role of multienterprise business networks and how these can enable integrated ecosystems and synchronized cross-enterprise processes.

Obstacles

- Because the technology was not available to effectively progress to E2E process orchestration convergence most organizations have been stuck at lower maturity analytical or transactional integration convergence. Now with composable microservice-based API centric applications, the technology is catching up to the need, making achieving Stage 3 convergence maturity more achievable.
- Technical debt, where companies have large scale investments in existing systems, is a barrier to achieving convergence, as the time, effort and cost to renovate a company's entire application portfolio is prohibitive.
- Organizational culture is a barrier to achieving convergence, as too many operations cling to rigid functional silos with processes optimized vertically within a function, but suboptimally across functional silos.
- Rapid adoption of SaaS-based siloed applications and decentralized technology investment models create obstacles for technical leaders to build a true E2E convergent supply chain.

User Recommendations

- Evaluate how fundamental operational processes are linked with and affected by processes that are controlled by other functional groups and systems within and outside their organizations.
- Adapt your organizational cultures and operational environments to enable coordination and synchronization of E2E processes by shifting your paradigms from a vertical (functional) view of the world to a horizontal (E2E process) view of the world.
- Break down functional silos by creating composite business processes that bring together subprocesses and activities across specific domains.
- Evaluate how fundamental operational processes are linked with and affected by processes that are controlled by other functional groups and systems within and outside their organizations.
- Leverage Gartner research to develop a composability purity test to evaluate the realities and roadmaps of technology vendors you are considering.

Gartner Recommended Reading

Understand the Need for Supply Chain Execution and Manufacturing Operations Management Convergence

Becoming Composable: A Gartner Trend Insight Report

Top Trends in Strategic Supply Chain Technology 2023

Digital Operating Systems

Analysis By: Simon Jacobson

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Digital operating systems are the next generation of corporate production systems. They marry the mature, core pillars of corporate production systems with smart manufacturing to create integrated development and application of digital, lean and continuous improvement principles and new leadership behaviors.

Why This Is Important

Prior investments to improve manufacturing's responsiveness and simultaneously remove constraints and build new capabilities exposed the limitations of established lean production systems. Digital operating systems help sense and respond to changing market conditions with speed and flexibility. They do so by converging the foundations of lean and continuous improvement with new requirements for talent and digitization to improve manufacturing operations and sustain new cross-functional capabilities.

Business Impact

When synchronized with designs for supply chain agility and data-driven performance improvements, then consistency, scalability and competitive advantage can be achieved. This requires simultaneous attention to aligning digital strategies with site-specific process capabilities, skills, culture and governance models. Without a digital operating system, the leverage of new technologies plus any new processes and measurable improvements beyond site-level efficiencies will not stick.

Drivers

- Designs for resilience and agility require stronger and frequent alignment between the manufacturing network and supply chain operating models. Smart factories are expanding and creating more data to analyze and accelerate the potential for accelerated change. Manufacturers have heavily invested in varied technologies to support site operations the past three years. While standard systems might exist, the guidance on how to leverage — or when to invest — is lacking. Manufacturers must now reinvent entrenched business designs and practices. Leveraging the combination of digital roadmaps, site capabilities, and continuous improvement requires new rules and procedures.

- Responding to unplanned market events with speed and flexibility has raised the profile of manufacturing operations and exposed significant risk in the underlying foundations of various systems, such as Toyota Production System (TPS), total quality management (TQM), and world-class manufacturing (WCM). These or similar systems aren't enough to meet new agility and speed imperatives or support the convergence of lean and digital/new talent requirements. Digital operating systems upgrade and expand the foundations of lean and CI.

Obstacles

Several factors which may be holding digital operating systems back from reaching maturity or mainstream adoption include:

- Ensuring site readiness for leveraging new solutions, which involves managing change of this magnitude so the as-is doesn't become so ingrained that it prevents innovation.

- Cultures with weak innovation appetite, change resistance and experiential bias.

- Uncertain alignment with the supply chain impeding scalability across sites and cross-functional integration.

- Cultures prioritizing a steadfast reliance on cost savings and efficiency gains at sites.

- Inconsistent harmonization of different methodologies (such as TPS, TQM and WCM) and subsequent digitization of those processes.

User Recommendations

- Adopt a templated approach to investments to ensure digitization and integration of existing lean and continuous improvement programs can be adapted to different site capabilities across the network.
- Focus on capability building first. Then identify the standard digital tools and define the operating procedures for how they will be leveraged. Anticipate there will be collateral benefit to diffuse into other supply chain functions for broader efficiencies.
- Ensure the dialogues on capability building and digitization are combined and not separate so initiatives are aligned and funded appropriately. Daily management and preshift meetings are a starting point.
- Define iterative progress and achievements to focus and define deployment phases by using a stage-based maturity approach. This ensures the right capabilities are in place for sites to leverage technology effectively.

Gartner Recommended Reading

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

Use the 5 Level Manufacturing Score Maturity Model to Support Strategic Planning

Production Systems 2025: Rewriting the Working Systems for Industry 4.0

Supply Chain Brief: Modernize Production Systems to Unlock Manufacturing Operations and Support Agility Imperatives

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

MOM Application Suites

Analysis By: Rick Franzosa, Christian Hestermann

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Manufacturing operations management (MOM) application suites extend manufacturing execution systems (MES) beyond production-execution management to include detailed production scheduling, production resource management (materials, assets and labor), process and product reliability (quality and compliance), and manufacturing data analytics.

Why This Is Important

The importance of MOM application suites is based on the need for extended application capabilities beyond traditional MES across manufacturing to provide more flexibility and agility at the plant level. The result of expanding these application suites is to help frontline workers make better decisions and respond in near real time to events on the plant floor without the need for communication with upstream systems (ERP/PLM/SCM).

Business Impact

The business impacts of MOM application suites are:

- They enable process optimization across different manufacturing disciplines. The trade-offs are required process changes and integration discipline between MOM suites and other enterprise applications.
- Process change will be high as MOM applications enable manufacturing operations process optimization and replace multiple disparate applications from different sources. This helps accelerate continuous improvement initiatives and digitization.

Drivers

- Users need capabilities beyond core MES to continuously improve upon efficiency, quality and cost. Seamless integration with capabilities such as material handling and warehouse management system (WMS), detailed plant-level scheduling, quality management and intraplant logistics are required to streamline plant processes.
- Increased focus on capabilities to support better manufacturing employee decision making and competency, fuel the need for better visibility of data from multiple manufacturing disciplines. This can be enhanced by MOM application suites that support a more diverse set of manufacturing functions.
- Manufacturers are looking for a common, scalable platform that can be deployed across multiple sites, enforcing standards and providing a unified view of production data.

Obstacles

- MOM application suites are positioned as functional applications, not enterprise applications, which creates an obstacle to enterprise and manufacturing network goals.
- They rarely have the same breadth of functionality as the built-for-purpose applications in production scheduling, resource management, quality or data analytics. Its value comes in providing an integrated, manufacturing plant-specific suite of tools.
- The preferred vendor approach is to build a MOM platform. This creates additional costs and challenges in integrating and rationalizing another platform into an enterprise.
- MOM implementations are more complex than MES, and are more likely to encounter cost overruns and are difficult to scale.
- Supply chain and manufacturing operations convergence are hampered by site- or plant-specific duplicative functions such as scheduling, inventory management and quality management.

User Recommendations

- Build out MOM functionality by examining the need in each solution area, and define where it makes sense to provide a capability (e.g., production scheduling, materials management and quality) as part of a MOM application suite, versus using a built-for-purpose enterprise-level application.
- Ensure implementation success by aligning the MOM application suites to your proven manufacturing operation processes and systems.
- Minimize MOM application suite integration challenges by teaming IT and end-user communities to define process and integration roadmaps that optimize end-user adoption and reduce integration complexity.

Sample Vendors

ABB; AVEVA; Critical Manufacturing; Dassault Systèmes; iBase-t; iTAC Software; Parsec Automation; Rockwell Automation; SAP; Siemens Digital Industries Software

Gartner Recommended Reading

Critical Capabilities for Manufacturing Execution Systems

Magic Quadrant for Manufacturing Execution Systems

Ignition Guide to Selecting a Manufacturing Operations Software Vendor

Innovation Insight for Smart Factory

Understand the Need for Supply Chain Execution and Manufacturing Operations Management Convergence

OT Security

Analysis By: Katell Thielemann

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Mature mainstream

Definition:

Operational technology (OT) includes hardware and software that detect or cause a change, through the direct monitoring and/or control of industrial equipment, assets, processes, and events. OT security focuses on protecting them. As threats and security solutions multiply, a generic category of OT security that was once dominated by network-centric tools is now evolving into multiple categories.

Why This Is Important

Once disconnected from IT networks, the increased connectivity of OT and IT systems has created new security risks. As operational systems are the centers of value creation, OT security has major relevance to organizations in national critical infrastructure, and to any other industrial verticals with operations and asset-centric environments. Network-centric security, with a focus on segmentation and firewalls, traditionally anchored OT security approaches, but new categories have emerged.

Business Impact

Whether it be nation-states targeting critical infrastructure and intellectual property (manufacturing is often targeted for cyber espionage), or financially motivated hackers deploying ransomware, the number of attacks on systems in production or mission-critical environments has increased over the past five years. The impact of operational disruption can range from mere annoyance to hundreds of millions of dollars, along with reliability, life and safety impacts.

Drivers

- Digital transformation initiatives are multiplying in asset-intensive organizations, in turn creating new risks that security teams may have no visibility into.
- Due to a rapidly changing threat landscape, asset-centric organizations are increasingly focusing their attention on the security risks they face outside of enterprise IT. They realize they are surrounded by cyber-physical systems (CPS) that underpin all their production, distribution and value creation efforts.
- International standards, such as IEC 62443, NIS2 and NIST 800 series, are emerging to provide guidance. In some industry verticals, security mandates, such as NERC CIP or TSA directives, are already in place. Given the close relationship between critical infrastructure and national security, and the growing concerns of targeted attacks, government-led efforts are on the rise, adding to the growing list of existing national legislations.
- One of the initial focus areas was network-based security, which has underpinned most OT security efforts for the last decade. But, many specific categories have emerged to deal with the fast-evolving threat landscape and introduce innovation in security operations. As a result, a singular OT security market is evolving.
- Some of the emerging new categories for CPS include protection platforms, cyber risk quantification platforms, secure remote access solutions, security services, network-centric solutions, or onboard diagnostics solutions.

Obstacles

- Organizations face cultural, governance and security controls challenges that prevent a one-size-fits-all approach to security. For instance, production assets often run 24/7 and cannot be stopped at will.
- Manufacturers often connect remotely to production assets to maintain and update them. If not done securely with consistent policies, this creates additional risks. They also often control deployment of updates on the basis of contracts and warranties, which can hamper security efforts.
- Shortages of OT security skills remain acute and growing.
- The age of systems and devices (up to 20 years) means no security updates are available anymore.
- OT security is evolving into CPS asset-centric security, enabled by platforms that support not only OT, but also IoT, industrial IoT, or smart building assets. This is changing OT security from focusing on segmentation and firewalls to placing the assets at the center of security, and layering defense-in-depth approaches around them.

User Recommendations

- Initiate risk discussions between IT security and production/engineering teams, and determine the current extent of OT security efforts.
- Deploy CPS asset discovery, inventory and network mapping security platforms.
- Determine immediate gaps, such as flat networks and missing or misconfigured firewalls.
- Accelerate security awareness and skills training for converging IT and OT infrastructures.
- Focus on organizational and cultural trust challenges between IT and OT personnel.
- Collaborate with your procurement team to demand that OEMs of OT systems ensure that systems are secure by design.
- Prepare for the new reality of CPS security as a centralizing discipline for securing the ever-growing list of IT, OT, IoT and industrial IoT systems, and for bringing together an asset-centric cybersecurity discipline.

Sample Vendors

Blue Ridge Networks; Booz Allen Hamilton; Optiv Security; Waterfall Security Solutions

Gartner Recommended Reading

3 Initial Steps to Address Unsecure Cyber-Physical Systems

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

Climbing the Slope

Industrial IoT

Analysis By: Simon Jacobson, Scot Kim

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

The industrial Internet of Things (IIoT) is a subsegment of the greater market of IoT. In manufacturing, it is used to improve asset management decision making and operational visibility, as well as control for plant infrastructure and equipment within asset-intensive industries and environments.

Why This Is Important

IIoT is a core building block for smart manufacturing, improving its reliability and accessibility by extending, augmenting or replacing operational technology (OT). IIoT improves how data sources (historic and real-time across operations and systems) are accessed, analyzed, contextualized, and leveraged. Overlay IIoT platforms and solutions pave the way for how to leverage cloud, edge computing/devices, sensors, and AI/machine learning (ML) to optimize performance through enabled applications and a digital thread across operations.

Business Impact

IIoT provides access to a wider range and deeper set of data sources with the power of extracting insights and improving data-based decision making (and therefore operational performance), influences trade-offs across the network, and identifies future opportunities for automation and cost-efficiencies. The impact that IIoT delivers is bringing insights into industrial data that legacy OT systems have failed to provide.

Drivers

- Smart manufacturing, Industrie 4.0, proliferating industry consortia and nationally driven industrialization initiatives placing IIoT at the center of their initiatives. This highlights the importance of interoperable platforms as a nucleus to an organization’s strategy, and not simply a nice-to-have technology.

- Better cost-efficiency in industrial operations by extending the functional life of capital assets.
- Improved productivity and operational excellence through improved quality and optimized asset performance.
- Improved data-driven decision making by frontline workers.
- Ambitious automation designs and the exploration of how certain processes can be managed remotely.
- Establishment of distributed manufacturing networks and servitization/“as a service” models.

Obstacles

- Organizational complexity, cultural impediments and process (re)engineering are required for success.
- IT and OT heterogeneity catalyze architectural debates and turf wars, impeding progress.
- Components for successful IIoT implementation are complex and of diverse maturity levels.
- Security concerns go beyond data confidentiality, integrity and availability to encompass the safety and reliability of physical operations.
- IIoT projects rely on interoperability which inherently introduces new integration challenges, making firms navigate a sea of standards, reference models and proprietary protocols.
- Resource requirements (skills, cost and integration) are often underestimated.
- Provider options continue to expand and create complications for manufacturing systems’ strategies.
- Even with robust ROI, the funding models for scalability are elusive.
- The knowledge to build, partner or acquire IIoT expertise and technologies is lacking.
- IoT-enabling technologies without any business value or business buy-in are still preferred.

User Recommendations

- Develop a plan to map data, processes and use cases with site capabilities. Then segment use-case pursuits into those that will enhance the core of operations and those that will foster future innovation and process capabilities.
- Use a maturity-based continuum to develop the roadmap by aligning current and future use with both site and supply chain business objectives. Leverage a maturity-based continuum to holistically plan architecture, deployment models, standard work and interoperability.
- Ensure alignment between IT, OT, engineering technologies (ET), frontline workers and line-of-business stakeholders, so they can accurately budget resources, identify the role of standards and clarify expected benefits.
- Examine the trade-offs around buy/build/acquire/partner diligently based on in-house capabilities, time, budget and deployment environment.
- Determine the prerequisites prior to embarking on an IIoT journey by identifying the vision, architecture and associated data sources to ensure successful transformational implementations.

Sample Vendors

Amazon Web Services; Augury; Automation Intellect; Braincube; Litmus Automation; Microsoft; PTC; Software AG

Gartner Recommended Reading

Magic Quadrant for Global Industrial IoT Platforms

Innovation Insight for Smart Factory

Quick Answer: How to Communicate the Value of Industrial IoT Platforms to SCADA Solutions

Emerging Technologies and Trends Impact Radar: Internet of Things for Industrial Manufacturing

Manufacturing Segmentation

Analysis By: Michael Dominy

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Manufacturing segmentation is an application of targeted supply chain segmentation to manufacturing processes. It involves designing and operating multiple standardized approaches to production and assembly processes. Each approach is optimized for a specific goal, such as efficiency, cycle time, customization or flexibility.

Why This Is Important

Manufacturing leaders traditionally have unique policies or approaches at independent sites, or focus on creating a single global or regional standard for manufacturing. Segmentation groups sites or lines with similar objectives and defines a standard production approach for each segment. This helps manage the complexity of the business while still providing economies of scale. Tailored designs maximize aligned performance goals such as cost, responsiveness, flexibility, agility or resilience.

Business Impact

Segmentation can differentiate within a site or across sites to provide dramatic improvements as it optimizes each for different outcomes. It might inform overall manufacturing network design (i.e., determine the location, ownership and charter for each site), improve asset utilization for cost or increasing flexibility, and reduce changeover times for agility. Standards across lines and factories can make capacity interchangeable to increase options to ensure resilience during disruption.

Drivers

The Hype Cycle position represents an average of varying adoption profiles for segmenting across versus within sites and has moved into the initial stages of the Slope of Enlightenment:

- **Segmentation across sites in the manufacturing network:** Insourced or outsourced factories dedicated to outcomes, activities or geographies is not a new concept. Different standardized production processes by manufacturing site are based on business requirements (product, market or customers) and role in the overall network strategy. A site will use global standard metric definitions with target sets based on region or product line, or focus on efficiency, responsiveness (cycle time) or agility (customization or flexibility).

- **Segmentation within a manufacturing site**: Segmentation within sites is less often adopted. Different production strategies for lines within a site are based on the characteristics of products and equipment or business needs. This is most common where large variation in products necessitates frequent changeovers or lengthy equipment setup times. Dedicating lines for high-volume products or customizing lines for small batch runs are common.
- **Resilience and agility:** Thoughtful and effective implementation and management of segmentation across the supply network can improve agility and resilience by purposefully identifying where variability and scale is positioned by site and within sites.
- **Expansion:** Expanding product lines, geographies and customer services prompts the view of the manufacturing network as a collection of capabilities that must be optimized.
- **Productivity:** Creating a menu of standard manufacturing approaches optimized for different outcomes boosts productivity, sheds excess capacity and cost, and shortens response times.
- **Innovation:** Experimentation with new technologies (e.g., 3D printing and robots) and new concepts (e.g., multimode facilities and mobile factories) promotes interest in standardizing. Complexity requires a handful of production approaches to achieve multiple outcomes. This uptick in interest accelerates the move to the plateau in the next two to five years.

Obstacles

- The initial segmentation of sites is often not ideally executed and has room for improvement in its definition and impact to the business.
- Inconsistent master data and lack of analytical capabilities to quantify cost/capability trade-offs negatively impact coordination across sites.
- Tailored line designs may require application of new technologies.
- The capabilities of lines will impact the extent that segmentation is possible.
- Regulatory requirements and qualification of production equipment and processes often complicate efforts. This is common in life science industries.
- Complex organizational change at all levels is required to align sites to demand and processes to specific outcomes — often leading to matrixed structures. Incentives, metrics, capacity allocation and productivity targets must shift and will vary by site. Supplier and partner relationships will evolve.

User Recommendations

To apply manufacturing segmentation:

- Formalize any segmentation that has unconsciously arisen within manufacturing sites with differentiated metrics targets.
- Use segmentation within sites with large product variety or long equipment changeover times.
- Segment sites or lines to optimize them for cost, flexibility or responsiveness.
- During network design, evaluate cost-to-serve and target specific sites to customer-centric attributes, such as price, speed of delivery and availability.
- Create interchangeability and redundancy to improve agility and resilience.
- Identify where external manufacturing partners are utilized based on spend and supply complexity.
- Define how manufacturing segmentation fits with other segmentations present in your supply chain.

- Implementing and maintaining segmentation requires executive sponsorship and governance specific to each segment. Explicitly define the outcome of each segment, what activities are performed differently and rules for what flows through the segment.

Gartner Recommended Reading

Build Segmentation Into Your Manufacturing Strategy to Deliver Business Outcomes

Segmentation 101: Apply Supply Chain Segmentation to Serve Diverse Needs and Reduce Waste

Combine SKU Segmentation With Inventory Calculation to Optimize Supply Plan Alignment

Manufacturing Operations Primer for 2023

Use the Hierarchy of Manufacturing Metrics to Connect Manufacturing and Supply Chain Performance

Energy Efficiency

Analysis By: Sarah Watt, Lauren Wheatley

Benefit Rating: High

Market Penetration: More than 50% of target audience

Maturity: Mature mainstream

Definition:

Energy efficiency enables a given amount of work to be undertaken using less energy. Practices range in scale from behavioral changes that can result in incremental energy savings to transformational projects such as equipment replacement. Projects rely on engineering skills, technology availability and capital investment. These projects can address multiple stakeholder drivers and as a result energy efficient enterprises can effectively reduce energy demand, manage emissions and contain costs.

Why This Is Important

Rising energy prices drive inflation across materials, transportation and operational costs. Energy efficiency actions can reduce energy demand, lowering costs and carbon emissions, which contributes to net zero goals. It is often an overlooked opportunity; the International Energy Agency reports that energy intensity has improved on average 1.3% in the last five years, but a 4% yearly reduction is needed to achieve net zero emissions by 2050.

Business Impact

Proactive management of energy costs creates a competitive advantage. Energy efficiency has three direct business impacts: energy demand management, cost containment and greenhouse gas emissions reduction. Energy efficiency activities may also catalyze strategic decisions on energy security in a dynamic political environment, such as dependence on Russian natural gas. Employee involvement in identifying ways to save energy improves engagement and project impact.

Drivers

- **Volatile energy market:** Energy is usually one of the top five costs businesses have to manage. Volatility in energy cost and supply is hurting business and driving inflation. On the supply side, oil and natural gas investments are declining while clean technologies have not scaled at sufficient pace to address the gap.

- **Technology and innovation:** Democratization of energy supply and cost-effective options for self-generation spotlights the need for enhanced load management. Improved automation with operational technology can improve energy efficiency, reducing the need for self-generation.

- **Energy transition:** Country commitments to net zero greenhouse gas emissions is a catalyst for the energy transition toward a low-carbon economy. Existing legislation such as the EU's Energy Directive, focusses business on energy savings, enabling the bloc to meet a 55% emissions reduction by 2030 (compared to 1990). Future taxes and carbon border adjustment mechanisms also act as catalysts for improved energy management.

- **Supply chain costs:** Energy efficiency opportunities and sharing best practices is not only an enterprise conversation, but must extend to supply chain partners. Reducing energy consumption and improving efficiency can limit increased raw material costs.

- **Energy efficiency gamification:** Increasing real time data is increasing the adoption of energy efficiency gamification either as part of data and analytics or as a stand-alone program/application. Typical strategies include increasing visibility; contests and rewards for conserving energy and water; social media elements, such as communities; and indicators of status and success, like badges and leaderboards.

Obstacles

- **Financial constraints:** Enterprises may not prioritize capital to energy savings projects. Alternative funding mechanisms include internal carbon pricing, which raises capital through each business unit being taxed on their greenhouse gas emissions.

- **Strategic goals:** Short-term energy efficiency activities may be hampered by the strategic goals of the enterprise. In mature slow-growth industries that have a large share of the market, leaders may not see the benefits. Alternatively, parts of the business that are being considered for divesture will not be prioritized.

- **Risk of stranded assets:** Previous energy efficiency decisions may result in stranded assets, as increased regulations are put in place to transition to a low-carbon economy. For example, a combined heat and power plant, which enables efficient generation of electricity and hot water, may be subject to increased tax, natural gas costs or security of supply issues.

User Recommendations

- **Increase visibility:** Identify significant manufacturing energy loads by conducting an energy site audit, undertaking a pareto analysis and identifying opportunities for improvement.

- **Utilize technology:** Install energy management and optimization systems to create visibility of energy use by equipment and process.

- **Develop site energy plans:** Use the increased visibility and insights gained in collaboration with engineering teams to develop a site energy savings plan. Use this plan as an input to the annual budget process to demonstrate projects cost, implementation timelines and returns. Where capital is not available, explore alternative financing arrangements such as energy performance contracts or government grants.

- **Implement projects:** Leverage engineering resources and third-party experts to help identify and implement energy savings projects. Ensure that anticipated savings are actually delivered, and if not, conduct a root cause analysis to identify corrective actions.

Gartner Recommended Reading

Tool: Identify Manufacturing Energy Savings Opportunities

Quick Answer: What Financing Options Are Available to Support My Sustainability Goals?

Market Guide for Commercial and Industrial Energy Management and Optimization Systems

Quick Answer: How Are Electricity Markets Changing as the Energy Transition Accelerates

Use-Case Prism: Tactical Energy Conservation Solutions

Cloud Computing in Manufacturing Operations

Analysis By: Rick Franzosa

Benefit Rating: High

Market Penetration: More than 50% of target audience

Maturity: Early mainstream

Definition:

Cloud computing is a style of computing in which scalable and elastic IT-enabled capabilities that support manufacturing operations are delivered as a service using internet technologies.

Why This Is Important

Cloud's progress across manufacturing operations continues to expand, though it varies by industry and use case. While manufacturers are not abandoning on-premises models for mission-critical applications, we have seen further growth in hybrid cloud adoption, with on-premises components replacing full on-premises systems. Manufacturers are in modernization mode, and as a result, remote process/work and intelligent edge devices are reaching greater maturity in support of hybrid cloud deployments.

Business Impact

Impacts of cloud computing in manufacturing include:

- Enabling new styles for technology consumption and information access.
- Contributing toward a flexible and agile manufacturing network when leveraged properly.

- Helping an organization standardize and improve processes.
- Easing remote access to applications and supporting remote workers.
- Bringing cloud closer to the manufacturing process via edge capability.
- Over time, reducing on-premises IT total cost of ownership (TCO) for both hardware and personnel.

Drivers

- Provider offerings have evolved across all segments, spanning quality management, manufacturing execution systems (MES), production planning and varying degrees of analytics. New market entrants are taking a “cloud-first” approach, building their applications leveraging cloud infrastructure providers.
- General acceptance of cloud computing grows in all markets as pockets of concern over data security, latency and exchange (between on-premises and cloud) are diminishing.
- Cloud services combined with platform as a service (PaaS) provide cloud application infrastructure services for custom applications and solutions, where the cloud attributes of scale and internet availability encourage innovation and high performance in manufacturing operations applications.

Obstacles

- The issue of shifting funding models. Yearly capital expenditure (capex) planning and cloud do not go hand-in-hand; there is adjusting of operating expenditure (opex)/capex ratios needed.
- Some manufacturing environments require on-premises solutions, and cloud solutions with on-premises "failover" are uncommon.
- Initial cloud-native solutions lack content and maturity of readily available on-premises solutions.
- Buyers are apprehensive about control of cloud costs and vendor monetization of data.
- Cloud-native/cloud-friendly offerings in manufacturing do not reduce the need for complex integration.
- Manufacturers are now concentrating on the details (e.g., cybersecurity, vendor lock-in), and really determining what is mission-critical and what is not.

User Recommendations

- Identify use cases for cloud computing by focusing on broad applicability to enhance existing process capabilities and overcome IT skills deficiencies across multiple sites.
- Minimize disruption by performing hybrid deployments that leverage existing on-premises systems.
- Protect your organization by aggressively addressing and eliminating the challenges of cybersecurity in cloud and hybrid offerings.
- Avoid the mass customization of cloud-based applications to site-specific needs by focusing on shared functional requirements.
- Protect your investment by demanding transparency from vendors regarding their cloud offerings — especially on contract life cycle pricing, data ownership and long-term TCO, as well as service levels and security models.
- Establish a clear and realistic understanding of the expected benefits of a move to the cloud by understanding benefits and trade-offs.

Sample Vendors

Apprentice.io; AVEVA; GE Digital; iBASE-t; Oracle; Rockwell Automation; SAP; Siemens Digital Industries Software; Sight Machine; Tulip Interfaces

Gartner Recommended Reading

Cloud Computing in Manufacturing Is Foundational Today and the Requirement to Operate in the Future

Innovation Insight for Smart Factory

Transform How Smart Manufacturing Is Funded to Drive Adoption

Asset Performance Management

Analysis By: Nicole Foust, Kristian Steenstrup

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

APM systems are business applications for optimizing reliability and availability of operational assets (such as plant and infrastructure) essential to the operation of an enterprise. It uses data capture, integration, visualization and analytics to improve asset maintenance activities. APM includes capabilities and functionality to support asset strategy, risk management, predictive maintenance, reliability-centered maintenance and financially optimized maintenance activities.

Why This Is Important

APM is an important technology for asset-intensive organizations to enable business outcomes with strategic asset maintenance decision support. Organizations invest in APM tools and technologies to reduce unplanned repair work, improve asset availability and safety, minimize maintenance costs and reduce the risk of failure for critical assets. Realizing the business can move beyond the key use case of equipment reliability, organizations leverage APM to improve overall business operations.

Business Impact

APM is an important investment area for asset-intensive industries and can deliver measurable benefits:

- Asset availability (reducing maintenance and inventory carrying costs)
- Improved uptime and cost savings can be substantial (benefits measured in millions of dollars per year)
- Improved scheduling of maintenance and planned outages
- Reliable data quality
- Effective alarm management
- Reduced manual data entry hours per month
- Optimized resources to monitor spatially distributed assets

Drivers

- With the increased focus on the overall availability of their assets in asset-intensive industries (not just breakdowns and repair costs), organizations need better solutions to deliver enhanced asset insights. Innovation in enabling technologies such as cloud, IoT and AI/ML are widening the scope and decreasing the deployment cost, aiding more awareness and use of APM.
- As operations take advantage of newer sensors (e.g., acoustic), drones and bots, APM has access to increased data volumes of better quality and granularity (or reduced latency) and accuracy, yielding richer use cases and more robust capabilities.
- Business processes supported by APM software are becoming an important core business capability for asset-intensive organizations. CIOs are increasingly realizing benefits that aid the market transition beyond the use of APM focused on equipment reliability to increasingly leveraging APM to also help improve overall business operations.
- Most APM projects are executed on the premise that data-driven decisions will improve equipment reliability and, therefore, reduce operational risk.
- The potential of reduced maintenance cost and downtime, coupled with higher levels of operational reliability, is attracting other industries; however, all are progressing at a varied pace.

Obstacles

- Limited availability of good-quality, consistent and the right asset data to support a more advanced maintenance capability.
- Limited adoption of asset management standardization (such as ISO 55000) as well as digital business immaturity constrains organizational ability to support advanced asset maintenance capabilities.
- Whether the vendor and product have proven capabilities for your desired asset maintenance activities and classes of assets within your industry, and if they align with your asset management strategy.
- Integration to your EAM to be able to execute APM recommendations, which may be complicated if they are from two different vendors.

User Recommendations

- Assess the maturity of your EAM system and have an integration plan with your APM before investing in APM, as CIOs should not expect to get all APM capabilities from the EAM vendors themselves.
- Identify the combination of asset maintenance capabilities to support your asset types and situations across the business. Most vendors do not offer all levels of APM maintenance capabilities across all industries and asset types. Thus, organizations may need more than one APM product, depending on the complexity of their businesses, the types of assets and their asset maintenance goals.
- Ensure IoT and operational technology (OT) systems compatibility by getting involved in the planning of IoT monitoring of plants and equipment.
- Source good data — that is, historical service and operational data — organizations looking to invest in APM should also expect to make investments in information management infrastructure to capture operational data where it doesn't exist today.

Sample Vendors

ARMS Reliability (a Baker Hughes company); AVEVA; Bentley Systems; Cognite; Detechtion Technologies; GE Digital; Hitachi Energy; IBM; SAP; SAS

Gartner Recommended Reading

2022 Strategic Roadmap for Asset Management

Market Guide for Enterprise Asset Management Software

Market Guide for Asset Performance Management Software

Use a Step Program to Orchestrate Maintenance and Reliability Technology

Manufacturing Network Design

Analysis By: Ronak Gohel

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Manufacturing network design is about optimizing locations, capacity, capabilities and product flow paths for a cost-efficient and resilient structure. The push for resilience and agility is requiring diversification of and flexibility in the network. Manufacturing leaders should use network design to view the network as a collection of capabilities, rather than a collection of sites, to optimally balance cost-efficiency and resilience.

Why This Is Important

Factors driving the increase in reviewing and redesigning manufacturing networks include ongoing shortages (e.g., labor, raw materials, land), geopolitical pressures and uncertain customer demand, driven by volatility, global trade policy uncertainty and cost pressures. Organizations that invest in a holistic approach to manufacturing network design can better assess the trade-offs between operating cost-effectiveness, resilience and capability to optimize network capacity.

Business Impact

After decades of pursuing ever-increasing productivity gains and cost-efficiency, leading manufacturers have found that a reactive response to each demand shift, trade uncertainty or disruptive event results in high operating expenses and a compromised customer experience. Organizations that are actively diversifying their networks are better able to manage risk events once they occur, with fewer disruptions to customers, positioning them for competitive advantage in the marketplace.

Drivers

- Global supply chains are being reshaped with more focus on improving operational control over supply chains. Some of the ways organizations aim to achieve this include increasing buffer inventories, adding or removing facilities, outsourcing various activities, integrating vertically to acquire new skills or IP, and rationalizing product portfolios and core markets.

- Large-scale disruptions as well as demand and supply volatility are pushing companies to analyze for a diversified and flexible production footprint and to evaluate strategic redundancies. These are now seen as a cost of doing business to protect future revenue streams or a source of competitive advantage rather than an inefficiency to be designed out.

- With labor shifting away from established ecosystems in China to other locations in and outside of Asia, the direct cost advantages of these locations are changing.

- The advantages of financial benefits (low-cost sourcing or tax credits to incentivize local manufacturing) that have driven facility location decisions have to now be weighed against a shift away from friction-free global trade due to geopolitical risk and constraints in labor, material and transportation capacities.
- The role of automation in manufacturing that changes cost structures include hyperflexibility with equipment, lot sizes and labor, and mobile factories. These are leading the move away from rigid automation for large-scale manufacturing to those that prize agility.
- Evolving technologies (e.g., IIoT; 3D printing; configurable robots; platform, product or plant harmonization; human-machine collaboration models) are being tested to support shifts away from low-cost region sourcing models.
- Noncost objectives such as sustainability or resiliency drive need to reanalyze the network to balance cost with other objectives.
- Pragmatic scenario analysis supported with advanced analytics can help drive data-based decision making for long-term strategies amid uncertainty.

Obstacles

- Designing footprints with an emphasis on factors that go beyond direct labor and material requires a focus on long-term objectives and carries execution risk.
- Creating and maintaining visibility to the extended supplier network and costs in an ecosystem with dozens of suppliers and shifting capabilities can be a barrier in global supply chains.
- Technology investments to automate data collection and model building can be high in complex networks with varying production processes, the role of partners and their interdependencies.
- The complexity of modifying business processes and being disciplined to holistically view conflicting objectives of cost-efficiency and resilience may make this capability take longer than a couple of years to mature.
- Creating scenarios that evaluate alternate network footprints, capacity and product flow models requires commitment to a strategic and repeatable process. Business process experts are required to build network models to understand trade-offs.

User Recommendations

- Optimize the network with input from design, manufacturing, sourcing, logistics, finance, legal and trade compliance. Strategy should be flexible and agile to minimize impacts as circumstances change.
- Define objectives aligned with enterprise-level strategic goals and cascade these to internal and external affected partners.
- Weigh the economic drivers for expanding into specific markets against environmental, social and governance ones to create a business case.
- Identify business constraints, create an optimized design and analyze trade-offs between cost, service and resilience. Test sensitivity of the new design to changes in cost variables.
- Explore constraints by site (capacity limits), capability (manufacturing processes), resilience (minimum number of sites), current and planned product portfolio, and regulatory/tax needs.
- Include sourcing in manufacturing make versus buy decisions.
- Factor the complexity of implementation in the decision-making process along with the financial costs.

Gartner Recommended Reading

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

Tool: Guide to Use Cases for Network Optimization Capabilities

Tool: Evaluating Countries for Manufacturing Site Selection

Strategic Considerations in Manufacturing Make-Versus-Buy Decisions

Market Guide for Supply Chain Network Design Tools

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

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

Appendixes

See the previous Hype Cycle: Hype Cycle for Manufacturing Operations Strategy, 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 constrains replacement	Maintenance revenue focus
Obsolete	Rarely used	Used/resale market only

Source: Gartner (July 2023)

Document Revision History

Hype Cycle for Manufacturing Operations Strategy, 2022 - 29 July 2022

Hype Cycle for Manufacturing Operations Strategy, 2021 - 16 July 2021

Hype Cycle for Manufacturing Operations Strategy, 2020 - 6 August 2020

Hype Cycle for Manufacturing Operations Strategy, 2019 - 2 August 2019

Hype Cycle for Manufacturing Operations Strategy, 2018 - 26 July 2018

Hype Cycle for Manufacturing Strategy, 2017 - 26 July 2017

Hype Cycle for Manufacturing Strategy, 2016 - 20 July 2016

Hype Cycle for Leaders of Manufacturing Strategies, 2015 - 21 July 2015

Hype Cycle for Leaders of Manufacturing Strategies, 2014 - 28 July 2014

Hype Cycle for Leaders of Manufacturing Strategies, 2013 - 25 November 2013

Recommended by the Author

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

Understanding Gartner's Hype Cycles

Tool: Create Your Own Hype Cycle With Gartner's Hype Cycle Builder

Hype Cycle for Advanced Technologies for Manufacturers, 2023

Table 1: Priority Matrix for Manufacturing Operations Strategy, 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 Fusion Teams Smart Factory	Circular Supply Chain Digital Operating Systems Flexible Quality Processes Generative AI in Manufacturing Operations Industry Cloud Platforms for Manufacturing Mobile Factories Supply Chain Convergence	Artificial Intelligence 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	OT Security Plant Engineering and Design Value-Added Manufacturing Services	Agile Learning Asset Performance Management Cloud Computing in Manufacturing Operations Composable Applications Energy Efficiency Manufacturing Network Design Manufacturing Segmentation MOM Application Suites Synchronized BOMs	Autonomous Things in Manufacturing Digital Threads Industrial IoT IT/OT/ET Alignment Machine Learning Mixed Reality Supply Chain as a Service	
Moderate				
Low				Sustainable Packaging

Source: Gartner (July 2023)

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Source: Gartner (July 2023)