SPOTLIGHT

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Smart manufacturing and modern Industry 4.0 are evolving with technological advancements, emphasizing the need for secure unified end-to-end visibility across the manufacturing ecosystem to enhance operations, efficiency, productivity, and competitiveness.

The State of Smart Manufacturing: Evolving to Next-Level Industry 4.0

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Introduction

The state of smart manufacturing and Industry 4.0 is evolving to the next level, with rapid technological advancements driving continuous innovation. Manufacturing companies are increasingly focused on achieving a unified manufacturing platform across and beyond their ecosystem. To advance smart manufacturing, companies are motivated to seek investments to upgrade and enable secure and resilient end-to-end connectivity not just on manufacturing operations but across the entire organization to optimize operations, boost efficiency and productivity, and enhance competitiveness through faster time to market.

AT A GLANCE

KEY TAKEAWAY

Modern Industry 4.0 involves adopting advanced technologies such as big data, cloud, AI/ML, and IoT to drive digital resilience, interoperability, and efficiency, enabling end-to-end observability and data-driven decision-making for optimized operations and minimal downtime.

This paper explores key industry trends, priorities, and use cases in smart manufacturing; the importance of information technology (IT)/operational technology (OT) connectivity; and strategies for implementing next-gen operations to increase organizational efficiency, resiliency, and agility. Bridging the gap between legacy systems and future-ready technologies is crucial to fully unlock the potential of modern smart manufacturing.

The Nuances of Smart Manufacturing by Industry Value Chain

Within the manufacturing industry, four distinct value chains play pivotal roles in shaping and understanding business strategies, market trends, consumer behaviors, technology trends, and operations: engineering-oriented value chain (EOVC), technology-oriented value chain (TOVC), asset-oriented value chain (AOVC), and brand-oriented value chain (BOVC) (see Figure 1).

Each of the four value chains represents a unique group of businesses, in turn requiring unique manufacturing processes and operations, contributing to the way leaders of organizations approach the way they conduct their business. By delving into these value chains, leaders of manufacturing companies can gain valuable insights into the interplay between design, innovation, production, and market positioning and better understand the dynamics of various industry verticals and subverticals.

FIGURE 1: ***Four Value Chains in Manufacturing***

Smart Manufacturing Focus				
	AOVC	**BOVC**	**EOVC**	**TOVC**
Examples	Chemicals, metals, textiles, paper, and building materials	Food and beverage, footwear, apparel, health and beauty, household, and toys	Auto, A&D, transit (rail and marine), machinery, consumer durables, and medical equipment	Computers, electronics, semiconductors, telecom, and medical imaging
Product Profile	Processed materials and compounds manufactured at large, expensive processing plants that become the raw materials for finished products	High-volume, low-complexity products that are manual-labor intensive with significant variation by segment/season and sold through retailers	Complex, electromechanical equipment with advanced materials, heat/aerodynamics/ fluids, and electronics, with multiple development partners and 5- to 50-year life cycles, (often) sold through dealers/ distributors	Complex electronic equipment with very high development costs (precision/quality), large amounts of software, manual-labor intensive, and downstream connectivity for markets with rapidly changing needs
Operating Profile	Low-demand/low-supply complexity (linked to economy)	High-demand/low-supply complexity	Low-demand/high-supply complexity	High-demand/high-supply complexity
Business Goal	Decrease time to market and increase product success rate	Deliver culture-driven innovation, balance delivery with demand, and NPS	Cost/time/quality-driven innovation and improve agility/resilience to change	Decrease time to market and volume and increase quality/reliability/yield

Source: IDC, 2024

Asset-Oriented Value Chains

AOVCs are characterized as process-oriented manufacturing by large investments in property, plant, and equipment and dealing with modest levels of variation in supply, manufacturing, and demand. These companies typically prioritize technology investments tightly aligned toward de-risking operations, improving equipment utilization, and increasing operational efficiency.

Brand-Oriented Value Chains

Characterized by branded products that serve consumer markets, B are required to manage supply and price through multiple tiers of the supply chain. They typically prioritize investments that help with demand planning and forecasting to maintain a relatively steady supply and elevate customer experience and customization abilities.

Engineering-Oriented Value Chains

EOVCs are characterized by segments driven by complex products that have a steady demand. They are typically challenged with long engineering cycles and order books, which make it difficult to attenuate demand and supply variation.

Technology-Oriented Value Chains

TOVCs are characterized by the physical flow of goods dictated by the iterating cycles of key underlying technology (e.g., processors) and can have high levels of variation in supply, manufacturing, and demand.

Industry Trends

Smart manufacturing represents a significant shift in the industrial landscape, driven by the convergence and rapid advancement of digital technologies and traditional manufacturing processes. Modern Industry 4.0 is influenced by various trends and priorities shaping the industry landscape, including:

- Adoption of IoT devices for real-time monitoring and predictive maintenance
- Integration of artificial intelligence (AI) and machine learning (ML) for process optimization and quality control
- Emphasis on sustainability and energy efficiency in manufacturing processes
- Implementation of agile and flexible production systems to meet the changing market demands

Industry Trends by Value Chain

AOVC

For AOVCs, smart manufacturing priorities include focus on maximizing efficiency and yield from existing assets to develop the next generation of production capabilities. Based on IDC's 2023 Manufacturing Value Chain Budget Guide, AOVCs are focused first on supplier network monitoring and asset management for their IoT projects and understanding product performance/new product development for big data and analytics.

AOVC companies often experience dynamic demand, high manufacturing overheads (high fixed costs), and numerous challenges on the upstream manufacturing front, with the majority of the concerns related to raw material availability and pricing.

Top business priorities for AOVCs include regulatory compliance, expanding into new markets, and attracting/retaining customers (see IDC's Manufacturing Value Chain Budget Guide, 2023).

AOVC Use Cases for Smart Manufacturing

According to *IDC's Worldwide Digital Transformation Use Case Taxonomy, 2023: Asset-Oriented Value Chains in the Manufacturing Industry* (IDC #US51062023, August 2023), AVOC use cases for smart manufacturing are:

- **Strategic asset management:**
  - **Asset instrumentation:** Real-time awareness of asset conditions will occur through dense deployment of wireless and wired sensors.
  - **Asset performance management:** Analytics is used to predict asset failures and degraded performance to reduce unplanned downtime and mean time to failure.
- **Smart plant:**
  - **Environmental resource optimization:** The instrumentation of assets includes energy monitoring at the plug level that provides consumption models that allow for energy costs in optimization calculations.
  - **Cognitive planning:** Sensors are deployed across the manufacturing environment to capture and analyze energy use and requirements down to the machine level, allowing cognitive systems to structure operations in a way that minimizes energy use.

- **Enterprise quality:**
  - **Cognitive root cause:** Connected quality metrology feeds an analytic model that can support automated Six Sigma analysis of quality anomalies with the ability to adjust processes in an automated way.
  - **Real-time risk and compliance:** Digital connection to compliance portals allows for reduced time to market and reduced risk of noncompliance.

BOVC

For BOVCs, smart manufacturing priorities include improving and ensuring product quality and increasing efficiencies, flexibility, and capacity utilization. Based on IDC's 2023 Manufacturing Value Chain Budget Guide, BOVCs will focus on supplier network monitoring and asset management for their IoT projects and resource allocation for big data and analytics.

BOVC companies experience fast-paced changing of customer preferences, demands, and expectations. They manage highly variable demand and align that demand with a relatively steady and reliable supply.

Top business priorities for BOVCs include innovation, expanding into new markets, and attracting/retaining customers (see IDC's Manufacturing Value Chain Budget Guide, 2023).

BOVC Use Cases for Smart Manufacturing

According to *IDC's Worldwide Digital Transformation Use Case Taxonomy, 2023: Brand-Oriented Value Chains in the Manufacturing Industry* (IDC #US51204523, September 2023), BOVC use cases for smart manufacturing are:

- **Strategic asset management:**
  - **Predictive maintenance:** Machine learning algorithms build an accurate predictive model of potential failures or degradation.
  - **Autonomous asset tracking:** Assets are monitored continuously, and issues are diagnosed seamlessly. Maintenance resources and activities are automatically triggered and launched, depending on the severity of the issue, type of asset, criticality, and so forth.
- **Resilient lean:**
  - **Cognitive inventory:** There will be real-time assessment of inventory position across all buffer locations, with connections to demand and capacity. Cognitively enabled inventory means that the system learns how to best meet business variables.
  - **Smart capacity allocation:** The instrumentation of assets includes near-real-time capacity monitoring at the machine level that provides consumption models that allow for optimization calculations across facilities.
- **Comprehensive quality:**
  - **Cognitive root cause:** Connected product quality metrology feeds an analytic model that can support automated Six Sigma analysis of quality anomalies with the ability to adjust processes in an automated way.

- **Collaborative resolution:** A collaboration platform includes the ability to bring contextual information into the disposition of nonconforming material. Case-based tools evaluate the efficacy of corrective actions.

EOVC

For EOVCs, smart manufacturing priorities include improving product quality, efficiency, and capacity utilization. Based on IDC's 2023 Manufacturing Value Chain Budget Guide, EOVCs will focus on creating experience ecosystems that transform the focus from designing, selling, and servicing complex products to evolving to where the product becomes the platform through which new digital products and services are delivered.

EOVCs are constantly experiencing evolving product configuration and designed/engineered-to-order complexities in a digital economy. This requires manufacturers in this value chain to develop robust production capabilities balanced with the need to improve product quality and capacity utilization and increase efficiencies.

Top business priorities for EOVC manufacturers include expanding into new markets, innovation, and operational performance (see IDC's Manufacturing Value Chain Budget Guide, 2023).

EOVC Use Cases for Smart Manufacturing

According to *IDC's Worldwide Digital Transformation Use Case Taxonomy, 2023: Engineering-Oriented Value Chains in the Manufacturing Industry* (IDC #US51040623, August 2023), EOVC use cases for smart manufacturing are:

» **Strategic asset management:**

- **Asset instrumentation:** Real-time awareness of asset condition will occur through the deployment of wireless and wired sensors and data-derived "virtual" sensors.
- **Predictive asset monitoring and performance management:** Machine learning algorithms build an accurate predictive model of potential failures that can be used to alert maintenance teams in real time; maintenance resources can be optimized through a tiered support structure, depending on the issue, type of asset, criticality, and so forth.

» **Resilient lean:**

- **Real-time scheduling:** Real-time assessment of current demand and available capacity helps continuously and intelligently re-sequence production lines.
- **Optimized materials consumption:** Product form-fit-function requirements reflect production capabilities, including additive manufacturing, and intelligent machine tools (robots) that can continuously optimize material usage based on current context.

» **Comprehensive quality:**

- **Cognitive root cause:** Connected metrology tools feed analytic models that support automated Six Sigma analysis of quality anomalies and automated adjustment of processes.
- **Requirements intelligence:** Integration allows quality and metrology tools to automatically adjust to specifications and requirements and continuous case-based learning to improve quality specifications in meeting customer requirements.

TOVC

For TOVCs, smart manufacturing priorities include maximizing yield from existing production capabilities and promoting the development of next-generation capabilities. Based on IDC's 2023 Manufacturing Value Chain Budget Guide, TOVCs will focus on yield/materials optimization and transportation management for their IoT projects and data visualization and business process optimization for big data and analytics.

Top business priorities for the TOVCs include innovation, attracting/retaining customers, and expanding into new markets (see IDC's Manufacturing Value Chain Budget Guide, 2023).

TOVC Use Cases for Smart Manufacturing

According to *IDC's Worldwide Digital Transformation Use Case Taxonomy, 2023: Technology-Oriented Value Chains in the Manufacturing Industry* (IDC #US51058423, August 2023), TOVC use cases for smart manufacturing are:

- **Strategic asset management:**
  - **Asset instrumentation:** Real-time awareness of the asset condition will occur through dense deployment of wireless and wired sensors.
  - **Centralized asset monitoring and diagnostics (M&D):** Assets are monitored and tracked, and issues are diagnosed at a central location. Maintenance resources are optimized through a tiered support structure, depending on the issue, type of asset, criticality, and so forth. There are still local maintenance personnel, but the majority of work is managed in the M&D center.
- **Resilient lean:**
  - **Yield management:** Real-time assessment of current demand and available capacity helps continuously and intelligently re-sequence production lines.
  - **Optimized materials consumption:** Incorporating 3D printing as an additive process and more intelligent machine tools (robots) supports continuous material optimization.
- **Comprehensive quality:**
  - **Manufacturing intelligence:** Integrated specification repository can adjust robotic and connected quality metrology. There is ongoing case-based learning of the efficacy of quality specifications in meeting customer requirements.
  - **Cognitive root cause:** Connected quality metrology feeds an analytic model that can support automated Six Sigma analysis of quality anomalies with the ability to adjust processes in an automated way.

The Convergence of IT/OT Connectivity

The seamless integration of information technology and operational technology is critical for advancing innovation and enabling smart manufacturing operations, through seamless connectivity and collaboration between traditionally siloed and monolithic systems. The key benefits of IT/OT convergence are achieving real-time visibility and increased control over manufacturing processes through a unified environment and end-to-end observability.

Historically, IT and OT were siloed, where IT was focused on the technology of the business such as networks, information processing, and data and cloud and OT was focused on the hardware and software for managing production

and operations in manufacturing. With the convergence and integration of these two systems, it bridges the gap to allow for real-time data exchange, which improves accuracy, enhanced operational efficiency, reduction in cost and waste, and greater control over operations due to improved decision-making. IT/OT convergence also helps manufacturing companies gain more transparency in their operations and helps with regulatory risk and compliance through their visibility into the operational and business processes to identify vulnerabilities.

While IT/OT convergence is crucial for organizations to evolve, it comes with challenges and considerations:

- **Mix of systems:** Integrating disparate IT and OT systems could be costly and could also require longer integration times. Manufacturing companies should do a thorough assessment of their systems to ensure interoperability and also identify potential risks and complications.
- **Security:** Increased connection points and interlinked networks may increase data security and cybersecurity risks. Companies should ensure they develop robust protocols such as AI-enabled security monitoring, event correlation, anomaly detection, and safeguards to protect sensitive data and critical infrastructure.
- **Incomplete integration:** Substandard collaboration between partners can impact the ability for real-time data processing. Working closely with partners and leveraging technologies such as edge computing and cloud-based analytics can help tie together the entire manufacturing process chain — from early-stage design to supply chain, production, and service.

Evolving to Modern Industry 4.0

Next-generation operations in smart manufacturing involve the adoption of advanced technologies and capabilities to drive digital resilience, innovation, interoperability, and efficiency to attain end-to-end observability. Secure and reliable connectivity across the company is key to enabling technologies such as big data, cloud, AI/ML, and digital simulations across multiple disparate systems for improved orchestration across all tools and systems, which is crucial for monitoring mission-critical business performance.

With reliable cloud-based platforms, manufacturing companies can now truly achieve end-to-end enterprise visibility, beyond just their plant operations. Companies now can extend their ecosystem to gain advanced observability from upstream to product and service development and sales and marketing and downstream to field service and customer service.

IoT sensors and interconnected devices enable manufacturing companies to gather relevant data to power predictive and real-time analytics to help drive strategic and faster decision-making. This not only helps companies optimize their workflows through the identification of bottlenecks but also helps with faster root cause identification, improvements in product quality, efficiency, waste reduction, and optimized allocation of resources for higher returns.

Manufacturing companies must build modern observability practices and embrace next-generation technologies to gain a competitive edge in their industry. Data-driven decision-making and continuous improvement in smart manufacturing operations (including technologies such as advanced analytics and artificial intelligence/generative AI [GenAI]/machine learning algorithms) can prevent or minimize outages through valuable insights and standardized workflows to keep business operations up and running with minimal to no downtime.

This enables faster time to market and improves an organization's agility to respond to fluctuating market and consumer demands through more autonomous and efficient end-to-end operations.

The Journey to Modernization: Key Elements

Modernization efforts in smart manufacturing require a holistic approach that addresses people, processes, and technology. In detail:

- **People:** They say the people in the organization determine the success of the business. This is crucial because workforce adoption of processes and technologies drives the day-to-day operations of the business and also determines the success of any investment. With the evolving digital transformation of the manufacturing industry, it is important for companies to monitor the changing knowledge and skills with each technology investment and to continuously support the workforce through upskilling and reskilling the workforce to adapt to technological advancements and new ways of working.
- **Process:** As manufacturing companies undergo their digital transformation journey with the introduction and integration of new technology and tools, leaders should actively monitor and streamline workflows to optimize processes to drive efficiency, resiliency, and agility. It is also important for existing governance models to be reviewed and refreshed to ensure risk and compliance for the organization.
- **Technology:** Manufacturing companies should have a clear road map for their digital transformation journey. Leaders should ensure that key organizational stakeholders conduct readiness assessments when selecting and implementing the right technologies, at the appropriate time to support organizational goals and objectives, including digitalization and automation solutions.

Conclusion

Rapid advancements in digital technology in recent years in areas such as cloud, GenAI, digital twins, and predictive analytics offer significant opportunities for organizations to mature their smart manufacturing approach to achieve enhanced competitiveness and timely, successful innovation.

With fluctuating market demands and the increased need to boost efficiency and productivity, manufacturing companies need to act on modernizing their operations to sustain a competitive and relevant ecosystem.

By embracing modern observability practices and industry trends, prioritizing IT/OT connectivity, implementing next-gen operations, and adopting a holistic approach to modernization, businesses can drive innovation and unlock the full potential of smart manufacturing to thrive in the digital age through end-to-end observability safely and securely.

About the Analysts

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