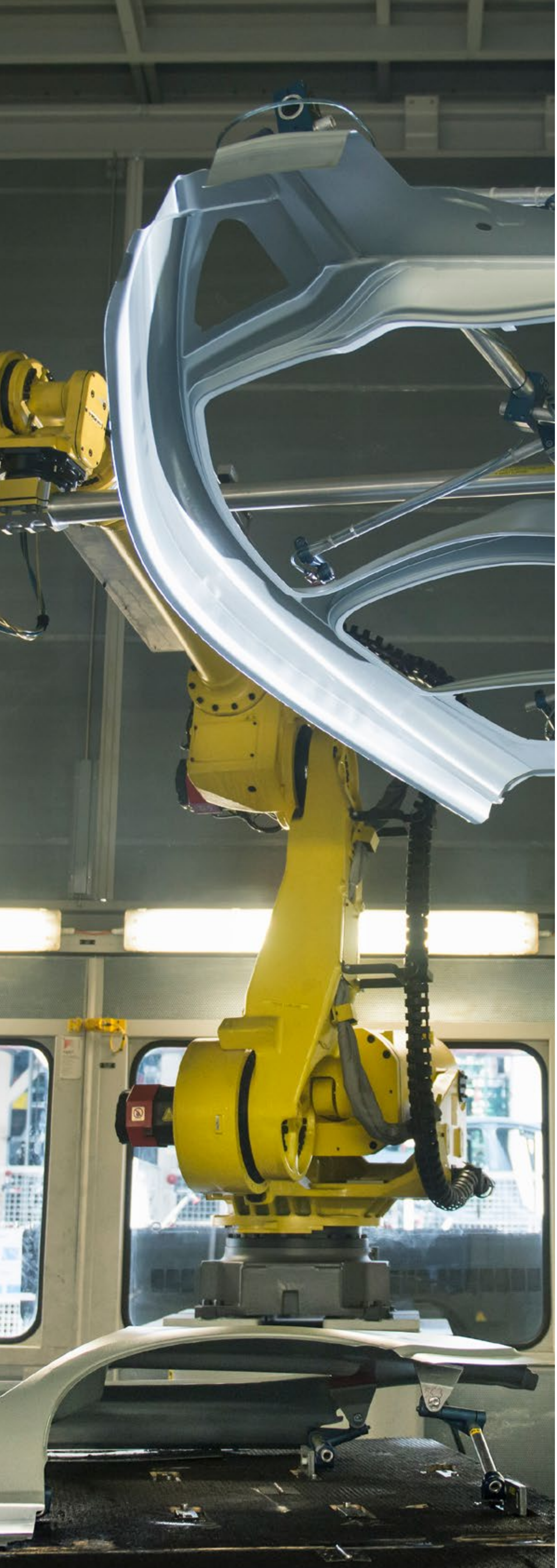

Expert Insights

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Smart manufacturing

AI technologies, intelligent insights

IBM **Institute for Business Value**

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A lack of shop floor connectivity and obsolete manual processes often stand in the way of getting products out the door more quickly.

Key takeaways

Factory floor data, fueled by robust combinations of technology, can generate powerful insights.
Smart plants are created by weaving powerful technologies into Industry 4.0 operations—think automation, AI, the IoT, edge computing, cloud, 5G, additive manufacturing, and digital twins. These technologies help manufacturers gain insights from structured and unstructured data, as well as share it across the ecosystem.

The human-machine partnership can propel factories to new heights of productivity.
AI can help drive automated, value-based workflows that free up humans to pursue higher-level tasks, for example, honing their digital expertise. Intelligent automation can help with that reskilling and also identify ways to redeploy human resources. In fact, employees will have opportunities to explore entirely new professions.

The intelligent manufacturer is at the heart of a broader ecosystem.
The smart factory connects to enlightening data on its factory floor and beyond. Integrating external contextual logistics with shop floor data steers directional shifts in real time. The results can be potent: improved quality, operational efficiency, preventative maintenance, proactive decisions, and enhanced workforce productivity.

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The muscle of manufacturing: Connected, predictive, self-optimized

What's an hour of shop-floor downtime worth? For almost nine in ten firms surveyed recently, it could be as much as USD 300,000. And one in four say that a single hour could cost upward of USD 1 million to as much as USD 5 million.[1] When production is disrupted or hampered by process inefficiencies, engineers and operators are the first to know. The problem is, it's typically after the fact and without the understanding of why it occurred or how to prevent it in the future.

A lack of shop floor connectivity and obsolete manual processes often stand in the way of getting products out the door more quickly. And, from a systematic perspective, many machines are isolated and disconnected. Thirty-nine percent of manufacturers state that one of their greatest challenges in achieving intelligent automation is the misalignment of processes and workflows that could support automated decision making.[2]

Connecting Internet of Things (IoT) devices and using cognitive capabilities to align workflows and processes are crucial capabilities of intelligent manufacturing plants. But these plants don't depend on just one or two technologies to work their magic. Intelligent plants are created by leveraging potent combinations spanning automation, artificial intelligence (AI), the IoT, edge computing, cloud, 5G, additive manufacturing, and digital twins to transform their operations. Deploying this vast array of technologies is complex and requires both IT and OT skills to architect and execute.

The results can be worth the effort. Intelligent manufacturing can facilitate improvement in production defect detection by as much as 50 percent, and improvement in yields by 20 percent.[3] Surveyed manufacturers also report intelligent automation has increased revenues by almost 8 percent.[4]

Optimizing the intelligent plant floor: What's your ultimate goal?

Organizations need a clear strategy to realize the benefits of intelligent manufacturing. Without crisply defined business objectives for the intelligent factory, ambitious projects—such as IoT-based data collection and advanced analytics—can wander into oblivion. Not only that, but advanced analytics, if not implemented correctly, could fail to achieve the expected return on investment and could even increase costs and risks. Knowing where an organization is going and what benefits to expect is essential. But to start, management needs to ask: what is the current state of our manufacturing plant? We've identified three stages of manufacturing sophistication—standard, automated, and intelligent (see Figure 1).

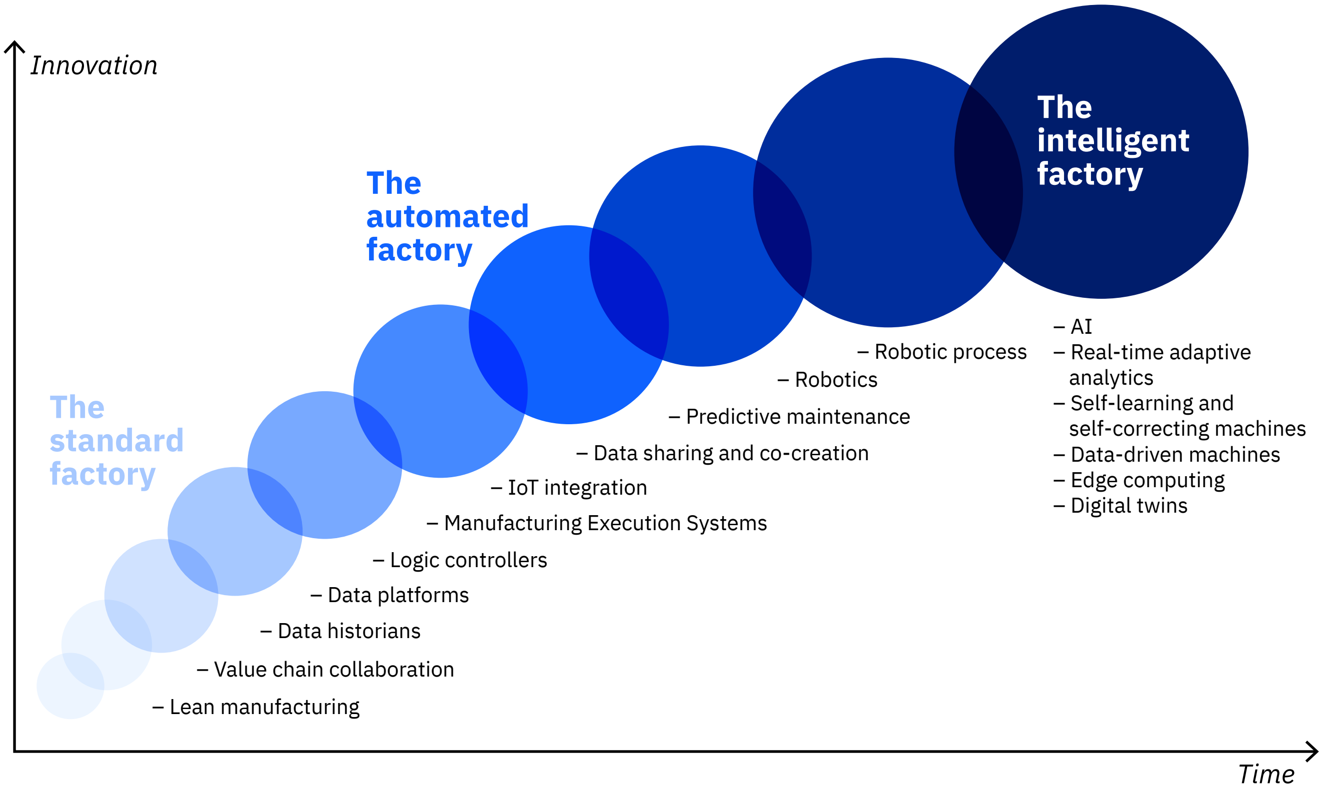
The standard factory: Holding its own

Standard factories monitor performance based on historical—not real-time—data. They've upgraded their shop operations with technologies and concepts such as Manufacturing Execution Systems (MES), which track and monitor current data about the production lifecycle and operations. The goal is to help ensure efficient processes.[5]

Lean manufacturing is a foundational first step in optimizing a plant floor. However, standard factories have typically not yet infused state-of-the-art technologies, such as machine learning and connected IoT, into their lean manufacturing practices. For example, supply-chain collaboration requires blockchain to have real-time, trusted, end-to-end visibility to the production floor's network of suppliers. Quality control measures could include light-directed order fulfillment, local tracking of material and products, and predictive warnings.

Figure 1

Ramping up to the intelligent factory



Source: IBM Institute for Business Value

We've identified three stages of manufacturing sophistication—standard, automated, and intelligent.

Correspondingly, value-chain collaboration with customers, suppliers, and logistics providers helps a manufacturer better address changes in its supply and demand chain and proactively update its manufacturing schedule. But these well-intentioned exchanges are often based on historical or aggregated data sources. In fact, only 39 percent of recently surveyed manufacturers agree that their supply-chain data is available in real time.[6] When manufacturers do empower their supply-chain data stream with real-time analytics, they can quickly address impacts on quality, cost, or supply.

Although efficient, typically most standard factories are not capable of delivering the short lead time and small lot-size adaptive production that could sustain a larger competitive advantage in the world of intelligent plants.

The automated factory: The power of robotics

The automated factory takes a giant step forward. It defines instructions for both hardware and software robotics to execute tasks consistently, without human error. As a result, real-time analytics can be more accurate, and highly improved predictive models can be created.

In reality, production automation and robots have been part of manufacturing for decades. Yet missing intelligence has meant limited success. Typically, manufacturing automation is based on control systems and programming languages that are not fully capable of adjusting to complex changing conditions, both internal and external. An isolated robot or cell might be efficient in executing its task. But that same robot or cell is not capable of optimizing customer orders or substantially impacting the overall equipment effectiveness (OEE) of the whole production facility.

The next leap in automation will entail robots and cells connecting and working together in an optimized way. For example, as the automation industry moves toward more open protocols, collaborative robots (cobots) and other transformative enablers flourish. Automation facilitates innovations such as lot-size-one, self-healing factories, and putting robots to work in areas where human interaction is required. The latest automation technology can engage in data sharing and co-creation within the manufacturing framework, learning from other units, and enabling plant optimization as a whole.

The intelligent factory: The shop floor sleuth

As we discuss in detail later, the foundation of the intelligent factory is an edge- and cloud-computing infrastructure that powers localized optimization and connected assets with AI algorithms. This interlock is the key to a plethora of data sources that provide information such as weather forecasts, market-demand projections that influence raw-material sourcing, inventory updates, and energy consumption.

On the shop floor, sensor-laden assets, equipment, devices, and AI-driven robotics all propel data-driven machine learning. Edge analytics facilitates real-time decisions from both humans and devices.

Digital twins that emulate plant assembly lines boost predictive maintenance to new heights and improve quality assurance.

SmartFactory^{KL}: Machine learning for quality management[7]

SmartFactory^{KL} is a prime example of Industry 4.0 cooperation between research and industry. This technology initiative, established as a nonprofit in 2005, brings together industrial and research partners in efforts to implement Industry 4.0 projects. Its more than 50 partners discuss, develop, and implement state-of-the-art use cases and related OT and IT concepts on the first multivendor Industry 4.0 demonstrator—an actual production line that has been demonstrated at the Hannover Messe, one of the world's largest industrial fairs. The demonstrator has been steadily extended to include AI self-learning and self-correcting in the past six years.

Following the best practices of Industry 4.0 engagements, SmartFactory^{KL} depicts an intelligent factory that is self-optimized yet does not remove decision-making power from humans. The base prerequisite is the integration of machines, applications, and people, and of course applying AI technology to assist in self-learning processes and actionable insights. For example, currently SmartFactory^{KL} can feel, hear, and see, with a focus on quality inspection. It can also provide information about equipment and production process status in different languages.

An additional benefit of SmartFactory^{KL} is the opportunity for partners to proof concepts such as time-sensitive networking and 5G connectivity, edge computing, multicloud services, containerization, and more.

One top-tier automotive company is using machine-learning algorithms to detect anomalies in the welding of auto chassis. Simultaneously, deep learning and video assess the weld quality using both human spectrum and infrared spectrum cameras. Microphones listen to the welding process and provide alerts about dirty, incomplete, or bad welds. All of these processes deliver input to a predictive model. This model can then assess the data and adjust the welding process as needed to meet quality standards and lower scrap.[8]

As our automotive scenario illustrates, the intelligent factory moves from a rules-based practice to a learning-based model. As a result, it needs to process large amounts of data faster, more accurately, and continuously. To support the rate and pace at which an intelligent factory must learn, the edge- and hybrid cloud-computing infrastructure is critical. This infrastructure supplies compute resources as well as rapid data movement, analytics, and inference.

In short, the ideal intelligent factory is self-learning, self-correcting, and self-directing. In that sense, it focuses inward. Yet as a full-fledged interconnected citizen, an intelligent factory proactively pursues intense outward engagement and data-sharing across its ecosystem. This ecosystem can include outside vendors and public/private partnerships that span the globe (see case study, "SmartFactory^{KL}: Machine learning for quality management").

In fact, a recent IBM Institute for Business Value (IBV) survey found that 56 percent of manufacturers report current implementations of AI-driven robotics—machines that act on internal and external data from IoT and other devices to both learn and make autonomous decisions. And 83 percent agree that intelligent automation will help their organization meet strategic challenges and improve business results.[9]

Connecting a manufacturer to the abundance of data generated by its factory floor opens up a productive new world.

Seamless integration: The intelligent cloudification of the factory

The factory floor is the pulse of operations. But that beating heart is impacted by an ecosystem that extends far beyond the physical facility. For insights to truly be intelligent, they need to incorporate internal information, such as workflow, energy, and expertise data, as well as external contextual logistics, such as geolocation, partner, supply chain, and environmental input.

Connecting a manufacturer to the abundance of both structured and unstructured data generated by its factory floor—and enabled by advanced analytics—opens up an exciting, productive new world. Improved quality, enhanced operations, KPI performance, data-driven insights, and proactive decisions are just a few of the benefits. As the connection is bi-directional, it can help to further optimize the entire supply chain or value network.

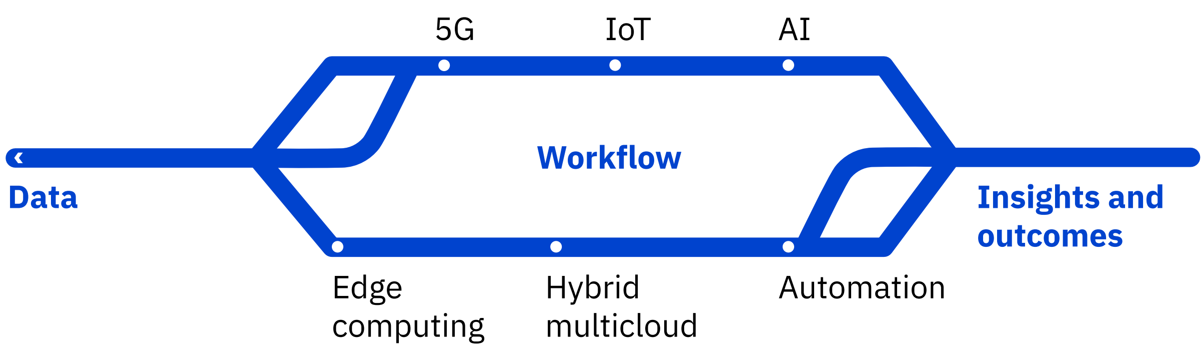
The intertwined trio: Edge computing, 5G, and hybrid multicloud

Edge computing is a distributed computing framework in which computation is largely or completely performed on distributed intelligent devices and nodes. Functionality and storage hover close to the facility—even the machine itself—conserving bandwidth, expediting response times, and alleviating connectivity concerns. Edge computing can also help automate the collection and management of compliance and regulatory information.[10] In one IBV study, almost 40 percent of leading companies say they are advanced users of edge computing, citing the ability to produce faster response times as the top advantage.[11]

5G, with its high-speed, low-latency connections, provides the agility of wireless connectivity, facilitating the interconnection of plant machinery and IoT-driven insights. A manufacturer could use 5G and edge computing to quickly enable automated machines and industrial robots and analyze IoT data in real time on the factory floor (see Figure 2). Many of today's agile manufacturers reconfigure their lines and assets daily and weekly to support variable contracts and customer customization. 5G lowers the cost for these manufacturers while keeping data pipelines running. 5G also has the capacity to establish large wireless sensor networks and to even implement augmented reality/virtual reality (AR/VR) applications for predictive monitoring. And as usual, the hybrid multicloud serves as the backbone of the system, aggregating high priority data and back-end functions (see "Insight: The benefits of a hybrid multicloud approach" on page 6).

Figure 2

Smart manufacturers use integrated technologies to produce AI-enhanced insights



Source: IBM Institute for Business Value

Insight: The benefits of a hybrid multicloud approach[12]

What is a hybrid multicloud? Think of an open standards-based stack, deployable across virtually any public cloud infrastructure. Think multiple external providers as well as on-premises. The environments are joined together to form one single hybrid environment. Yet management can be on- or off-premises and across multiple providers. A hybrid multicloud architecture provides a manufacturer the flexibility to move workloads from vendor to vendor and across environments as needed, and swap out cloud services and vendors as the need arises.

The human-machine interchange: AI + data + automation

In a state-of-the-art, interconnected factory, the exponential data volume, which often includes time series data, prevents traditional analytics from deriving value. AI is needed throughout the IT infrastructure to collect, analyze, monitor, and learn from that data, as well as help manage the data flows. Additionally, AI, machine learning, and automation infuse data with timely, contextual insights. In fact, four of five leading organizations report that implementing intelligent automation is one of their most important business objectives over the next few years.[13] And 55 percent of manufacturers report either piloting or adopting machine learning, with another 21 percent planning to invest in the technology by 2021.[14]

For both discrete and process manufacturing, using unsupervised and supervised machine learning improves production processes. AI uses asset data and predictive models to enhance machinery utilization, optimizing maintenance schedules and workforce management. AI can also drive visual or acoustic models that spot production glitches and monitor the quality of produced goods.[15] Running these models through edge computing facilitates proactive action and adjustments to optimize operations. Expenses saved from these efficiencies can fund future expansions and upgrades.

With data samples often taken at sub-second intervals, the volume of time series data is vast. AI decision making, or inferencing, that occurs at the edge can react more quickly. Additionally, the edge fosters low latency and limits the amount of data managed both locally and in the cloud. The edge helps alleviate stresses on the network and avoids large data cloud expenses.

AI is also needed to cull useful subsets from daunting data volumes. Additionally, AI can aid in data labeling, helping ensure the accuracy of models or classifiers. Case in point: one production line at a state-of-the-art manufacturing plant might encompass 2,000 different pieces of equipment. Each component could have 100 to 200 sensors that continuously collect data, adding up to 2,200 terabytes a month (see Figure 3).[16] AI is needed to build correlations and relationships between data sources, identify new KPIs and their interdependencies, and highlight missing data that caused a failure mode to elude prediction.

A digital twin is designed to receive input from data-gathering sensors in its real-world counterpart.

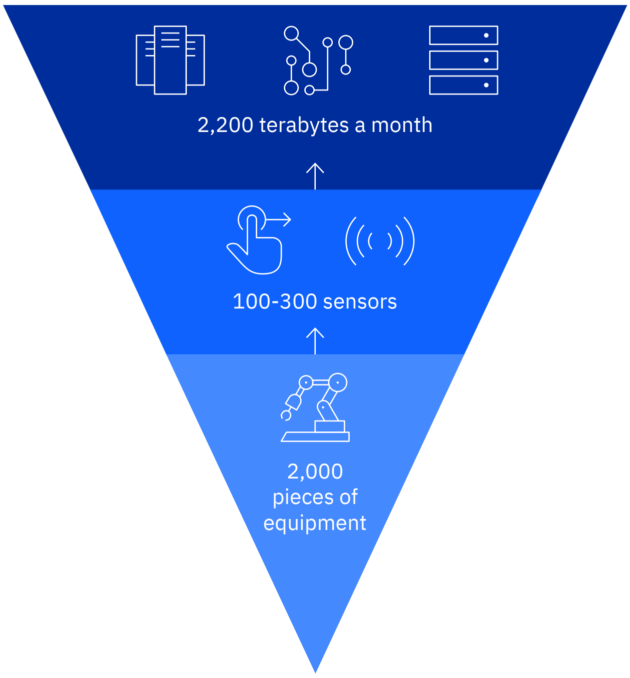
Automation goes hand in hand with AI. As large manufacturers experience pressure to launch more products more quickly, they cite automating production processes as the biggest area for improvement.[17] In fact, according to a recent IBV study, seven of ten operational executives reported that digitization and intelligent machines lead to higher-value work for humans. Sixty-one percent said intelligent machines will create a meaningful impact on changing job descriptions and activities in the next three years.[18]

Digital twins: A decisive win

Connected-machines infrastructures. AI-driven information and processes. Humans freed up for higher level tasks and skills development. They all contribute to myriad possibilities, and one of the most intriguing is digital twins. In fact, 75 percent of organizations implementing connected devices already use digital twins, or plan to within a year.[19]

Figure 3

AI is needed to extract insights from exponential data volume.



Source: IBM Institute for Business Value

Digital twins are virtual replicas of physical devices that data scientists and design specialists use to replicate scenarios from actual devices—sometimes, as a prototype, before the devices are even built. Digital twins are also evolving technologies such as robotics, advanced analytics, and AI learning systems.[20]

A digital twin is designed to receive input from data-gathering sensors in its real-world counterpart. A digital twin should behave like that real-life equivalent, using external forces to show possible reactions to event-driven scenarios such as component failures. The twin could also be designed based on a prototype of its physical counterpart—or could even be the prototype. Digital twins can provide valuable feedback as a product is refined.[21] When used in maintenance, they often have no rendered components and only exist within the maintenance system itself.

Consider how digital twins enhance the potential of relevant data collected from the IoT. That data is aggregated and refined through AI and machine learning processes, then funneled through what's in effect a sensor-connected virtual simulator—the digital twin. Potential advantages for manufacturers are considerable, with the production of better-quality goods at top of the list. Manufacturers can also incorporate predictive maintenance that's been validated through a digital twin into shop floor equipment. The result? Optimized machines, products, production processes—even entire facilities.[22]

The intelligent manufacturing plant: From challenges to champions

As in most endeavors worth undertaking, evolving to a truly intelligent manufacturing plant inevitably requires mastering challenges. The more an organization anticipates and plans for these tests, the more they'll be rewarded with success. Three typical concerns faced by manufacturing plants as they advance toward intelligent, connected operations include:

1. The pitfall of pilot scalability

We started this conversation by stating the importance of a manufacturer understanding its end game. The lack of a crisp vision, roadmap, and operating model strategies for the intelligent manufacturing plant leaves too much to chance. The result? An intelligent manufacturing implementation that fails to gain traction.

After all, these solutions can be challenging. For example, one manufacturer could plan on deploying five machine-learning and deep-learning models for each of the 1,000 fabricators in their pilot plant. In addition, this company may have 350 plants globally. Adding to the complexities are digital tools that manage deployed AI models at scale.

Yet, with a solid vision in place, intelligent manufacturing initiatives can develop a supportive enterprise architecture and a consistent hybrid cloud approach. These steps enable the open flexibility and data integration required to succeed. A comprehensive data strategy, vigilant security measures, and airtight governance are also must haves.

Data integration should include legacy ERP and planning application data, and encompass the customers, suppliers, and distribution partners within the manufacturing ecosystem. Simulation, modeling, and predictive analysis can then interpret that data to evaluate inventories, networks, demand volatility, and supply availability.

All of these measures can help contribute to an intelligent manufacturing initiative that realizes its full potential—and doesn't stall out in that ambiguous zone between failure and success. These measures are also essential for enabling innovative agile delivery that can help ensure fast benefits. Agile delivery should always be the model for an intelligent manufacturing execution.

2. Security and the interconnected shop floor

When a shop floor evolves from a self-contained, isolated unit to a buzzing hub of ecosystem information, the potential is enormous. But the vast amount of data and intellectual property shared between suppliers, manufacturers, logistics providers, and customers creates vulnerabilities and cybersecurity risks. In the past, most manufacturing networks enjoyed high degrees of security because they were not connected to broader IT networks and the internet. The rise of IT and OT integration poses additional risk.

Intense vigilance is required across technology, both informational and operational. A cybersecurity strategy and execution plan is essential to reducing incidents and breaches.

An effective cybersecurity strategy should:

– Monitor and control data flow across networks and devices
– Develop a security plan that spans the value chain and protects intellectual property
– Establish, manage, and test incident response plans and capabilities
– Incorporate tools such as blockchain and AI-enabled cognitive security solutions to help detect security concerns and facilitate faster responses
– Apply advanced cybersecurity monitoring and analytics for incident detection and remediation
– Determine the ratio of IoT-related incidents, days taken to detect an incident, and days needed to respond to and recover from an incident
– Include a security operations center for centralized practices and controls.

In intelligent manufacturing, the first movers can reap the majority of the benefits.

3. The people perspective: Reskill, retrain, redeploy

By its very definition, an intelligent manufacturing plant optimizes its operations with AI and automation, often helping to lessen the impact of human fallibility. Manufacturers report automating workflows, activity monitoring, and asset utilization as common intelligent automation use cases.[23]

Still, 26 percent of surveyed manufacturers report not using intelligent automation for any tasks whatsoever. But by 2021, all of those organizations plan on adopting intelligent automation in at least some areas. In fact, 56 percent say they'll use AI for departmental, cross-enterprise, and even expert tasks that require problem solving.[24] Correspondingly, management needs to foster a mindset in which employees view these technologies not as threats but as assets that promote informed decisions, deep learning, problem solving, and quick onboarding by newly skilled workers.

With new technologies come new skills and new professions. In one study, 43 percent of manufacturers have added "data scientists/data quality analysts" to their payrolls, with 35 percent more anticipating doing so by 2024. A third of surveyed manufacturers report adding "machine learning engineers or specialists," with 70 percent planning to do so by 2024. "Collaborative robotics specialists," "data quality analysts," and "AI solutions programmers/software designers" are also on the rise.[25]

Additionally, concerns about automation eliminating jobs are often unfounded. A profession that seems vulnerable to automation may not necessarily be replaced—the concepts are sometimes confused and misreported.[26] Skilled trade jobs, for example, include many complex tasks that are not so easily automated. Yet, for many manufacturers—and employees—jobs that are unsanitary, dangerous, or tedious are prime candidates for automation. Successful workforce transformation should combine and augment existing capabilities with new data- and AI-driven skills.

The intelligent manufacturer: The benefits of blazing the trail

By transitioning to an intelligent factory, manufacturers can benefit from a value-based workflow that incorporates what are often incremental technologies. In a recent IBV benchmarking study, manufacturers that embrace IoT and automation pilots and implementations cite significant benefits when compared to peers that delay adoption of these technologies.

On average, 43 percent of the leading manufacturers report using intelligent IoT—compared to only 29 percent of their peers—across inventory management, predictive asset maintenance, detection of unplanned production issues, and facilities and energy management.[27]

And the investments have paid off. These pioneering manufacturers report outperforming their industries in revenue growth 32 percent more often than their peers. And they also report a higher return on assets: almost 17 percent compared to just 8.4 percent. Additionally, these manufacturers enjoy more frequent finished-goods inventory turns than their less adventurous peers—21 versus 14. And a full 95 percent of these leading manufacturers report that more automation would be useful and practical in their facilities.[28]

These trailblazing manufacturers perform at a superior level in lead time, quality, and cost against their competition. These are the manufacturers that are poised to transform their industries and dominate future value chains. This is not a time to wait for others to lead. In intelligent manufacturing, the first movers can reap the majority of the benefits.

Action guide

Smart manufacturing: AI technologies, intelligent insights

1. Transform data into intelligent actions.

Data is the key to supply-chain visibility and operational intelligence. Establish a comprehensive, consistent enterprise architecture and incorporate a hybrid cloud approach to support open flexibility and facilitate security-rich data integration. Embrace the integration of IT and OT domains, a necessity for AI-driven information and recommendation exchange.

Use AI technologies and cognitive solutions to reveal patterns that might otherwise go undetected. AI systems understand unstructured information in a way similar to humans. But they not only consume vast amounts of data with far greater speed, they learn from interactions. Uncover ways to apply that intelligence to plant and production functions and activities, powering real-time insights that are decisive and actionable.

2. Create manufacturing processes that can "think."

Standardized supply-chain processes and systems are foundational. From there, overlay digital technologies to help optimize workflows and provide integration with ecosystem partners and platforms.

Balance work performance metrics with acceptable levels of disruptions. With IoT devices monitoring asset performance in real-time, predictive analytics can determine component availability, anticipate potential failures, and provide recommendations for managing disruption. Better yet, when deviations occur, AI models can deliver key control settings to bring the manufacturing process back to optimum operating parameters. This avoids quality problems, throughput disruptions, and even improves energy efficiency.

3. Cultivate your digital skillset.

Many organizations lack the in-house expertise required to execute, track, and improve intelligent plant execution through predictive analytics, cloud, AI, and connected devices. Tactics to close the capabilities gap include reskilling existing employees, leveraging apprenticeship and internship programs to train talent, and taking advantage of emerging educational programs and platforms that enhance employee skills. Talents to develop include data management, visualization, and analytical skills—or obtain these capabilities from ecosystem partners. Partner with firms that provide a wide range of talent and experience—and new perspectives. Enable your team to rapidly gain key skills by learning from their peers. AI and analytics are slated to play an important role in predicting skill supply and demand, and these technologies can also facilitate personalized learning.

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