

THE INTELLIGENT FACTORY IS OPEN, AUTONOMOUS, AND EVER-EVOLVING

Intel is empowering manufacturers to thrive as factories of the future, driven by data and ready for any demand





THE RISE OF THE INTELLIGENT FACTORY

The world of manufacturing is irrevocably changing—and doing so very quickly.

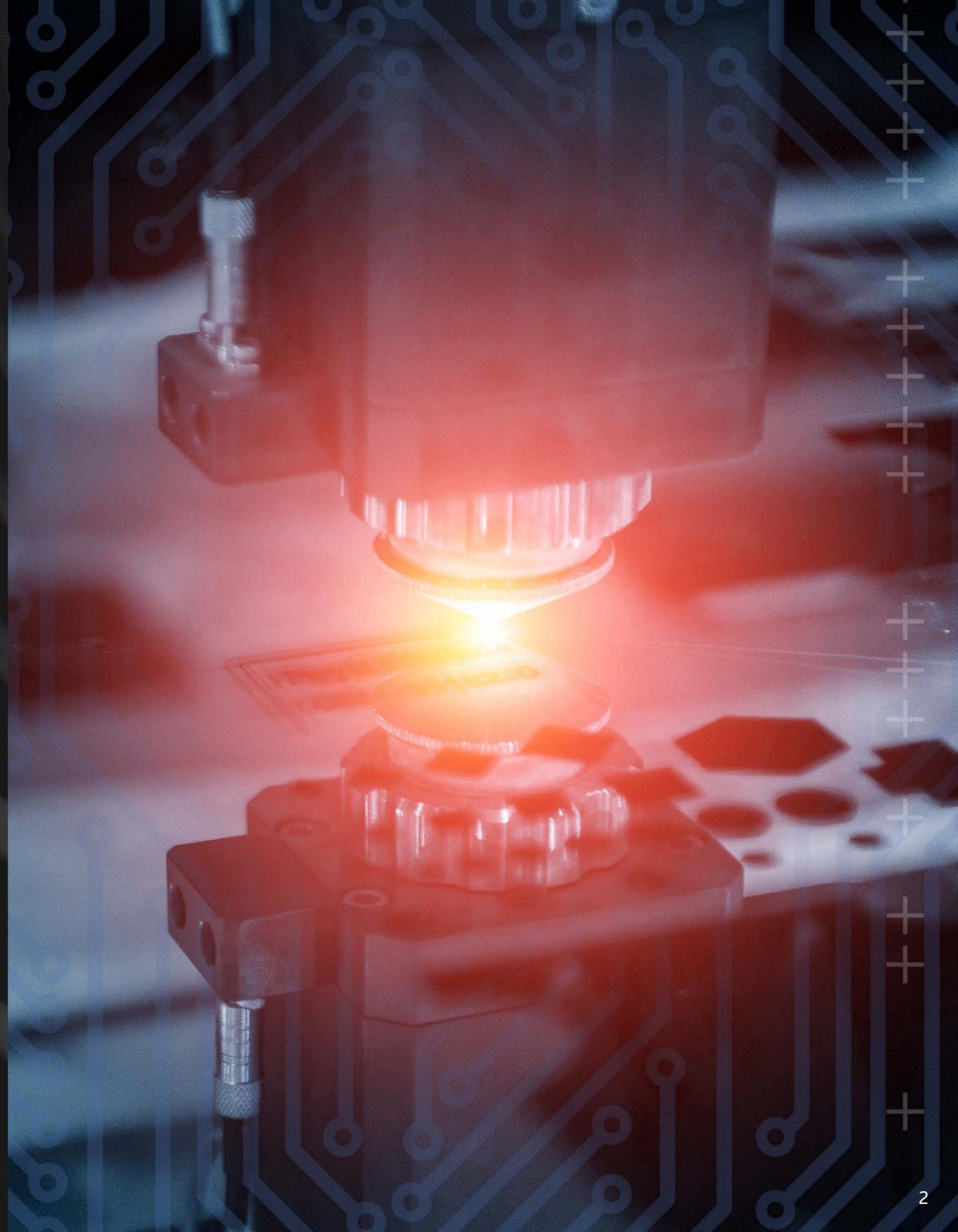
Customers demand more personalization. Manufacturers demand faster response to market uncertainties while pushing operational tolerances. Product quality and worker safety must be more tightly managed. Competitors are popping up all over the globe, and new technologies such as 3D printing are redefining who is a “producer.”

Manufacturers still experience up to 800 hours of unscheduled downtime annually, 30% of it unexpected,¹ while their skilled workforces are aging, leaving 2 million jobs at risk of not being filled.²

Fueled by Industry 4.0 and the Industrial Internet of Things (IIoT), a new kind of factory is emerging to address these pressures—one that is cloud connected, data driven, and architecturally open.

It is not just a “smart factory” marked by greater machine automation. It is an “intelligent factory” marked by hyper-agility, autonomous production, and the use of data as a transformative force for business.

64% OF MANUFACTURERS EXPECT
THEIR FACTORIES TO BE FULLY
CONNECTED BY 2022³

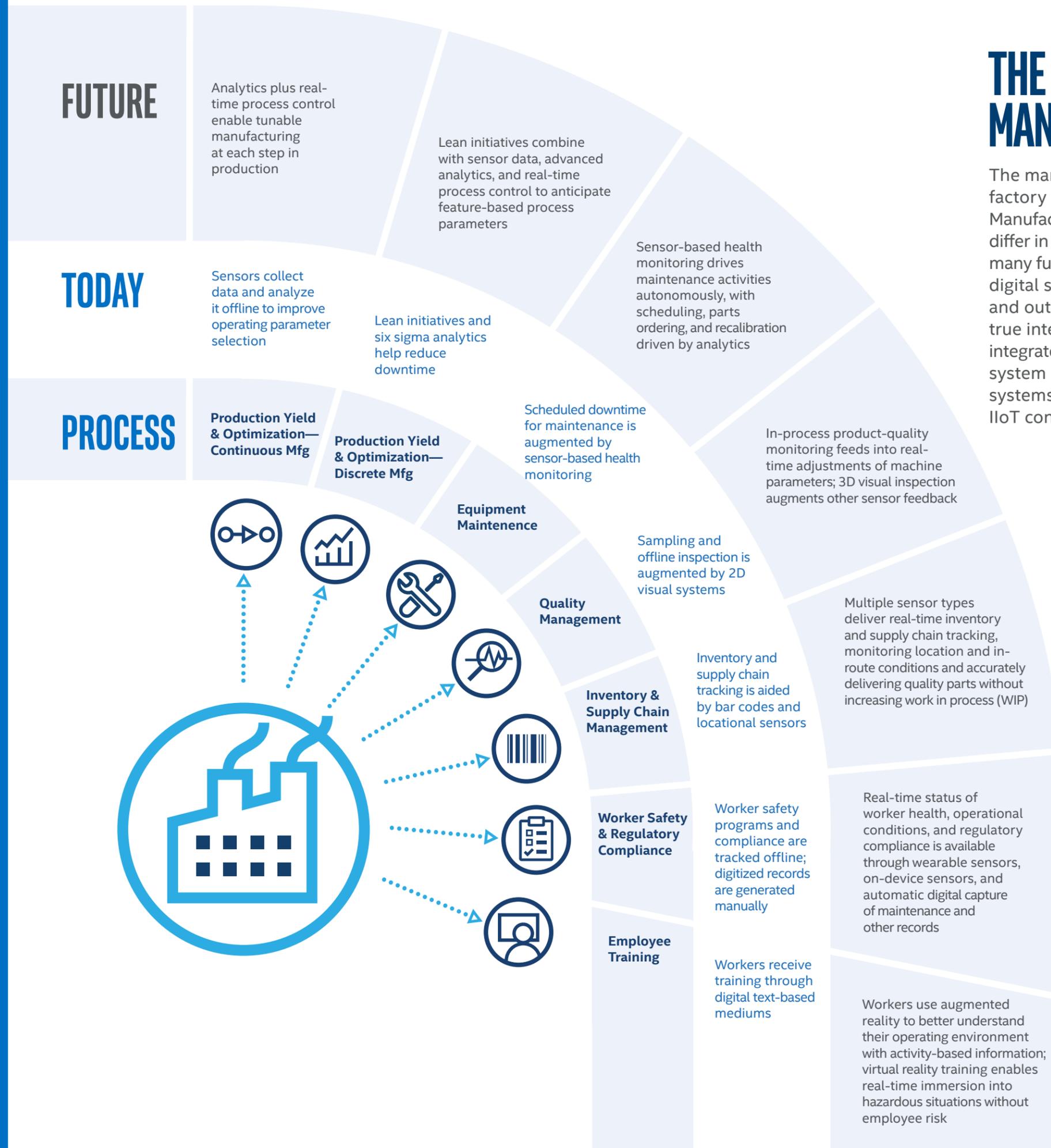


IMAGINE...

- **A manufacturing facility** in which software-defined systems enable each workpiece to direct itself through appropriate production stations and tell various machines and autonomous materials-handling carriers what needs to be done to create a completely custom product...
- **A continuous production line** that is so autonomous it can self-tune in real time based on the nuances of incoming organic materials, or feed forward the needed process changes to increase production yield...
- **A factory** in which downtime is extremely rare because machines have sensors that monitor their health and anticipate maintenance needs before failure occurs...
- **An entrepreneur** with an open-architecture factory system who can create completely custom products using additive manufacturing through a 3D printing hub.

These scenarios differ widely from today's rigidly organized, mass production environments, but technology is rapidly evolving to deliver on these capabilities for manufacturers of all types.

Powered by IIoT, generalized compute technologies, complex data analytics, and distributed, virtual manufacturing, the factory of the future will be an increasingly autonomous system. It will operate with such flexibility and customization that "economies of one" will effectively compete with today's economies of scale.



THE EVOLUTION OF MANUFACTURING

The march toward the intelligent factory has long been under way. Manufacturing operations today may differ in their level of automation, but many fundamental areas already use digital solutions for greater control and output. The key to achieving true intelligent factory status is to integrate every process and business system into a holistic "system of systems" that is run by data and IIoT connectivity.

WALKING THE WALK: THE CHANGING FACE OF MANUFACTURING AT INTEL

“For Intel, manufacturing serves as the underpinning for our business and allows us to provide customers and consumers with leading edge products in high volume. The unmatched scope and scale of our investments in manufacturing helps Intel maintain industry leadership and drive innovation.”

—Intel CEO Brian Krzanich

DATA-DRIVEN QUALITY CONTROLS AT INTEL:

25% YIELD LOSS IMPROVEMENT

20% SPARE PARTS COST REDUCTION

10X FASTER DEFECT DETECTION⁴

The promise of the intelligent factory is of particular importance and interest to Intel. As a manufacturer ourselves, we have factories all over the world, each precision-tuned for efficiency and quality.

Our traditional automation systems are augmented with IIoT-enabled capabilities, such as data-driven materials handling and advanced analytics. These systems process about 5 billion data points per day per factory, enabling factory engineers to extract needed information in seconds instead of hours.

For example:

- Big data analysis helps us detect the potential failure of critical testing units before they can begin wrongly categorizing “good” devices as “bad”
- Image analytics speed up the once hours-long manual task of segregating true rejects from marginal units by verifying them moments after they pass through an inspection module
- Non-invasive vibration sensors and an IIoT gateway predictively detect and control fan filter unit failures that could lead to extended downtime and wafer defects
- Machine learning is helping us visualize and automate the control of equipment performance, confidently validate product quality and conformity to specifications, and achieve accurate, verifiable process diagnostics

These and many other IIoT-enabled efficiencies are teaching us how to use our data to accelerate output, generate higher yields, and lower mean time to repair—typical benefits of the journey toward a fully intelligent factory.



WHAT MAKES AN INTELLIGENT FACTORY DIFFERENT

The intelligent factory is a natural outgrowth of the “digital convergence” already under way between information technology (IT) and operational technology (OT). It has several characteristics that set it apart from every factory that comes before it:

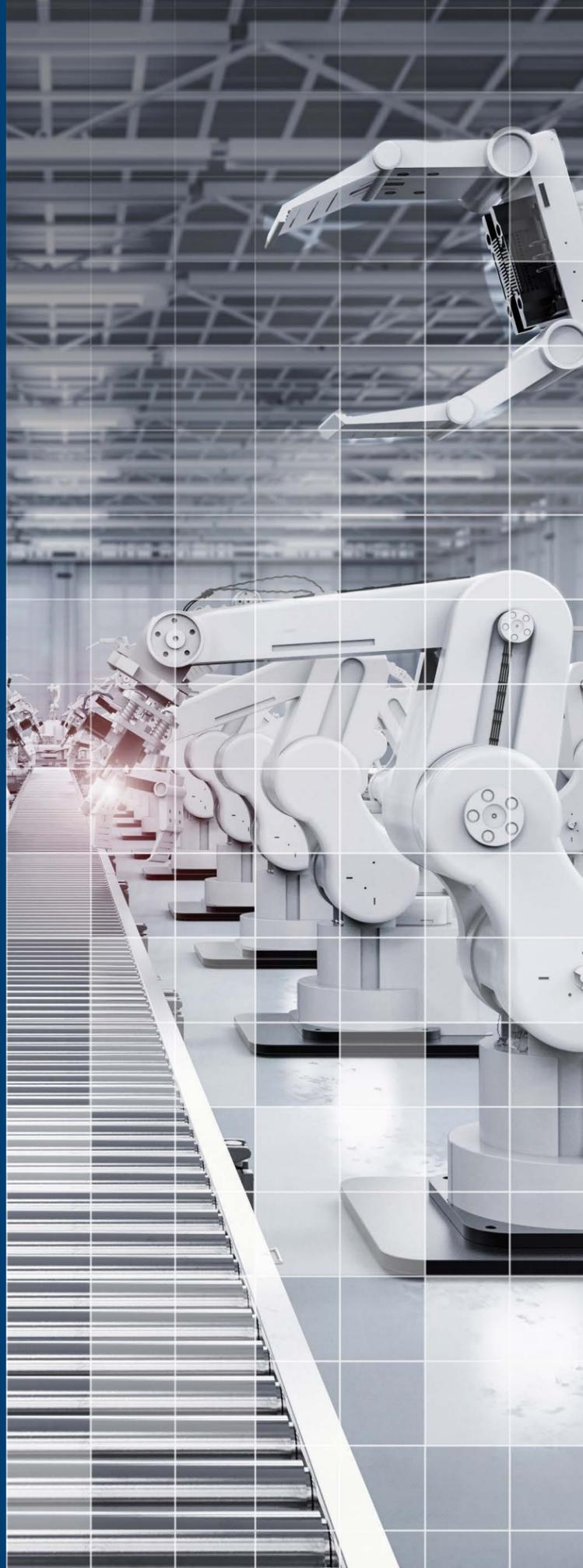
Hyper-agility—The intelligent factory uses data and IIoT connectivity to nimbly adjust and control all aspects of operations in near real-time, with near full automation, across each plant and supply chain.

Interconnectedness—Operating as a self-managing “system of systems” and hub of human-machine collaboration, the intelligent factory emphasizes cooperative activities among humans, machines, and production systems throughout the manufacturing ecosystem.

Fluidity—Autonomous and self-adapting, the intelligent factory enables manufacturers to expand IIoT’s application and value to support changing strategic business capabilities.

“Highly automated and information-intensive, the factory of tomorrow will look like an integrated hardware and software system...fueled by vast quantities of information..., moderated by analytical systems..., and comprised of intelligent machines that learn, act, and work alongside highly skilled human beings in safe and collaborative environments”⁵

—Frost & Sullivan Manufacturing Leadership Council



1 SMART, CONNECTED, AND DATA-DRIVEN

IoT and digital investment is the foundation for proactive, self-aware factory operations, maintenance, and innovation.

Sensor-equipped machines, open and interoperable systems, and reliable, real-time compute and connectivity unite machines and systems across the intelligent factory.

Product, raw materials, equipment, production lines, and control systems all have compute and connection capabilities, enabling them to collect and share data that can be analyzed in context and in real time.

An open, software-defined infrastructure drives machine and production line configuration, updates, and activities. It optimizes materials usage and product quality, enabling low-volume/high-mix production and greater business innovation.

Manufacturers can optimize their environment with a mix of equipment from a variety of OEMs, and the same machines can be provisioned to take on many roles. An open infrastructure also equips workers with actionable information about machine status, processes, and output.

Throughout the factory, end-to-end (E2E) security at both hardware and software levels helps mitigate vulnerabilities as more machines and systems are connected.

2 A SELF-MANAGING “SYSTEM OF SYSTEMS”

The factory functions as individual but interconnected systems, each with a high degree of flexibility, efficiency, and autonomy.

Future factories eventually become one large system comprising hundreds of smaller systems that operate independently yet act as one.

From production and maintenance to supply chain and security, each system and subsystem uses AI, machine vision, deep learning, and edge analytics to communicate with and control the factory’s entire realm of materials, equipment, and production lines.

Self-monitoring equipment detects when quality could suffer due to degradation, then schedules its own servicing. Materials follow the most efficient path through the appropriate set of processing steps, rather than along rigidly defined paths. Workloads across multiple physical assets are consolidated at all architecture layers to provide the flexibility required to respond to fast-changing demands. Orchestration of applications and services across commodity-class hardware enables data aggregation and control to provide new levels of performance, maximum efficiency, and end-to-end security.

Within this self-organizing environment of machine-to-machine communication, operational efficiencies improve and unplanned downtimes are reduced or eliminated. Production becomes so responsive to custom requests and materials variations that the factory essentially operates at “economies of one” to compete with today’s economies of scale.

3 A HUB OF HUMAN-MACHINE COLLABORATION

Employees work more safely and are empowered to make faster, more educated, innovative responses to business needs.

Machine-to-human collaborations require a high degree of intelligence and task focus. Safety is a high priority when working within fully distributed systems that can act without the need of central authority.

Although fewer humans are on an intelligent factory floor, they are digitally assisted, better connected, and more informed through mobile and wearable devices such as helmets, smart vests, and smart glasses.

Workers use augmented reality and data visualization to overlay useful information about production, maintenance, and product status. Virtual-reality training efficiently teaches them how to operate equipment. Co-bots and workers collaborate on complex tasks, while repetitive, injurious work is handled by robots. Wearables monitor a worker's health and further ensure their safety.

A companywide digital culture encourages the use of data for daily work, freeing employees to respond with greater creativity to resolve issues and support business success. A younger workforce is attracted through updated technology, safer work environment, and roles better suited to their generation.

4 AUTONOMOUS AND SELF-ADAPTING

The factory becomes smarter and more autonomous over time, using data to optimize resource allocation and transform business.

As more machines and systems become tightly connected, manufacturing matures into an intelligent factory model in which OT and IT converge and strategically engage in transformative business decisions.

AI and deep learning produce increasingly detailed, accurate, and meaningful digital models of equipment and processes, enabling more nuanced, data-informed planning. Devices gain autonomous agency, responding to events at a much higher cognitive level and acquiring intelligence over time. Production controls become self-running and fluid, and new, market-driven business approaches emerge.

Aided by the insights and automation from data, manufacturing efficiency and product quality—once the primary objectives—are joined by production flexibility as manufacturing drivers.

Amid this continually evolving environment, the factory and its systems become increasingly intelligent and self-knowing; increasingly autonomous and self-running; and increasingly cooperative and self-distributing with systems beyond themselves.



WHAT DEFINES AN INTELLIGENT FACTORY?

The intelligent factory has the most promise for larger discrete manufacturers and continuous manufacturers, offering benefits such as:

- Real-time flexibility in software-defined production lines without human interaction or process interruption
- Data-driven machine automation at high tolerance levels
- Multi-way communication between all things connected
- Analytics that provide visibility into machine status to predict and prevent problems
- Sensor-equipped wearables that boost worker productivity and safety
- Open, fully interoperable systems and smooth data flow
- End-to-end security along the entire data flow
- Automated management, using only software and digital policies

ACHIEVING CUSTOMIZATION WITH THE INTELLIGENT FACTORY

In environments marked for decades by high-volume/low-mix production, manufacturers now face a growing expectation from consumers and industrial customers to deliver lower-volume runs, the production of just one unit, or products made to exact order. Producers must act quickly to convert their systems into highly tunable, reconfigurable, and customer-centric operations.

Similarly, manufacturers with high-value work in process (WIP) must take an increasingly customized view of production in order to compensate for highly variable raw materials, maximize the value of each run, eliminate wasted WIP, and avoid the risk of non-compliant finished goods.

Intelligent factories make it possible to reconfigure throughput to run smaller production quantities with the same efficiency as high-volume leads. Using IIoT connectivity and data, control systems can gain the real-time flexibility they need to adapt production without human interaction or process interruption. They can automatically account for variations in the quality and properties of raw materials. Production lines can be quickly optimized for a single design or for common derivatives of the same design. Factory management systems built for real-time control can also collect and analyze historical operational data in order to forecast future implications.

DRIVING SUSTAINABILITY WITH THE INTELLIGENT FACTORY

The increasing global concern for sustainability is bringing a new focus for manufacturing operations to emphasize energy use, WIP reuse, and even end-of-product-life reclamation and ingredient reuse. For some businesses, adopting sustainable practices is mandated by the regulatory area where they operate; for others, embracing sustainability is a key part of what makes them attractive to employees and customers.

Data and IIoT connectivity in the intelligent factory can drive sustainability through integration and intelligent operations across the supply chain and the factory. Access to real-time data and analysis can create greater visibility and transparency, encourage ethical behavior, and enhance the commercial performance and reputation of the organization.

“In the next 10 to 15 years, factories and plants across industry sectors will be high-tech engines of mass customization, able to respond quickly and effectively to changing customer and market demands.”⁶

—Frost & Sullivan Manufacturing Leadership Council

TECHNOLOGIES THAT ARE MAKING THE INTELLIGENT FACTORY HAPPEN

New technologies and their jargon need not be confusing and intimidating. Here is a brief look at the fundamental terms and technological capabilities you're likely to encounter as you learn more about the intelligent factory. For more detailed information about each topic, please go to [Intel.com/IOT/](https://www.intel.com/IOT/) for our company perspective on technologies for the intelligent factory and how to design with Intel.

UNDERLYING TRENDS

OPEN ARCHITECTURE

Continued adoption of open standards and open source software across industries is spawning new innovations in industrial control systems for continuous, batch, and discrete processing. Workload consolidation at the edge is maturing to support a wide range of multi-function use cases at equipment and machine levels (e.g., robotics control, analytics) as operational environments adopt IT concepts and methods.

SOFTWARE-DESIGNED SYSTEMS

Software-defined systems enable performance at scale for manufacturers. Edge data, control, and analytic systems can extend across multiple tiers for end-to-end views of a factory or supply chain. These systems are increasingly managed remotely as they become more autonomous. Key software-defined capabilities include coordinated, multi-level workload consolidation, as well as distributed coordinated control and factory-wide analytics.

AUTONOMOUS SYSTEMS

The more IIoT capabilities that industries embed into their hardware and software systems, the more autonomous their environments will become. Everything from individual machines to factory-wide processes, from analytics to mass customization, will be affected as autonomous capabilities mature.

INDUSTRIAL INTERNET OF THINGS (IIOT)

The Industrial Internet of Things (IIoT) is a set of technologies that brings modern automation and communication capabilities to factories. IIoT-enabled factories use advanced sensors, actuators, computers, algorithms, and networking capabilities to enable machines to analyze data, make decisions, and perform actions autonomously. These machines share information with other machines, humans, and enterprise-wide systems in a secured and timely manner for monitoring and controlling factory operations.

BIG DATA

Big data refers to the explosively increasing amount of data being generated from millions of IIoT-enabled sensors, devices, and machines around the world. Proliferating daily by the terabyte, big data is characterized by the three V's: volume (the amount of data), variety (different types of data), and velocity (the speed of data generation). The hardware, software, and networking techniques used to manage and utilize big data are called big data analytics.

EDGE COMPUTING

Edge computing lowers data costs and latency by processing data right where it is generated—at the source machines themselves (the “edge”). By putting data analytics and automation functions at the same place where data is collected, edge computing enables new capabilities to address the modern realities of industrial big data.

MACHINE LEARNING AND DEEP LEARNING

A popular approach in AI, machine learning (ML), refers to algorithms by which a computer automatically learns relationships within sufficiently large datasets, then prepares “trained models” that can be deployed in industrial operations. For example, ML techniques can be used to train a machine to automatically detect defects in manufactured goods.

Deep learning (DL) is a sub-category of machine learning. It represents trained models using successive (deeper) layers of relationships among the original data, and adds intermediate computer-generated data. For some tasks, DL-generated models perform more accurately than humans.

INDUSTRIAL MACHINE VISION

Machine vision (MV) technology combines cameras, computers, and algorithms to analyze images and videos and make relevant decisions automatically. For instance, MV technologies can be used for equipment maintenance, defect detection, quality control, inventory verification, product labeling, security monitoring, etc. Augmenting industrial machine vision with AI such as machine and deep learning is enabling newer and more accurate factory-automation applications.

TIME SENSITIVE NETWORKING

Time Sensitive Networking (TSN) technology enhances standard Ethernet-based networks by adding timing-related attributes like synchronization, low-latency, and streaming channels. In intelligent factories, large volumes of data will flood the networks. TSN-enabled networks and devices will allow machines to exchange time-critical data with guaranteed bandwidth and deterministic latencies. TSN is being standardized by IEEE.

THE INTELLIGENT FACTORY JOURNEY— ONE STEP AT A TIME

Transforming into an intelligent factory is neither easy nor quick, but it is worth every resource applied to it. The most successful journeys begin with smaller, incremental steps to increase digitization within the factory. Systems must be set up to communicate across the enterprise and exchange data seamlessly in real time. Workforces must reinvent themselves to become more digitally savvy and confident with data-driven decisions. Leadership must establish and uphold a companywide digital vision and culture.

Early stages typically use IIoT to improve operations through data-driven use cases, such as predictive maintenance and in-process quality optimization. In transformative stages, IIoT becomes a strategic business differentiator, enabling flexible, market-driven, mass customization capabilities through autonomous, real-time, and demand-driven production.

Some IIoT-connected manufacturers will retain an overall factory look and feel, but selectively apply data-based automation. Others will be so tightly connected across the factory and with their vendors that the entire value chain will work with greater autonomy and data-driven cooperation.

Whatever their path of implementation, each manufacturer will have a rich collection of IIoT offerings from which to create their factory of the future.



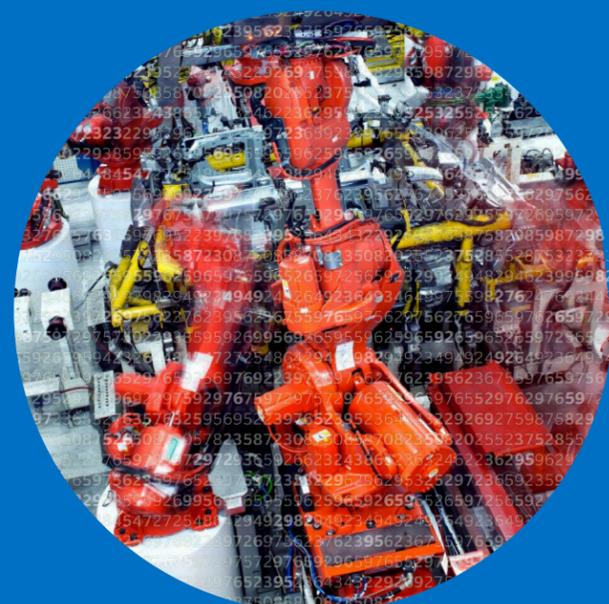
1 INCREASINGLY INTELLIGENT (SELF-KNOWING)

The factory knows real-time status of all operations, processes, inventories, and equipment, and can predict problems



2 INCREASINGLY AUTONOMOUS (SELF-RUNNING)

The factory repairs and maintains itself, and adjusts and optimizes production, while humans focus on business strategies



3 INCREASINGLY COOPERATIVE (SELF-DISTRIBUTING)

The factory operates autonomously with other systems, such as supply chain, inventory, ERP, and HR

WHY THE INTELLIGENT FACTORY NEEDS A DIGITAL CULTURE

Technology alone will not help a company transition to an intelligent factory: creating a “digital culture” will be essential.

A digital culture is one in which employees from factory floor to boardroom understand and embrace the value of IIoT as a way to continuously improve the manufacturing environment and promote learning.

It ensures workers, supervisors, and leaders can confidently interact with digital technologies, equipment, and processes as they shift from lagging, reactionary responses to anticipatory or instant responses based on data-driven systems.

42% OF MANUFACTURERS
ARE MAKING “GOOD TO
SUBSTANTIAL PROGRESS”
WITH INDUSTRY 4.0⁷



INTELLIGENT FACTORY SUCCESS STORIES

REAL-TIME DATA DRIVES PRODUCTIVITY

Connectivity, asset monitoring, and predictive maintenance analytics on key assembly lines at **Bosch*** have increased productivity by 20% per year since 2012.⁸

DEVICE SENSORS INCREASE EFFICIENCIES

With real-time production line monitoring via mobile devices, RFID, and Wi-Fi, **Stanley Black & Decker*** has 24% better equipment effectiveness, 10% better labor utilization efficiency, and 10% better throughput.⁹

AUGMENTED REALITY SPEEDS INSPECTION

Product inspectors at **NNS Shipbuilding*** regularly use digital tablets to speed their work—in one case reducing a typical 36-hour inspection process to a slim 90 minutes (more than 30x faster).¹⁰

WEARABLES REDUCE RISK OF INJURY

DorsaVi* and **VINCI Construction*** designed an IIoT sensor-equipped wearable to measure changes in worker posture, leading to 85% less high-risk back usage, 84% less back-muscle activation, 70% less high-risk movement repetition, and a 17% increase in productivity.¹¹

AI AUTOMATION RUNS THE MINES

Rio Tinto* mining has deployed 69 self-driving trucks at an iron ore mine in Australia, saving 500 work hours per year per truck, and is planning autonomous drilling and train operations.¹²

EMPOWERING YOUR INTELLIGENT FACTORY—THE INTEL ADVANTAGE

Intel is accelerating IIoT adoption and providing the foundational technologies and trusted expertise to enable the intelligent factory to grow and be realized.

We are at the center of a vibrant ecosystem offering technologies and services that deliver IIoT solutions in various forms:

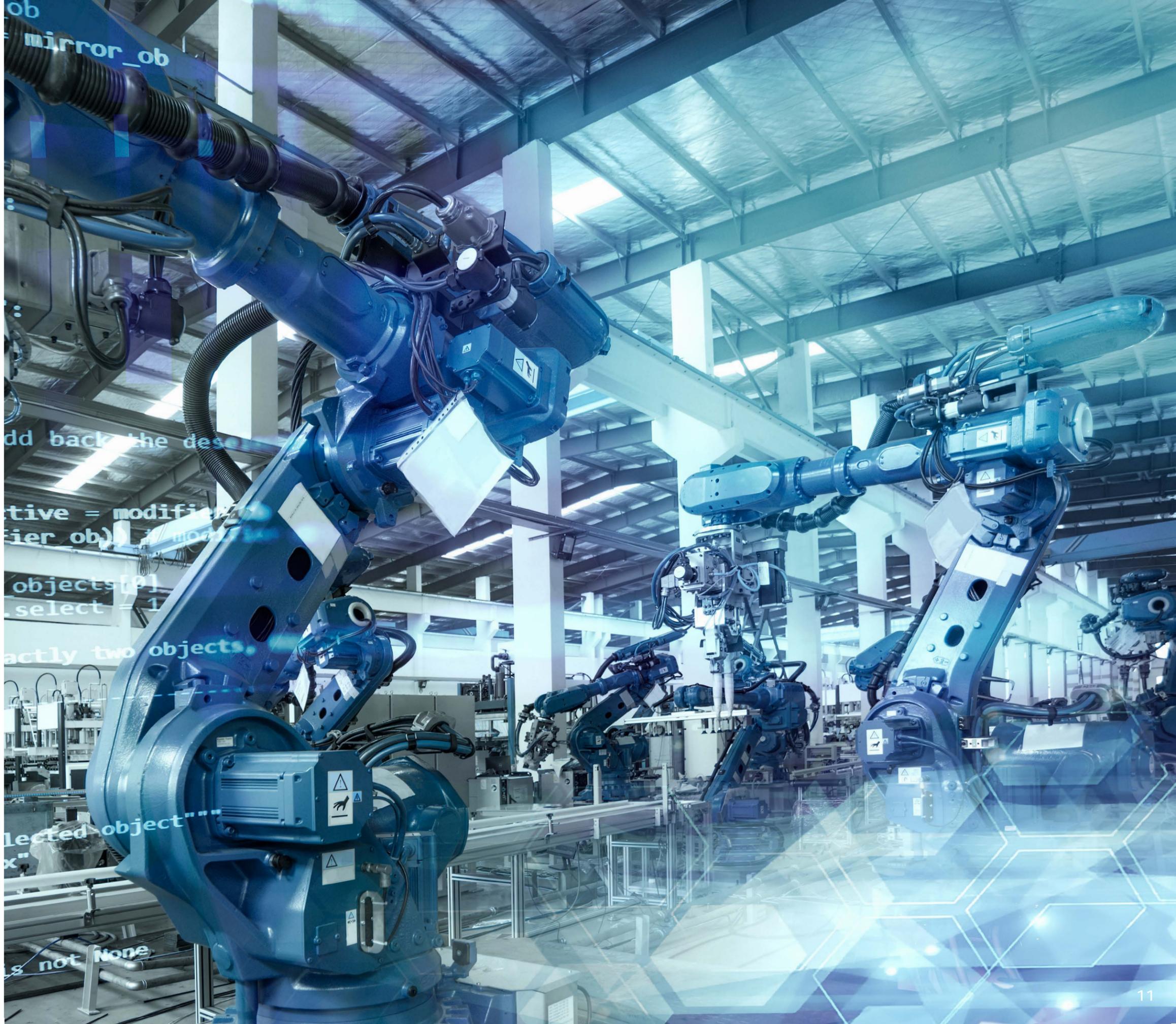
- Devices that can be purchased from equipment manufacturers, automation vendors, or distributors
- Systems that can be procured via system integrators or automation vendors who configure and customize as necessary
- Market-ready solutions that are already successfully deployed and preconfigured, so they can be installed with minimum effort

We have demonstration labs and workshops where Intel experts in industrial automation and technology will help you see the big picture and plan a path to your goals.

As IIoT leaders and industry influencers, we are ready to lead your business from the “smart” factory of today to the fully intelligent factory of the future, driven by data and ready for any demand.

For more information on how to start this exciting journey, please contact your Intel representative or go to

[intel.com/manufacturing](https://www.intel.com/manufacturing).



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