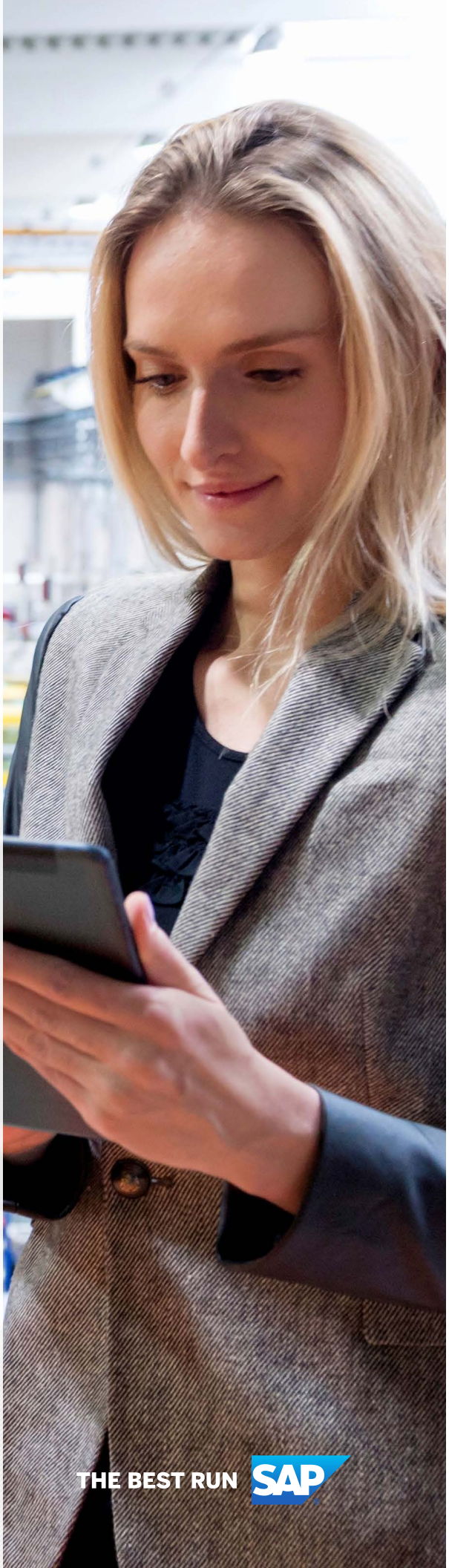
SAP's Strategy for Industry 4.0

January 2020



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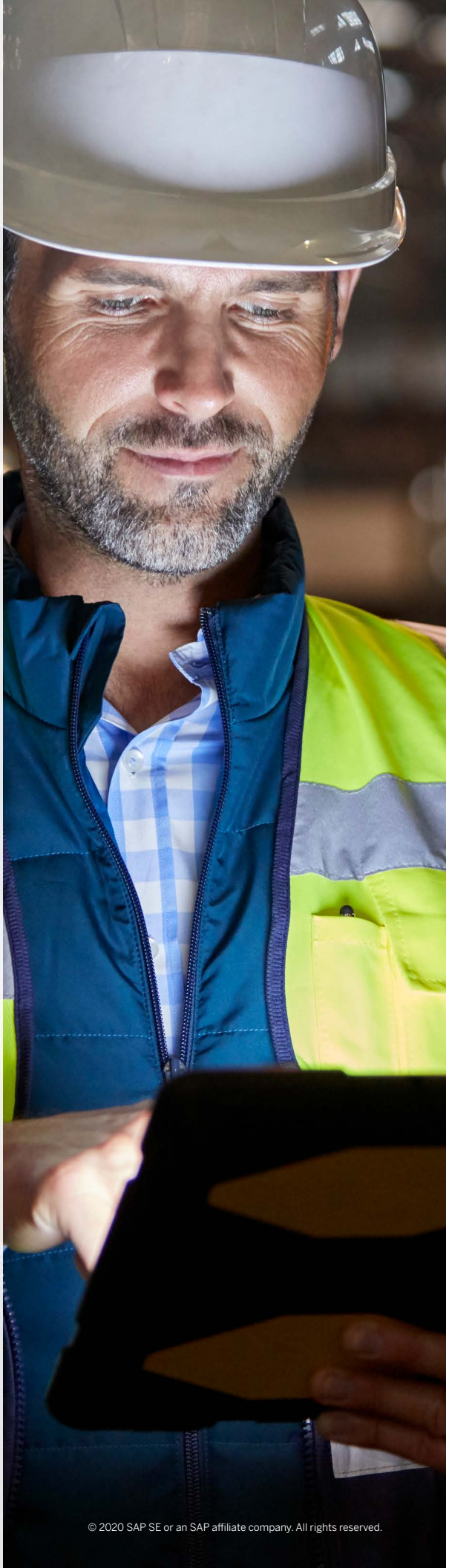


Executive Summary

Manufacturing companies are challenged to increase productivity while producing individualized products with high quality in an environment of constantly changing and varying customer demand. Many companies recognize Industry 4.0 as strategic priority to turn these challenges into opportunities.

Industry 4.0, or the Industrial Internet of Things (IIoT), is about industrial transformation using new digital technology that makes it possible to gather and analyze data across machines and business systems, enabling faster, more flexible, and more efficient processes to produce higher-quality individualized goods at lower cost. Technology innovations like the IoT, edge and cloud computing, Big Data lakes, artificial intelligence, sensors, autonomous systems, and cobots are drivers for the change. Creating value from Industry 4.0 requires an industry-specific approach as business goals and challenges vary by industry – and even by company.

Industry 4.0 will radically change production across discrete and process industries. Production equipment will become highly autonomous. The way humans work in production will change, with workers getting tailored information and decision support with smart devices. The production software stack will see a shift from transactional production execution to data-driven business process execution and optimization. All sensors, devices, machines, and so on will be connected.

Data infrastructures enable an enormous amount of operational data to be ingested, processed, and analyzed. Application modules using container technology will be distributed between cloud and edge. Edge computing enables execution of cloud-managed application modules at the production site to ensure reliability and low latency of business-critical functions. Integration will be much higher as, for example, automated guided vehicles interact with production lines and warehousing systems.

With this level of connectedness, it is key that the architecture principles guiding the solutions are secure, interoperable, portable, open, modular, affordable, and extensible. SAP is an active user and a major contributor to various industry standards and related open source projects.

SAP can help you make Industry 4.0 your everyday reality. With SAP solutions and technology, you can bring data-driven customer devotion and operational flexibility to the entire business. You can build intelligent, individualized products by connecting each customer's voice to everything from product planning to delivery. You can create the kind of production process that adapts dynamically to different demands, setups, and workflows, while using intelligence and networks to integrate every machine, partner, and employee. Plus, you can connect the entire company – bringing together logistics, sales, and service – so every step is orchestrated, and you avoid the gaps or delays that keep you from delivering the best-possible experience.

SAP provides unique solutions for Industry 4.0. For many organizations, Industry 4.0 is a manufacturing-, factory- or distribution-center-focused effort. And while that is a part of the SAP story, it's not the whole story. We believe organizations can truly achieve the benefits and impact of Industry 4.0 by embracing it holistically across their entire organization. SAP has the broad solution portfolio to unlock the value of Industry 4.0, combining the power of intelligent manufacturing in factories and plants with end-to-end business processes execution across the supply chain. And we bring all Industry 4.0 players together, orchestrating the ecosystem including machine and equipment makers, technology and application providers, and standards-setting organizations as well as system integrators.

SAP's approach to Industry 4.0 combines three business priorities to one leading strategy:

- Focus on customers, so their input and preferences are the source of all you do
- Reinvent production, using intelligent assets and processes that dynamically adapt to changing priorities and deliver customization at scale
- Connect the entire company, orchestrating, sales, service, and logistics with production to transform how you work

With SAP solutions and technology, you **put Industry 4.0 to work company-wide** – right now and going forward – so you can stay connected to your customers, integrated with your partners, and far ahead of your competition.

THE MARKET

MARKET DYNAMICS

Until recently, supply chains were mainly measured by efficiency metrics. Today, new trends are emerging that present complex challenges and put supply chain and manufacturing at the center not only of business success but also of a company's differentiation strategy. Companies in manufacturing industries face numerous challenges. They need to produce smarter products while maintaining high quality in volatile markets. Customers demand individualized products down to lot size 1. Lifecycles of products get shorter and shorter. Faster time to market is key for staying competitive. Business models change from selling products to delivering solutions. Many companies recognize Industry 4.0 as a strategic priority to turn these challenges into opportunities.

WHAT IS INDUSTRY 4.0?

Industry 4.0, or the Industrial Internet of Things (IIoT) is about industrial transformation using new digital technology that makes it possible to gather and analyze data across machines and business systems, enabling faster, more flexible, and more efficient processes to produce higher-quality individualized goods at reduced cost. This transformation will improve resource productivity and efficiency, drive agility and responsiveness, speed to market, and enable customization to meet customer needs.

More specifically, Industry 4.0 refers to the **intelligent networking of machines and processes** for industry with the help of information and communication technology. The digitalization of the industrial production environment in factories, plants, and warehouses is **driven by technology innovations** that appeared in the aftermath of the Internet and cloud revolution: IoT-connecting devices; machine-to-machine communication; distributed computing; new edge and cloud technologies, such as containers, microservices, and event-driven architecture; times series and Big Data lakes; machine learning and artificial intelligence; new mobile user experiences, such as augmented or virtual reality to enable digital workers; autonomous systems and vehicles; and cobots and robots.

Most large corporations and many midmarket companies have piloted use cases to assess the business value of Industry 4.0. In a recent McKinsey global survey among discrete manufacturing customers, 68% of respondents recognize the strategic priority.[1] While 41% are still piloting, 29% have started to deploy at scale with significant purchase decisions being visible in the market. Companies successfully deploying Industry 4.0 at scale focus on business value not technology, mobilize and train their workforce on new technologies, and move toward an integrated IT infrastructure and automation technology stack. And they manage the company by data-driven processes rather than transactional processes.

1. "Industry 4.0: Capturing Value at Scale in Discrete Manufacturing," McKinsey & Company, July 2019.

APPROACH FOR INDUSTRY 4.0

Creating value from Industry 4.0 requires an industry specific approach as business goals and challenges vary by industry and even by company. There is no one-size-fits-all Industry 4.0 approach.

Three distinctive clusters can be identified for discrete manufacturing based on the average lot size and the number of variants per factory:

- **Engineer-to-order production** models found in industries like shipbuilding, high-end machinery, and aerospace, executing on small or individual production orders, strive for high efficiency in manufacturing down to lot size 1.
- **Mass-customized production**, typically in automotive, agriculture equipment, and industrial components, aims at maintaining high-sequence throughput and consistent quality despite increased product variances.
- **In high-volume production**, such as consumer electronics, commercial equipment, or semiconductor chips, full automation (lights-out production) drives further productivity increase while changing product mixes require higher flexibility or production line adaptation.

In **process manufacturing**, lot size becomes batch size while variants per factory translates into the number of different formulas or recipes per plant.

- For **order-based specialty production**, multiproduct facility utilization becomes most important. New technologies allow tailoring of products to individual needs, but require efficient use of production equipment.
- In **mass-production, batch-oriented industries**, such as fine chemicals, paper, metals, construction materials, food, or pharma, high throughput objectives are increasingly combined with compliance, regulation, and traceability requirements.
- For **commodities**, such as petrochemicals, bulk chemicals, and ore in mining, asset efficiency of continuous flow production on a global level drives further optimization.

Figure 1 shows examples of Industry 4.0 scenarios that have emerged to deliver short-term business value across discrete and process industries.

Figure 1: Industry 4.0 Scenario Examples Across Industry Clusters

	Discrete manufacturing			Process manufacturing		
	Engineer to order	Mass customized	High volume	Specialties	Mass production	Commodities
Production model	Order based	Sequence based	Demand based	Order based	Batch based	Continuous flow
Productivity imperative	Efficiency at lot size one	Throughput and quality at mass customization	Flexibility at full automation	Multi-product facility utilization	Throughput with compliance	Global asset efficiency
Business trends	• Increasing demand volatility • Ability to compete locally in global market • Service business models • Integrated systems	• Consumerization and personalization • Supply chain agility	• Shorter product lifecycles • Increasing labor cost (in low-cost locations) • Circular economy	• Deglobalization • Tailored formulas (medicine, biotech)	• Supply chain agility • Decarbonization and sustainability • Compliance and regulation	• Growth in emerging markets • Regionalization • Circular economy
Industry 4.0 scenarios	• Digital twin (digital product and process) • Digital worker (paperless) • Data-driven optimization (quality, automation)	• Flexible and adaptive production (automatic guided vehicles, routing, scheduling) • Extension of automation and cobots • Inline quality control	• Lights-out factory (full automation) • Tracking and traceability • Automated quality assurance	• Digital enablement of operators and field services • In-process quality control	• Data-driven throughput optimization • Traceability and regulatory compliance • Connected logistics	• Digital plant and simulation • Digital field services • Predictive maintenance

INDUSTRY 4.0 CUSTOMER EXAMPLES

Discover how three clusters of **discrete manufacturing** companies have addressed their business problems with the help of SAP solutions.

Customers running **engineer-to-order production** models see benefit from the tight integration between engineering and manufacturing.

- A metalworking customer increased their manufacturing performance by digitalizing the manufacturing process. With engineering now fully integrated to manufacturing, current information on latest engineering changes is sent to the shop floor. Automated optimization of setup times for operations is supported, and each component that is being manufactured can be easily identified by mobile devices. Benefits include the elimination of bottlenecks by targeted control of manufacturing as well as the reduction of lead times and planning effort.
- In the aerospace and defense industry, customers with long-term manufacturing projects have hundreds of engineering changes as well as strict requirements for product quality and production process reliability. They have experienced faster time to market as a result of the tight integration between engineering and manufacturing.

In the case of **mass-customized production**, where every product is unique, product-specific information needs to be integrated automatically from the shop floor to customer-facing roles.

- **Caterpillar Inc.**, one of the world's largest construction equipment manufacturer, wants to give their customers the same real-time response they get in a store. They see this as a key value-add for their customers and a differentiator for them. To accomplish this, the company has moved their entire manufacturing operations to what they call "retail speed." Now, manufacturing provides the current status of the shop floor in real time in a centralized system, delivering one version of the truth and enabling proactive business decisions at strategic, tactical, and operational level.

High-volume production manufacturers focus on the efficiency and seamless operation of their plant.

- These include manufacturers of electrical and electronic components like Harman International Industries Inc., ebm-papst, and Endress+Hauser Conducta GmbH+Co. KG. These companies have combined automated manufacturing and manual assembly into one digital process, enabling digitally networked manufacturing and leading to harmonized global production processes. They closely integrated customer interactions with manufacturing operations and have centralized and standardized master data. They have simplified user interfaces on the shop floor using digital instructions, which allows them to go paperless, and have implemented active process interlocking and control. Manufacturing equipment is set up automatically with parameters taken from the production order; material and tool setup is verified; and traceability information is collected automatically, increasing process stability. This has resulted in increased flexibility, more robust processes, higher uptime, and reduction of capital employed.
- Other examples can be found in the automotive industry where an OEM as well as a supplier have started transforming from fixed assembly lines to modular assembly processes. They connected assembly stations with automated guided vehicles, bringing new levels of flexibility to an already highly automated process. This has resulted in increased throughput, improved uptime, and lower capital expenditure on shop floor equipment while still supporting increased product diversity.

Process manufacturing customers are also benefiting from running a digital plant.

- **BASF** SE is managing plant equipment and collaborating with suppliers using the SAP Asset Intelligence Network, which provides increased visibility through a one-stop shop for asset-related information from all suppliers.
- **Koehler Paper Group** produces more than 500,000 tons of specialty paper and board annually for the global market. They are using insights gained from billions of records of unstructured data collected from their paper production processes, within the SAP HANA® platform to increase accuracy in quality management and, as a result, improve product quality.

INTELLIGENT MANUFACTURING OF THE FUTURE

FUTURE OF PRODUCTION

Just like today, production facilities of the future will look different depending on the industry, production process, localization, and cost of labor. Regardless, Industry 4.0 will radically change production across discrete and process industries. It will enable manufacturers to **increase productivity and asset efficiency** while delivering a larger number of customized as well as personalized product variants or batches with higher quality.

This development will be enabled by a **change in production equipment**. Across production facilities, logistics will be digitalized and executed by increasingly smarter and autonomous robots and vehicles. Production machinery will become highly autonomous, with robots performing increasingly complex tasks. In very large facilities, remote surveillance of equipment and processes, with drones, for example, will become the norm. In discrete manufacturing, the factory will become a flexible hybrid system of robots and humans, additive and subtractive manufacturing, composites and metals, digital and analog processes, and so on. Classic assembly lines will be replaced by flexible manufacturing islands, with modular production assets like flexible robots and fixtures, storage vehicles, or flexible production processes like 3D printing. Machine vision can be used to automatically detect quality issues, classify inventory, and control processes.

The **way humans work in production** will also change. Smart glasses (or similar devices) and augmented reality will be increasingly relevant, for example, in complex assembly or hazardous work environments, to guide employees through work processes and – in combination with computer vision – notify employees of any errors or safety hazards. Wearables will help protect the workforce by detecting critical situations, such as fatigue or accident risk, and automatically call for help when there's an accident. More comprehensive wearable solutions, like worker exoskeletons, can support and enhance workforce performance. Consequently, the required skill set of the manufacturing workforce will evolve, requiring manufacturers to undertake significant cultural change.

Production IT will become ever more important to drive further automation and higher productivity through digital orchestration of the production processes. In factories, 3D production simulations will be key to support flexible, modular systems, and logistics will be enhanced by work pieces communicating even more extensively with production machinery. Across production facilities, edge computing will be critical to ensure reliability of crucial execution functions and efficient processing of data. We will see further adoption of analytics platforms that work easily with disparate or unstructured data sets generated by IIoT to drive advanced analytics scenarios such as predictive maintenance to optimize asset utilization.

With increasing digitalization and use of IIoT come new threats. To prevent hackers shutting down factories or misusing critical assets, a cybersecurity infrastructure meeting the highest standards will become increasingly important, potentially employing blockchain technology with its tamperproof ledger to secure IIoT scenarios.

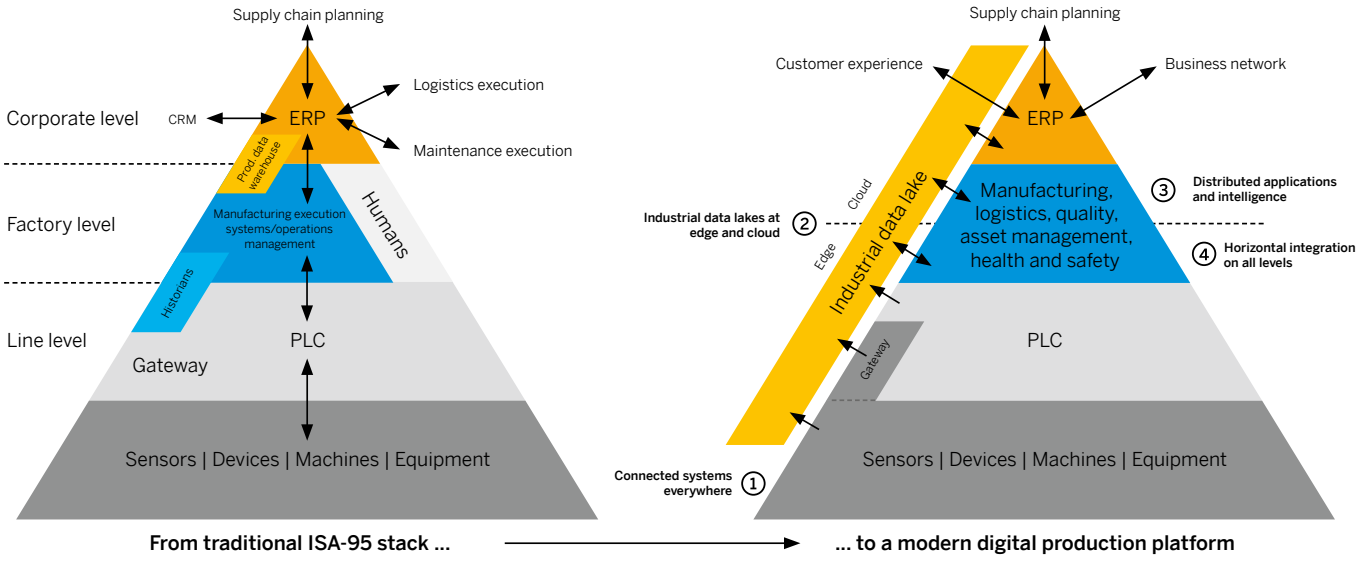
EVOLUTION OF PRODUCTION SOFTWARE STACK

With manufacturing companies rolling out Industry 4.0 technologies, the traditional production software stack – standardized through ISA-95 with a manufacturing operations management layer at the factory level connected to both enterprise systems such as ERP and shop-floor control systems (PLCs and SCADA, for example) – will see a seismic shift from transactional production execution to **data-driven** business process execution and optimization.

As a result of technology trends and buying decisions, the traditional ISA-95 production stack is evolving into a digital manufacturing platform (see Figure 2) with the following four key drivers:

- All sensors, devices, machines, and other equipment in factories, plants, and warehouses **will be connected**. This includes not only traditional controllers but also a variety of gateways, Internet protocol connectivity, mobile (5G) industrial networks, and short-range and wide-area technologies.

Figure 2: Evolution of the ISA-95 Stack to the Digital Production Platform



- **Data-driven optimization** requires adequate data infrastructures to ingest, process, store, analyze, and distribute the enormous amounts of operational data. Both edge and cloud solutions will coexist in addition to traditional historian solutions. Note, however, in most cases, the operator retains the access and distribution rights for data (data sovereignty and governance).
- **Intelligent algorithms and applications** working on industrial data will be executed close to the data, depending on latency, relevance, and time horizon. Many solutions will be distributed between edge and cloud, for example, to learn in the cloud and execute algorithms at the edge. Edge computing enables execution of cloud-managed application modules at the production site to ensure reliability and low latency of business-critical functions.
- While traditional production stacks integrate on the planning level (for example, production orders, transport orders, or maintenance orders), modern manufacturing platforms will **integrate not only vertically, but also horizontally** between different domains. Examples include interaction of automated guided vehicles with production lines and warehousing systems or inline process control to influence production scheduling.

OUR SOLUTIONS FOR INDUSTRY 4.0

Manufacturing companies are challenged to reduce cost, increase productivity, and improve quality and asset utilization, while delivering high service levels to fulfill constantly changing and varying customer demand. Automating processes, digitalizing operations, and leveraging detailed information from the shop floor operations allow companies to continuously improve and deliver the expected business outcomes. Companies with such a digital backbone are able to start transformational Industry 4.0 projects to expand their business and even develop new business models. Such projects have an impact beyond the factory boundaries and affect adjacent lines of business. Transforming a company from producing standard products to smaller lot sizes or to lot size 1 requires not only changes in the factory but in product design, sales, planning, logistics, purchasing, and delivery.

The common thread for Industry 4.0 is the **digital twin**. The base capabilities include capturing a digital representation of a specific asset or system characteristics: as designed, as manufactured, and as operated. Just doing this adds tremendous value because operating manuals, diagrams, service instructions and records, performance records, and failure modes can by maintained and updated in near-real time across the network, eliminating manual effort and errors. Building on this data, companies can develop capabilities that enable them to predict future states based upon historical data, change the behavior or performance by adjusting variables, and simulate possible outcomes by adjusting several variables to determine the best result before instructing the physical system.

NEW PRODUCTS BECOME PERSONALIZED, CONNECTED, AND INTELLIGENT

A tangible example: smart clothes such as personalized sport shoes. These shoes are produced and shipped exactly to the desires of the consumer.

Desires delivered

They connect to applications that help the consumer track sport performance.

Intelligent product

And these intelligent shoes provide information to the manufacturer's design department to identify improvement points for designing and developing the next generation of sport shoes.

A similar story can be told for intelligent and connected machines, such as a computer numerical control (CNC) machining center. During the production of the CNC machining center, the supervisor, technician, and worker are supported by IT systems that empower them for their daily routines and (unforeseen) events.

Empowered people

When the CNC machining center is delivered to the customer (in this case, a manufacturer), the machining center already knows its capabilities, the information it needs to share, and its status. With this information, the machine is plugged in to the network of the manufacturer. The SAP® Digital Manufacturing Cloud solution knows the machine's capabilities and can start dispatching production orders to it for the upcoming shop-floor tasks. The machine became an intelligent asset in the smart factory.

Intelligent asset

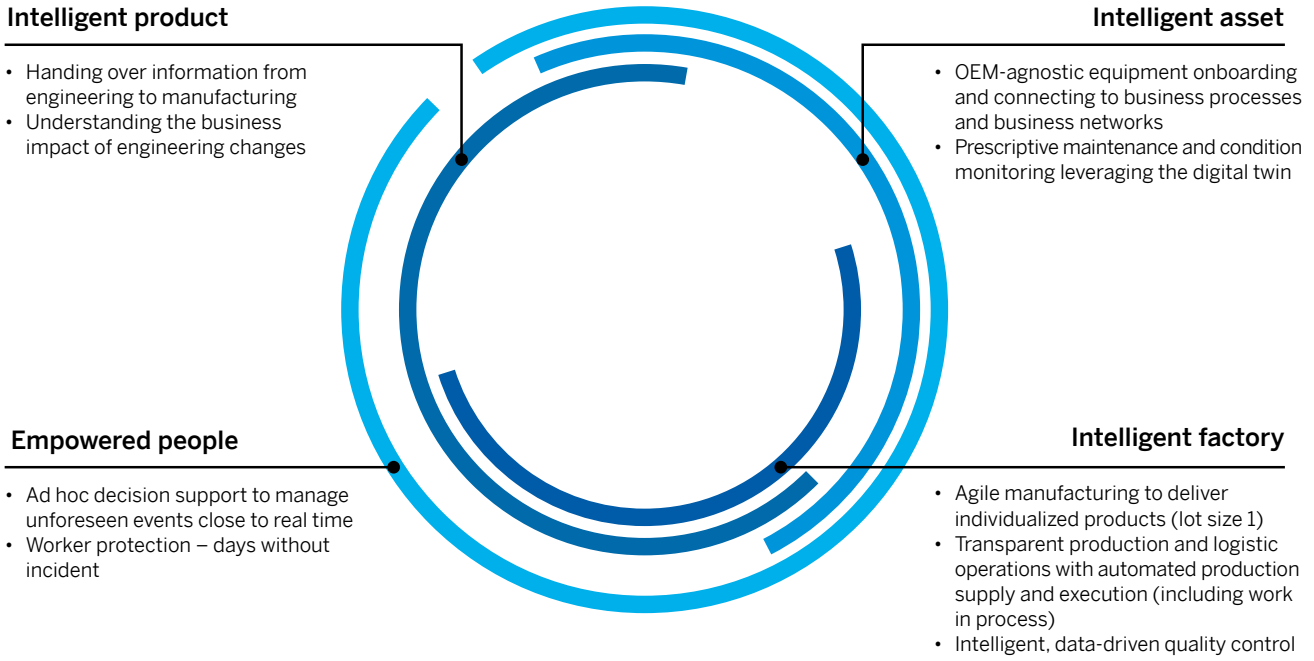
Smart factory

It connects to SAP Asset Intelligence Network to share health and other indicators with the producer, who uses this information to keep the machine up and running. And the producer can also use this information to improve the next generation of CNC machining centers.

THEMES AS DRIVERS FOR INDUSTRY 4.0

SAP believes that Industry 4.0 is driven by four themes providing distinct value to the business (see Figure 3). Intelligent products are built and configured to meet exactly what customers need. Intelligent assets are linked to all processes and are dynamically maintained. Intelligent factories use data and intelligence to run as autonomously as possible and deliver customized products at scale. Empowered people are equipped with all the tools and information they need to do their best work.

Figure 3: Industry 4.0 Themes and Use Case Examples



Intelligent Product
Intelligent products are more complex than classic ones, and most often they are individualized. Handling these products in the different lines of business and leveraging the advanced capabilities of these products require special IT capabilities.

Typical Industry 4.0 use case examples for **fully integrated manufacturing engineering processes** cover:

Handover. Handing over information from engineering to manufacturing usually takes a long time and includes a high number of manual and error-prone steps. Often, there is no standard process for phasing late engineering changes into manufacturing. SAP is addressing this pain point with the SAP S/4HANA® Manufacturing solution for production engineering and operations, providing capabilities to keep the engineering and manufacturing information in sync.

If components are exchanged, added, or deleted by the product engineer, the system will identify and visualize in 3D the components that need to be changed on the manufacturing BOM and routing. SAP intends to provide functionality that highlights changes in production manufacturing information such as welding or tolerances and hands these over to manufacturing master data and orders.

Change impact. Understanding the business impact of engineering or sales order configuration changes is a very tedious process today. Getting the engineering changes from the design department or (envisioned) from the sales order configuration, the SAP S/4HANA Manufacturing solution intelligently identifies impacted objects within the system (manufacturing BOM, routing, production orders, purchase orders, inventory, or others) and gives advice on where to incorporate these changes.

If, for example, the engineering department is replacing a special component "A1" with component "A2," the system not only identifies the manufacturing-related master data and orders, it also indicates if there is a dedicated purchase order for "A1." In this case, the responsible purchaser can be informed early to avoid replenishing inventory that is no longer needed.

SAP intends to support changes from engineering as well as sales orders, even if they come in very late. This capability can be a differentiating factor for companies that are driving for high customer centricity or for reducing time for new-product introductions. The challenge is when changes are affecting already-started production orders and determining if these changes must be propagated down to the machine layer.

Intelligent Asset
In many companies today, the actual asset health is unknown, and data is collected and handled in several silos. This leads to significant amount of avoidable downtime and inefficiency. Often, the maintenance activities are not well aligned with manufacturing, leading to unused capacities or missed opportunities for high-priority orders.

Typical Industry 4.0 use case examples for **leveraging assets intelligently** are:

OEM-agnostic equipment onboarding, connecting to business processes and business networks. Onboarding equipment is usually a time- and effort-intensive task. SAP intends to support onboarding of assets as "plug and play." This includes creating the digital twin of the asset, establishing connectivity, and enabling data ingestion and use of these assets in production processes and in business networks. SAP's focus is on greenfield as well as brownfield scenarios – easy onboarding of new and older assets.

Prescriptive maintenance and condition monitoring leveraging the digital twin. Asset maintenance is a significant cost factor for many companies. Especially in asset-intensive industries, the goal is to increase operational asset performance and reduce cost. Moving from reactive to data-driven asset management helps manufacturers reach this objective. For example, maintenance jobs will be driven directly by the asset, connected through IoT technology and facilitated by predictive algorithms to preempt failure. With asset central foundation, SAP provides one common data repository that's used by SAP Asset Intelligent Network and SAP solutions for digital manufacturing as well as engineering and logistic solutions. The SAP Predictive Asset Insights solution delivers textual and event analysis from ERP data. To enhance the analysis, machine learning algorithms are applied to time-series data coming from sensors on IoT-enabled assets. This is taken further by modeling a high-fidelity digital twin of the asset and using mathematical models such as structural dynamics, thermodynamics, and fluid dynamics to simulate behavior.

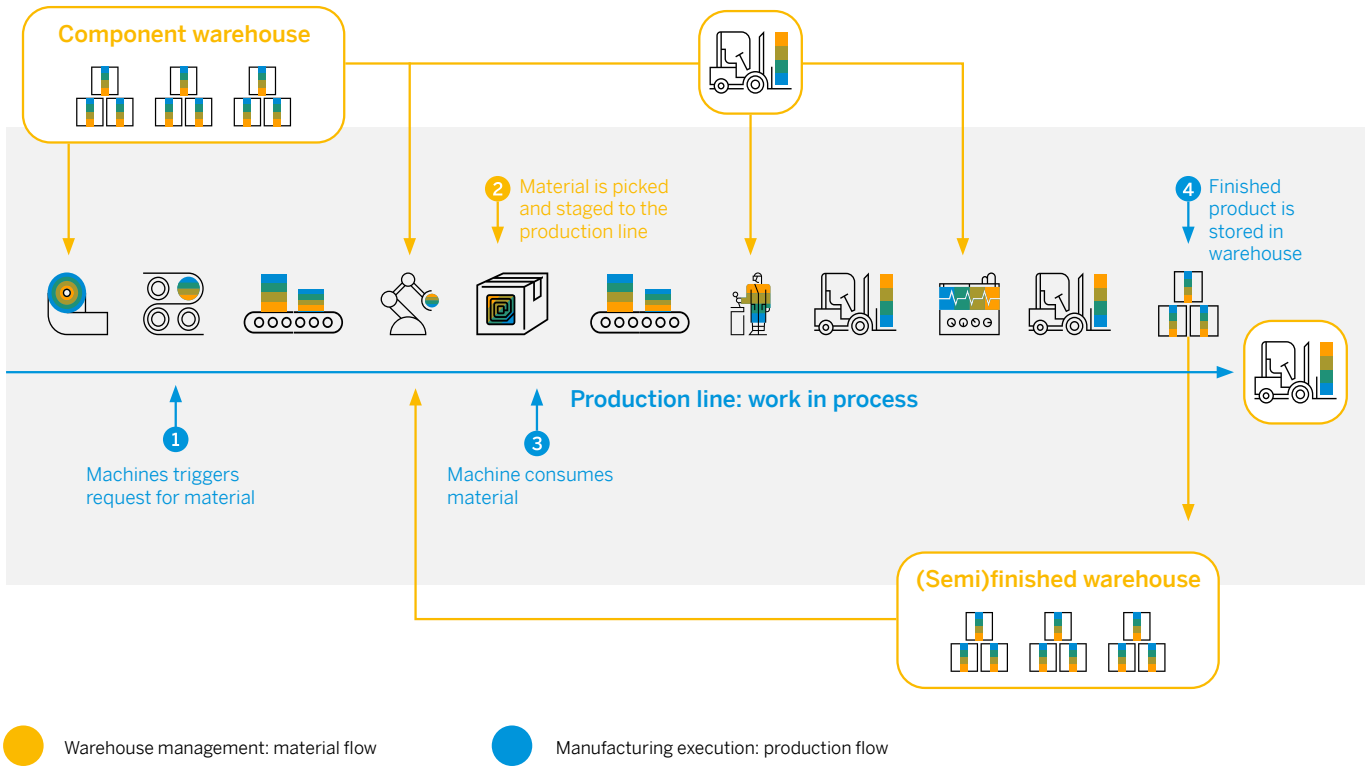
INTELLIGENT FACTORY
A smart factory is agile and adaptable and will support different production scenarios. It is also elastic, able to deal with varying production volumes and to easily support new manufacturing technologies, such as additive manufacturing. The intelligent factory uses manufacturing operations management with predictive and prescriptive capabilities, real-time data, feedback loops with engineering and ERP, and network capabilities for design collaboration.

Typical Industry 4.0 use case examples:
Agile manufacturing to deliver individualized products (lot size 1). Consumers today expect products that are tailored to their needs and wishes. Significant changes are required to manage highly configurable, complex products from engineering to manufacturing, including warehousing and delivery, with same performance and cost of mass production. SAP has a product portfolio with the width and depth to support this end-to-end scenario -starting with the sales process, followed by material and capacity planning in SAP S/4HANA, integrated with the SAP Manufacturing solution, all connected to machines and operators to make sure the product is produced as ordered. All data is collected, helping ensure that the full product history is available when needed. Only with end-to-end integrated systems can manufacturers achieve "desires delivered" at low cost.

Transparent production and logistic operations with automated production supply and execution. Including work in process (WIP) (see Figure 4). To help ensure smooth production material staging, transport between operations (WIP) and put away of finished products are key for higher throughput with minimum inventory and space.

Triggers for staging, transport request for WIP, and putaway are automatically performed by machines, sensors, or manually by the worker. Automated production supply and dynamic, flexible WIP transport across workstations, including warehouse staging, pickup, and put away, is the goal of the SAP solution portfolio.

Figure 4: Production and Logistics Scenario



Intelligent, data-driven quality control. To achieve high-quality, products manufacturers use structured methods like Six Sigma, 8D, and FMEA. Based on this, products are being inspected at various stages in the process chain. SAP solutions like SAP S/4HANA, SAP Digital Manufacturing Cloud, and SAP Manufacturing Suite provide the quality management capabilities needed to define and execute inspections and to analyze various quality KPIs.

When it comes to root cause analysis, it is important to have information on surrounding parameters that might have influenced product quality, such as temperature, vibration, or humidity. Sensor data must be put in context with business information to identify quality-relevant patterns. SAP intends to integrate AI methods into the value chain and production process to continuously learn and improve. Patterns learned through predictive quality capabilities delivered with the SAP Digital Manufacturing Cloud solution are continuously checked during production, and nonconformances are identified early.

Empowered People

Although the degree of automation will increase further, people in the plant will continue to play an important role. Operators will fulfill tasks that cannot be automated – more complex tasks that are often related to decision-making. IT solutions need to provide more support to people with tailored information or recommendations.

Typical Industry 4.0 use case examples with **people empowered by intelligent IT systems** are:

Ad-hoc decision support to manage unforeseen events close to real time. With Industry 4.0, the working environment will change. The degree of automation increases, and operators and supervisors must handle more complex tasks. Unforeseen situations are a challenge, requiring ad hoc decisions in near-real time.

If components are not available in the expected quality, the production sequence must be changed without impacting the most-critical customer orders. The same is true for an unplanned machine breakdown. With SAP Digital Manufacturing Cloud, the supervisor is always informed about the current situation on the shop floor and can react in case of any unpredictable changes. SAP intends to use AI to help the operator and supervisor make decisions faster, taking options into consideration. Access to corporate business data, combined with live data from sensors, assets, and products such as usage data, can help operators reduce delays and response times, and to detect problem sources more quickly.

Workforce protection, days without incident. Protecting your workforce is paramount. By combining IoT-enabled monitoring, geo-fencing, real-time analytics, and integration technology offered by SAP, an intelligent environment, health, and safety system can help prevent incidents by alerting and guiding workers in real time to avoid unsafe areas and tasks in the workplace. Wearable devices can help to inform the worker in any kind of situation. The augmented view becomes a new user experience for providing environmental information to the worker. Supervisors can get real-time awareness of the location and health of employees as well as insight into the environmental conditions around them. They can react in case an employee needs help or guidance.

OVERVIEW OF SAP SOLUTIONS

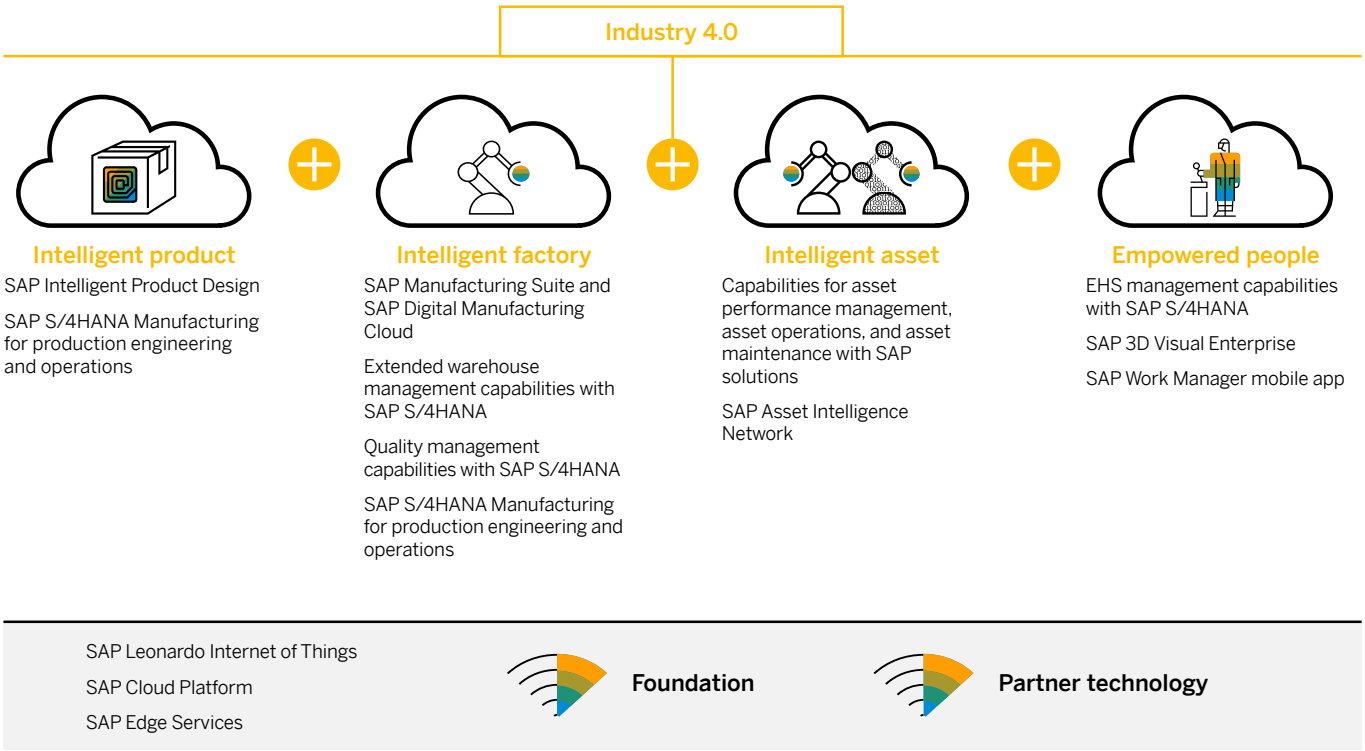
SAP has the broad solution portfolio to unlock the value of Industry 4.0, combining the power of intelligent manufacturing in factories and plants with end-to-end business process execution across the supply chain.

SAP's Industry 4.0 approach combines three business priorities to one leading strategy:

- Focus on customers, so their input and preferences are the source of all you do
- Reinvent production, using intelligent assets and processes that dynamically adapt to changing priorities and deliver customization at scale
- Connect the entire company, orchestrating, sales, service, and logistics with production to transform how you work

Figure 5 depicts current SAP solutions that support the Industry 4.0 themes.

Figure 5: Selected SAP Products and Partner Technology Supporting Industry 4.0 Themes

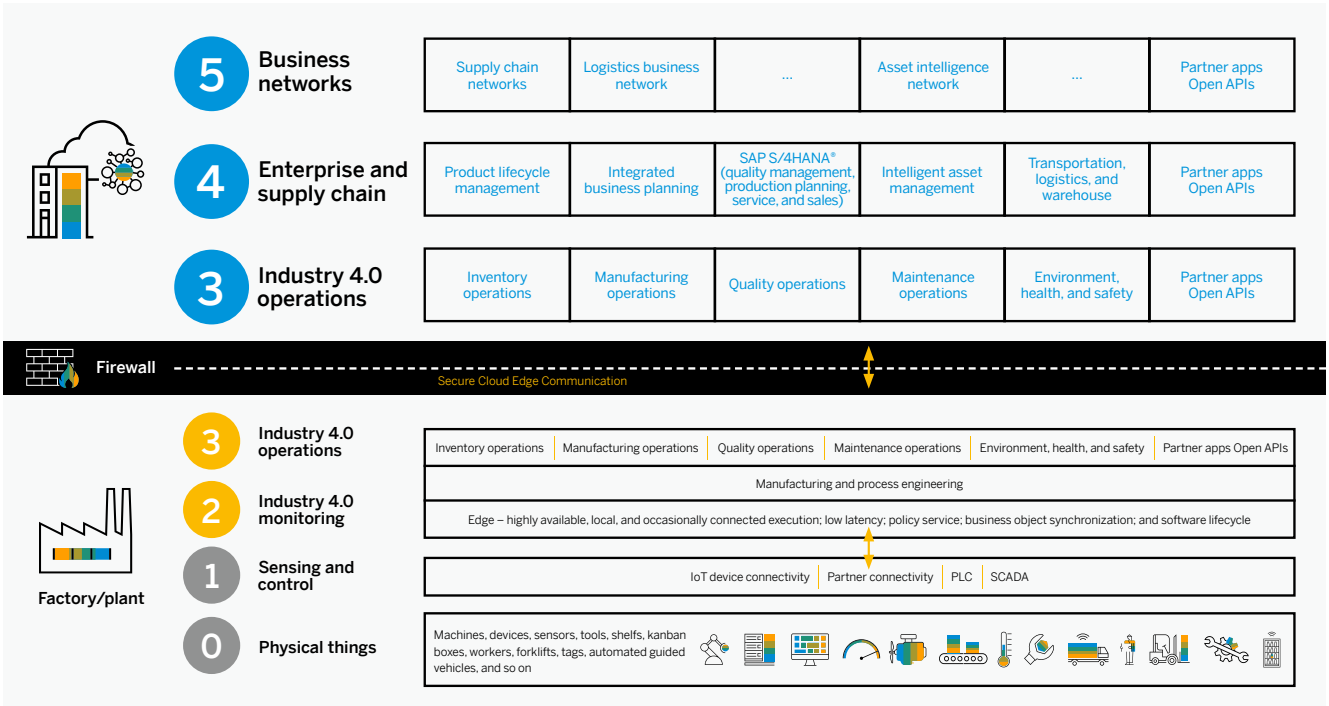


Technically, the solution portfolio consists of SAP S/4HANA as the business backbone, integrated with SAP Cloud Platform, with cloud and on-premise applications that extend the core with innovative Industry 4.0 scenarios and connectivity to devices in the factory. Going forward, the portfolio will be further complemented with additional intelligent edge components that allow resilient production with mission-critical capabilities in the factory.

To address the Industry 4.0 themes and use cases, SAP is building a comprehensive solution portfolio that integrates business processes horizontally and vertically.

Meeting customer demands requires resilient and flexible production capabilities. Manufacturers expect high availability, low latency, and secure operations, requirements that are addressed by the SAP portfolio of on-premise and cloud solutions. For safeguarding mission-critical business processes operated in the cloud, SAP will offer distributed edge capabilities. The edge includes dedicated hardware and software components deployed on the production site and orchestrated centrally from the cloud. Figure 6 shows the target solution blueprint.

Figure 6: Target Solution Blueprint for Industry 4.0



To complement SAP's Industry 4.0 business process capabilities, SAP provides an architecture to support interoperability, integration, and extension. Where needed, standard solutions can be augmented with customer-specific capabilities. This helps tailor processes to individual or differentiating customer needs.

ENABLING FOUNDATION FOR INDUSTRY 4.0

SAP solutions supporting Industry 4.0 follow common principles regarding architecture, security, and standards. The main architecture principles are security, interoperability, portability, openness, modularity, affordability, and extensibility.

ARCHITECTURE

Cloud, Big Data, and the IoT have become key enablers of digital transformation. The technology related to embedding sensors in machines with connectivity to transmit data has advanced tremendously. Furthermore, the cost of sensors and power consumption has dropped, while connectivity has become ubiquitous. The result is that every "thing" – from industrial equipment to plant operations and to every imaginable consumer product – is now **connected and sharing data**. SAP Cloud Platform is an open platform designed to help you innovate, integrate, and extend applications with agility, flexibility, and choice. SAP solutions that support Industry 4.0 are built on SAP Cloud Platform, and you can use integration technology to connect cloud applications with other SAP and third-party cloud and on-premise applications. Thanks to our multi-cloud foundation, you can leverage the latest cloud-native technologies and benefit from major hyperscaler infrastructures. Big Data, SAP Leonardo technologies such as IoT and machine learning enable the efficient ingesting, storage, processing, and analysis of large volumes of device and business data.

An architecture for Industry 4.0 must be able to support dynamic, data-driven production optimization. SAP provides an edge solution for Industry 4.0, extending a subset of cloud capabilities to the edge, close to the source of data. Typically, edge processing means processing near or on the factory floor or warehouse, with connectivity to PLCs, sensors, and automation systems. SAP understands that companies need to integrate SAP applications with data residing in existing data lakes. An example from Industry 4.0 would be to access time-series data in specific hyperscaler services for reading asset information to be incorporated in maintenance processes. With the SAP Leonardo IoT solution, this time-series data can be contextualized with Industry 4.0 business process data such as asset or work order and easily consumed by SAP applications.

SAP will continue to deliver applications and services based on SAP Cloud Platform, specifically the Cloud Foundry environment, making use of modern cloud programming models. An important aspect of cloud applications is microservice architecture and containerization, which is a shift away from a typical monolithic application design with inherent scaling limits toward massively scalable components, allowing for variety of workloads and consistent availability. Container orchestration systems, specifically Kubernetes, will be used to deliver the microservices and development in the area to extend and choose location of execution.

With respect to **application lifecycle management**, all aspects, including orchestration, for both cloud and edge components will be cloud-based. While SAP cloud and edge solutions supporting Industry 4.0 will manage their own components centrally, customers will manage and control updates to their cloud and edge components to ensure updates are not disrupting their business operations. Kubernetes provides horizontal scaling for infrastructure and application development; enables high availability and a common platform from cloud to edge; and facilitates low-latency application access on the edge.

Related to openness, it is important to allow for extensibility throughout the entire architecture, both cloud and edge. An extensible architecture will enable SAP customers and partners to customize and adapt the available software offerings and realize greater business value. Extensibility cover a wide range of areas, including, but not limited to, field level extensibility, user interface extensions, extending standard APIs, and custom, often domain-specific, machine learning models.

SECURITY

The promise, benefits, and value of the IoT have been documented extensively, but with it also comes a whole host of concerns about IoT security. It is not surprising that many of the privacy and security failures in IoT are in the consumer space. The industrial operator can place demands on vendors and make educated choices how to apply security best practices. Our decades of experience in IT and enterprise security have resulted in best practices that can be applied to IoT landscapes.

Depending on where your connected devices are deployed, environmental factors and physical constraints also need to be considered. Given the connectivity of equipment to cloud systems, it is imperative that all communication and access is properly secured using end-to-end encryption. Modern security practices follow a risk-based approach that considers both the ease of an attack and the impact should one happen – giving a strong indicator of how much security you'll need.

Apply proven security technologies, tools, and best practices used in traditional IT landscapes. In many cases, they can be implemented directly: by using digital certificates or equivalent, by restricting what IoT devices can do and which ones they can communicate with, and by adding protection and monitoring mechanisms. Data authorization and identity management are key items necessary to help ensure proper security, since in many cases the underlying processes contain proprietary information and are part of mission-critical systems.

OPEN STANDARDS

In a fragmented market, the promise of standards in smart manufacturing is very important. The transformation of existing machines and assets into the age of networked production is difficult. Open standards are the key to Industry 4.0 success. They enable lower integration costs, faster adoption, and scale and are the only way seamless interoperability between multiple vendors can be enabled. While technical lower-level standards are broadly adopted in a factory today, the higher-level standards that describe semantics, data models, data management principles, part classification rules, and so on have yet to be implemented by most providers.

SAP is an active user, and a major contributor to various industry standards and related open source projects. Our portfolio of solutions for Industry 4.0 supports a wide variety of open standards ranging from technical standards such as Cloud Foundry, Kubernetes, MQTT, and OPC UA up to product classification standards such as eCl@ss and Asset Administration Shell, which supports the digital exchange of product and service descriptions based on standardized data formats.

THE ECOSYSTEM

PLAYERS

The ecosystem supplying owners and operators of factories, plants, and warehouses historically has been highly fragmented, with multiple players playing multiple roles at multiple levels within the factory. Advancing Industry 4.0 requires strong cooperation between ecosystem players. Nobody can do it alone, due to current market fragmentation, complexity of the shop floor, and expectations of digitalization. Figure 7 shows the multiple dimensions of players in SAP's ecosystem for Industry 4.0.

Figure 7: Industry 4.0 Ecosystem Players

For Industry 4.0, SAP orchestrates a strong ecosystem with partners of complementary strengths in the 12 dimension shown in Figure 7. Together with our partners, we deliver Industry 4.0 relevant solutions to the owners and operators of manufacturing sites, plants, and factories. Providers of complementary solutions and services participate in, and benefit from, the SAP PartnerEdge® program.

While covering all dimensions of the above-mentioned Industry 4.0 ecosystem, SAP will be focusing on:

- Partnering with hyperscalers to support customers' desires to reap the benefits provided by Big Data, data lakes, and affordable, cloud-based infrastructure as a service
- Promoting the use of standards, such as OPC UA, and standardization efforts, such as eCl@ss
- Executing innovative approaches with OEMs of factory equipment. Companies in this space are among the members of the Open Industry 4.0 Alliance.

OPEN INDUSTRY 4.0 ALLIANCE

SAP has helped incubate the Open Industry 4.0 Alliance. The purpose of the alliance is to create customer value in factories, plants, and warehouses by **driving agreed-on compatibility and interoperability** within the IT/OT infrastructure. This will enable owners and operators of factories and plants to ultimately pay less for connectivity and integration, allowing them to spend more on Industry 4.0 related value.

The alliance creates guidelines for interoperability of IIoT or Industry 4.0 solution components based on existing standards, using best practices where standards are missing. Members of the alliance provide Industry 4.0 or IIoT-relevant modular solution and professional service offerings that are compliant with the guidelines of interoperability.

The aim of the alliance is to create a "yellow pages" of the members' offerings, products, and professional services that are compliant with Open Industry 4.0 in order to provide companies with a broad range of interoperable components that differentiate in their feature and functionality rather than on proprietary interfaces. With this, it is intended to cover up to 80% of the shop floor of our customers and ease connectivity and integration on the OT and IT levels in the Industrial IoT solution stack.

This initiative was started in the German-speaking region, with a plan to expand to Europe, followed by North America, and then worldwide. With more than 40 members today – and open to new members, the Open Industry 4.0 Alliance will continue to grow.

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