THE PRINTED CIRCUIT ASSEMBLER'S GUIDE TO...™

Advanced Manufacturing in the Digital Age

2nd Edition

Oren Manor

Siemens Digital Industries Software

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The Printed Circuit Assembler's Guide to...™ Advanced Manufacturing in the Digital Age

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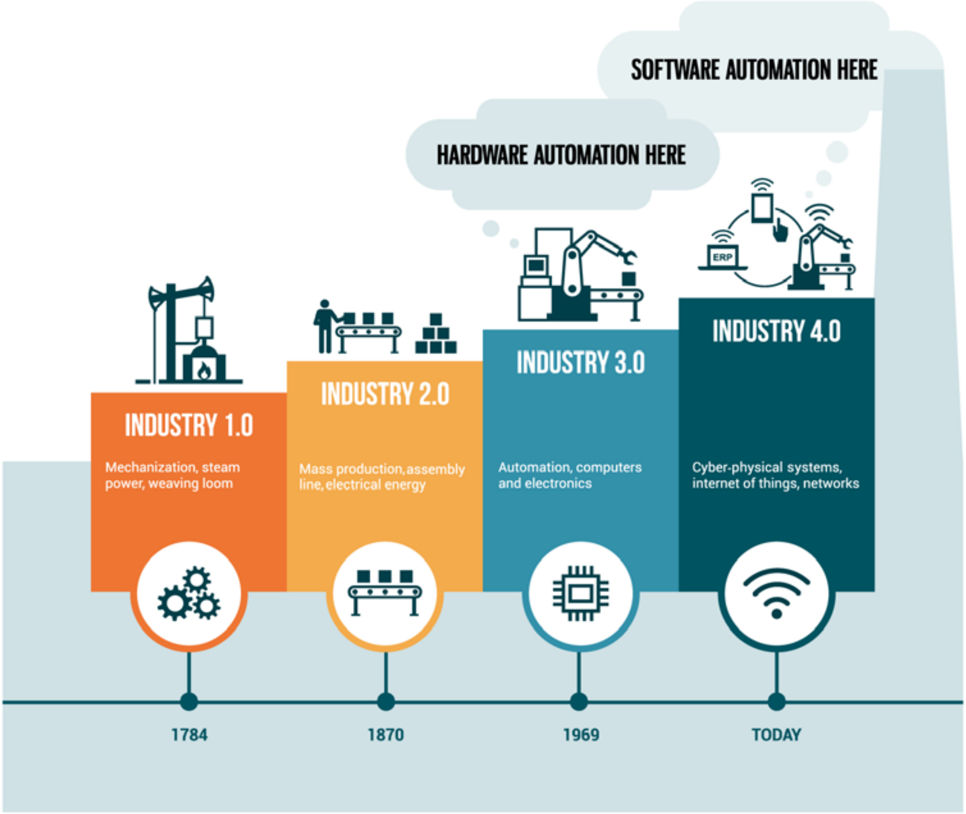
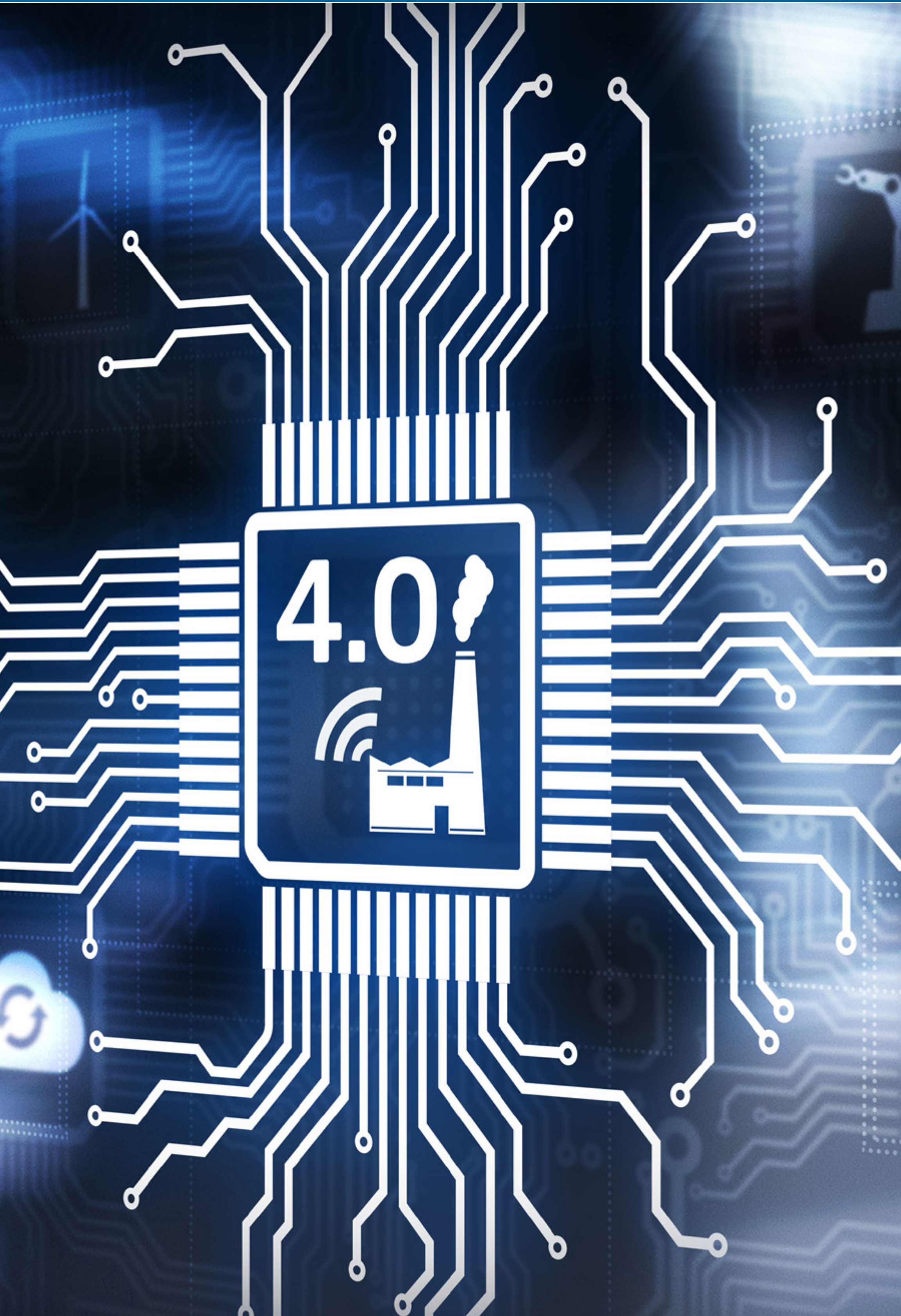
Introduction

As manufacturers continue to innovate effective solutions to today's demanding market trends, digital solution providers need to continue to leverage new and emerging technologies—such as IoT, the cloud, and augmented and virtual reality devices—in support of optimized productivity. In "Is This a Manufacturing Revolution?" Siemens Digital Industries Software imagined what a PCB manufacturing operation converted to Industry 4.0 would be like and discussed the challenges in the journey to get there [1]. In this book, I will look at advances since then, how things have changed in the electronics manufacturing industry, and what are some of the most important steps to consider when building a digital manufacturing company that transforms Industry 4.0 concepts into reality.

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Chapter 1

Evolving Data Management and Analytics

The foundation of a smart factory is data, and today's factories are data-rich environments. No matter what size the operation, if manufacturers can emulate the technology giants and use analytics to make the most of their data, they can get further value out of the transformation to Industry 4.0 (Figure 1.1).

Tony Hemmelgarn, president and CEO of Siemens Digital Industries Software, explains that by 2025, "We'll have to cope with 100 billion connected devices, each with a dozen or so sensors collecting data. You must have smarter products and intelligent manufacturing, all producing data, which ironically creates a much more complex world that we have to deal with."

The competitive advantage is no longer about the assembly process or discrete equipment selection, but it is about creating a smart factory that is able to convert these vast amounts of data into actionable and meaningful intelligence in real time. Manufacturing operations must be agile enough to use it to meet market demands that are in a constant state of flux.

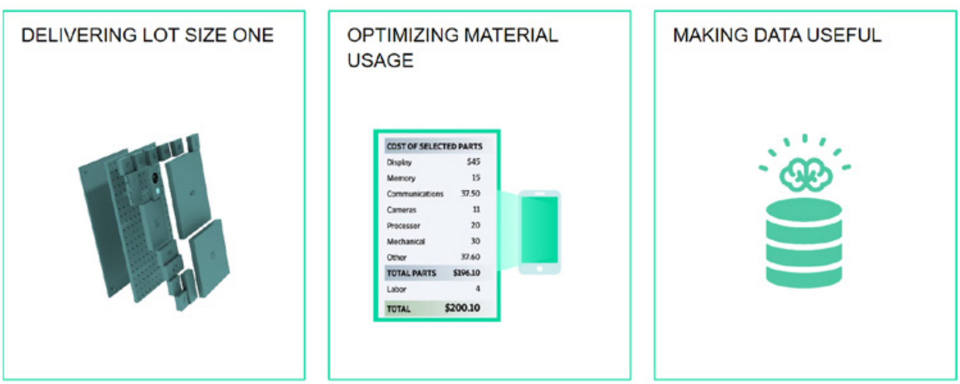

Figure 1.1: Trends driving change in electronics manufacturing.

As we have learned, more data does not necessarily lead to clearer insights and better decision-making. Access to masses of data can actually result in people and artificial intelligence (AI) systems drawing wrong conclusions or seeing connections between factors where none really exist. “Studies have shown that many of the correlations are just flat-out false; they don’t make sense,” says Hemmelgarn.

But that does not mean that big data should be avoided; it just needs to be managed and interpreted better and smarter. As a business, you want to move faster than your competition, lower development and production costs, respond to customer demands better, and create new business models to out-innovate the competition. The next step is to figure out how to use the complexity of all this data, and the many data points in your operations, as a competitive advantage.

Some of that data will be processed in the cloud, some at the edge, and some directly on a chip or a specific piece of equipment. Each of these areas will be examined. But the biggest challenge for each business is to make sense of all of the data they are gathering. Analytics based on that data are still being defined. The decision about what data points to monitor and collect is important to avoid drowning in unnecessary and irrelevant datasets.

The volatile, rapidly changing markets and consumer demands we see today are just the beginning of what will define the state of technology in the future. Right now, what is defined as “the edge” and “the cloud” as well as the interactions of all of these components that drive those systems—including quality, performance, and price—is in its infancy [2].

The big data market is also shifting. Companies have gone from putting either nothing or everything in the cloud to using a more strategic mix of storage and processing. They are rethinking what to keep local versus what to ship to the cloud, and how data analysis can benefit their business. This process is squeezing out middle-market players and changing what gets shared, how that data is used, and how best to secure it.

This upheaval has broad implications for the whole supply chain. On the one hand, more data is allowed to move freely between different vendors, no

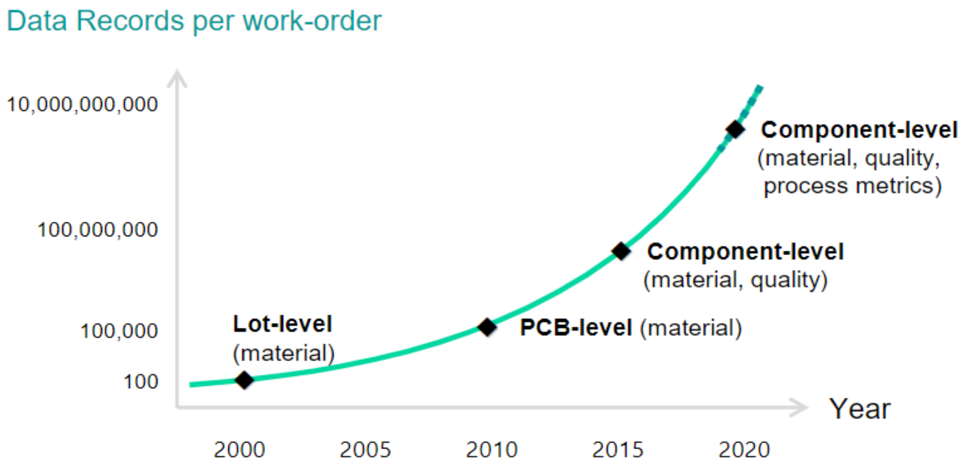

Figure 1.2: Manufacturing data availability.

matter where they sit in that chain. That can go a long way toward improving the quality of chips and systems, reducing the cost of design and manufacturing, and shedding light on supply-chain constraints (Figure 1.2).

Manufacturers today are managing a highly complex supply chain. Traceability is a requirement. People want to know what set of tools the product or system was assembled on, and how many people may have seen a similar problem. Data analysis can help offset these concerns about liability, especially in markets where safety is a huge concern, which is a gating factor to adoption and purchase, such as for automotive, medical, and mil/aero.

The key to avoiding problems is to analyze all available data intelligently, particularly in critical areas. This means collecting much more data than in the past and analyzing it with insight and experience about what can go wrong and what really matters if it does go wrong. John O'Donnell, yieldHUB's CEO says, "There needs to be continuity in that data. New customers want 15 years of data storage, which is a big change from the previous one or two years of data currently being stored. You'll see this with machine learning and AI next, but the challenge here is that some data can be very messy." [2] And some OEMs require data for longer than 15 years.

Chapter 2

Cornerstone of Smart Manufacturing: The Convergence of IT and OT

The foundation on which data management and the resulting analysis needs to be built is information technology (IT) *and* operational technology (OT). For Industrial 4.0 to be turned into a reality, an alliance of IT and OT has to happen. Smart manufacturing cannot exist without this cornerstone.

Few business functions are hit harder by digital transformation than IT and OT. Traditionally, these departments have operated in isolation from each other, but for digital transformation in the factory to occur, they have to align. People can resist this kind of fundamental change to the way they do their jobs, but if IT and OT employees can see how their departments benefit from aligning their processes, everyone in the company can move forward. Manufacturers can start embracing Industry 4.0.

A factory is like a living organism with many different parts to it; materials, machines, and the people and the systems that they use to do their jobs. If IT and OT were sharing real-time data to make better business decisions, predict customer trends, and remain ahead of the competition, this would result in improved manufacturing processes, which leads to higher production performance and lower costs (Figure 2.1).

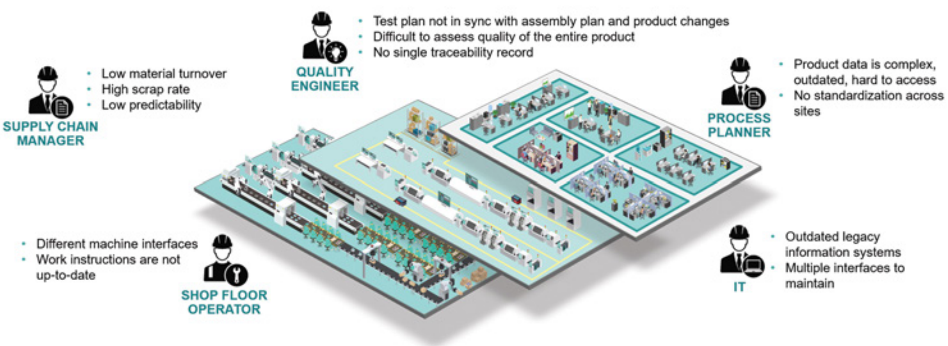

Figure 2.1: Challenges holding organizations back from realizing the benefits of Industry 4.0 initiatives.

Strong leadership from key stakeholders in the company can ensure that both IT and OT collaborate, providing them with best practices and tools to use can help the company make better products [3 & 4]. Enterprises often underestimate the complexity of this convergence. Priorities for what the company stands for and what it wants to achieve has to come from leadership. It is the duty of top-level leadership to adapt and bring about this paradigm shift to create an atmosphere of total collaboration between IT and OT. With senior-level buy-in and commitment to adoption, the two departments can be empowered to pull in the same direction with the right technology and access to the data they need. If this cannot be done, the company will not survive the digital transformation.

IT has often been seen by enterprises as a cost center, and they are not involved in the day-to-day operation or long-term organizational plans. Their role has been limited to a reactionary role responding to company needs as they arise. This is not going to work in today's market because business needs require a proactive team that can anticipate needs and is ready before the need is imminent.

For Industry 4.0, management should see IT as one of their biggest assets to achieving their business goals. Leaders need to understand how to optimize the entire manufacturing process to achieve their goals. IT and OT managers (CIO and COO) need to have in-common and overlapping goals and targets that they have to work together on. One suggestion is to create a joint task force—if not a specific department—with joint governance and responsibility that executes projects, harmonizes duplicated or overlapping systems and processes, and promotes developing interdisciplinary skills missing in most companies. This cultural shift requires time, effort, and a progressive plan and is the greatest challenge for leadership.

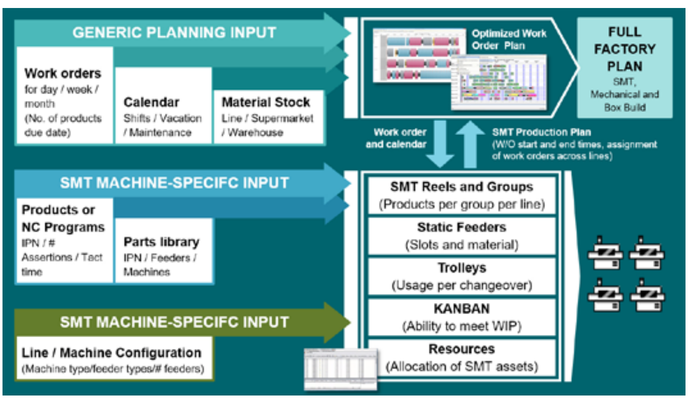

Figure 2.2: The connected factory enables accurate, combined, and optimized production plans.

After having put the joint organization in place, simple pilot projects that offer tangible value and a low-risk benchmark for the company can provide a good opportunity to train people progressively to develop a mix of IT/OT skills. These kinds of initiatives also help managers learn to share goals and develop a new shared governance model de facto. Effective governance for IT/OT projects can be underestimated. IT typically has stronger models than operations for managing projects, but they cannot be applied to OT simply as is. Cooperation means adapting those models for use in operations while considering the different impacts of projects and different cultures.

Challenges Faced by OT

Some of the specific challenges for OT are using multiple versions of software or firmware; upgrading hundreds, thousands, or even millions of devices to new firmware versions; and ensuring adequate testing and quality assurance before production rollout. OT now must keep up with the rapid increase of networking features, capabilities, and standards. These changes are introduced at a fast pace to an IT industry exploding with new mobile communications, consumerization of IT, virtual desktops, cloud computing, and new computing/communication platforms, such as tablets and smartphones.

Not only is OT faced with this convergence with IT, but the traditional methods for the development and management of industrial applications also have to adapt to the increasing complexities of systems. Ad-hoc approaches to scope, architect, design, build, and maintain operational systems in groups of silos are no longer feasible and will most certainly not lead to success.

And the roles for industrial engineers and ICT professionals are changing. Developing complex systems now requires rigorous system engineering methods and formal lifecycle development processes. Modern control systems require significant expertise in embedded systems and security to architect, design, build, and maintain. Industrial applications require a multidisciplinary approach involving subject expertise, software, computing, and communications. Operational effectiveness requires integrated business planning, portfolio management, project delivery, and ongoing operations governance.

Of all of these challenges, one of the most critical is security. Security breaches and cyberattacks in IT/OT components and systems can lead to devastating consequences, such as power failures, blackouts, and loss of confidential information and documents. Continuous efforts to devise adequate policies, procedures, and culture throughout the organization are necessary to overcome and avoid these challenges.

Chapter 3

Security for IIoT

One Gartner report says 80% of the security issues faced by OT are almost identical to IT, while 20% are unique and cannot be ignored. The similarities are a result of the adoption of IT technologies by OT over time. Further, Gartner's definition of OT security is "practices and technologies used to (a) protect people, assets, and information; (b) monitor and/or control physical devices, processes, and events; and (c) initiate state changes to enterprise OT systems [5].

Many of the concerns of OT security are the same as IT security, particularly in areas such as the network. As we converge IT and OT and create more digital tools and systems for the smart factory, IT security and security platforms are increasingly overlapping into OT environments. This is a necessary process but also introduces risk, bringing some of the IT security "sins" of the past into the OT environment.

However, unique requirements in OT will continue to require special approaches to security. We can look at OT as a subset of IoT—the "industrial internet" or "industrial IoT" (IIoT). OT is the "first generation" of IoT specifically designed for industrial use, often in long-term deployments. Its endpoints are embedded in industrial environments, aircraft and automobiles, assembly lines, and airports. OT and IoT share many of the same underlying components: sensors, actuators, meters, machine-to-machine communications, and embedded systems. However, OT historically has had a different level of security—the mechanical origins for many of its systems, whereas IoT is rooted almost entirely in digital architecture. But this is changing as OT systems become primarily digital.

Security decisions will be affected by OT and IoT similarities and differences and how the components are used to build them, arranged in various ways for different industrial, commercial, and consumer solutions. Vendors will be crossovers in the OT and IoT worlds. We already see mixed OT/IoT scenarios in telecommunications and multimedia areas as well as autonomous vehicles. Remember that not all security scenarios for OT apply to IoT and vice versa.

Regulatory uncertainty and global concerns about the security of OT systems around the world are fueling the interest in OT security solutions. These concerns are even more urgent than the more nebulous, generalized concerns about securing IoT because many OT environments have direct, immediate impacts on people and the environment. OT failures literally have the capacity to kill or maim people and cause severe environmental damage.

Chinks in the Foundation of OT Security

OT components may not have basic IT security requirements when they are built, focusing instead on achieving functional goals. Thus, these components may be insecure by design and vulnerable to cyber-attacks. Most companies heavily depend on their OT vendors because of the general lack of knowledge related to industrial automation. This situation leads to vendor lock-in, which erodes the ability to implement security fixes.

"Most companies heavily depend on their OT vendors because of the general lack of knowledge related to industrial automation."

With an important role in monitoring and controlling industrial processes, OT systems are part of critical national infrastructure and require enhanced security features. Thus, close cooperation between IT and OT departments is necessary for change and incident management as well as security standards development and implementation. Today's factories are full of smart equipment connected to the enterprise network infrastructure, thus opening many back doors to potential cyberattacks.

“Digitalization helps us to control the process and be quick and ready to change from one order to the other, compared to programming the machine manually.”

– Alessandro Ballabio
Production Engineering Manager
ROJ s.r.l.

Chapter 4

Cloud and Edge Computing

The cloud plays a huge role in Industry 4.0, especially in data processing and storage, quality control, and manufacturing execution systems. The amount of data to be stored and processed requires large storage and server facilities that are expensive to build and maintain. Gartner predicts the worldwide public cloud service market to grow at a compound annual growth rate of 12.6% by 2022 to $331.2 billion. Applications that manufacturers rely on (e.g., business intelligence, supply chain management, and enterprise resource planning) will see the highest spend on software as a service (SaaS), reports Gartner.

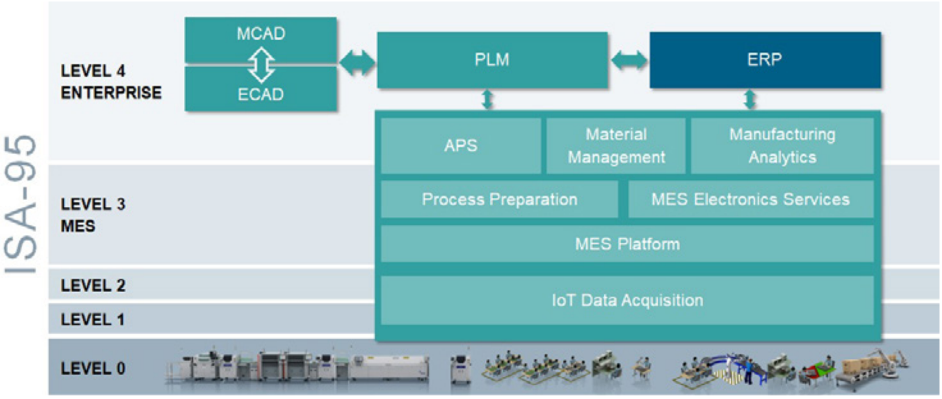

Figure 4.1: Smart factory hierarchy.

So, what can you do with IoT-specific services (network-based services that interact with an internet-enabled device) in your operation (Figure 4.1)?

- Provide IoT-specific connectivity
- Remotely provision, monitor, manage, and control devices
- Provide IoT user or device security services, such as authentication, authorization, data encryption, and malware detections/prevention

- Remotely update device firmware and software
- Receive data from environmental or subject sensors that generate data about the device's subject, such as medical patient data rather than about the device itself
- Store and manage data from IoT devices
- Use dashboards to summarize device, environmental, and subject data (IoT-collected data)
- Provide analytics and diagnostics based on IoT data
- Provide maintenance services based on IoT data
- Provide functional services or trigger actions based on IoT data
- Provide device as a service (DaaS) where customers pay for usage or functionality of an IoT device rather than buying or leasing the device
- IoT services can be layered on top of existing devices, machines, and networks to improve product quality, increase equipment uptime, and reduce equipment maintenance costs

Siemens MindSphere—a cloud-based, open IoT operating system—enables these applications. First, data defined by the customer is collected and transferred. Then, the data is analyzed, and the information relevant for optimization is made available as recommendations for action. Because MindSphere

Figure 4.2: Digital twin applications in manufacturing.

is an open IoT operating system, it is possible to obtain data from industrial devices from a wide variety of manufacturers, no matter the brand. Moreover, MindSphere provides customers and developers with the capability to develop applications and digital services, apply them, and make them available to other people. In this way, new service and business models are possible (Figure 4.2).

Even if a company is not yet ready to use enterprise cloud solutions, experts recommend ensuring that any new equipment purchased is outfitted with sensors and internet capability so the equipment can be connected later. Cloud-based solutions offer manufacturers cost-effective data storage and data security as well as services such as enhanced analytics, machine learning, and insights around operational efficiency. Now, manufacturers can leverage high-performance computing offered by cloud services to support their digital transformation. However, cloud computing also carries risks. Relying on cloud-based solutions for mission-critical activities within the factory leaves the operation vulnerable if the internet fails.

Thus, businesses are looking to mix in edge computing—an on-premise network—to their data-management strategy. For manufacturing, this is the software and hardware inside of the factory that is close to the data source, typically on a device within the factory's own network. Maintaining real-time analytics on-premise means that manufacturers will be able to access accurate data on the performance of their operations and make business-critical decisions without relying on the cloud to keep going at least until cloud access is restored. For example, if a manufacturer uses cloud computing for applications like SaaS or infrastructure as a service (IaaS), losing these functions temporarily will not affect the business if critical applications are retained on-premise.

Another benefit of edge computing is its speed. When working on the edge, data only needs to travel a short distance. This enables mission-critical data to be processed as fast as possible, avoiding any machine-based latency issues around real-time activities.

The cloud is important for manufacturers to manage huge amounts of their data efficiently and effectively as well as provide access to an incredible array of services that empower Industry 4.0. But if a loss of access to the cloud leads to productivity and change management issues because operators need to switch back and forth between analog and digital ways of working to keep the operation running, they are likely to lose confidence in the company's digital transformation ambitions.

> **"A hybrid cloud-edge strategy enables manufacturers to gain maximum value with minimum risk."**

A hybrid cloud-edge strategy enables manufacturers to gain maximum value with minimum risk. Working with a vendor who can provide a hybrid strategy allows manufacturers to get the best of both worlds, leveraging the cloud for storage, heavy processing, and complex analytics while maintaining mission-critical operations on the edge.

As with OT and IT, security is an important consideration for a company's data-management strategy that includes cloud and edge computing to enable Industry 4.0. Before deciding which supplier to work with, each vendor's security credentials need to be rigorously checked. Manufacturers should ensure that technology vendors implement end-to-end encryption with strong encryption keys along the entire value chain to protect critical production data. A vendor's encryption must be up to the appropriate level of standards that spans from cloud to edge computing because bad actors can track the vulnerability of data throughout the network, and low-bit encryption can be cracked easily.

How vendors conduct their security updates and patches is also important because required updates are inevitable. Manufacturers need to ask their vendor what the process is for finding and fixing vulnerabilities, and how they communicate those essential updates to their customers. IoT devices should also be segregated from the company's main, general network. Larger networks are exposed to more vulnerabilities, so separating IoT devices guarantees that nothing on the wider network can interfere with the data collected on those devices.

Many people assume that cloud computing is less secure than managing data on-site. However, a serious security compromise can stem from the smallest of issues. For example, many manufacturers run older Windows computers without up-to-date security. By using these older machines, they are essentially opening the door to hackers who want to access the enterprise network. Good network security is closely related to physical access. After all, in an on-site server room with little or no security, anyone could gain access, pop in a USB stick, and steal sensitive information.

Cloud vendors store data in locations often removed from large population centers that are locked down with security guards and numerous physical barriers between any would-be hacker and the target server. The cloud offers more network resilience. Businesses that rely on on-premise servers face exposure and operational risk during an act of force majeure, such as a fire or natural disaster. With the cloud, that risk is spread over multiple secure locations, significantly reducing the chance of disruption.


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Chapter 5

The Foundation of Industry 4.0

At its basic level, an IoT device can be defined as any stand-alone internet-connected device that can be either monitored and/or controlled from a remote location. Each company using an IoT solution will also be building an IoT ecosystem, which is the foundation of Industry 4.0. This ecosystem is comprised of the components that enable devices to connect to the internet, such as remotes, dashboards, networks, gateways, analytics, data storage, and security—both software and hardware. One of the most valuable aspects of such an ecosystem is to be able to take the silos of information collected, analyze that information, and then optimize processes across a company's systems to become more efficient.

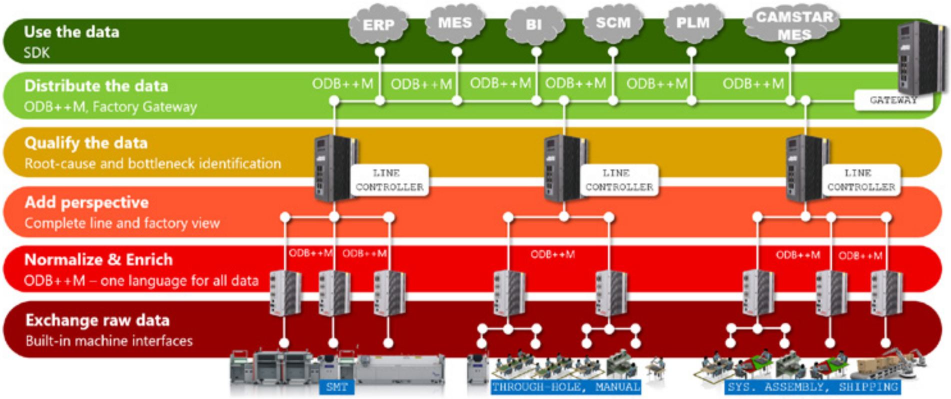


Figure 5.1: Big data flow.

When adopting IoT solutions, start with three main considerations [6]. First, assess which parts of the production cycle can be automated and/or monitored most effectively with IoT devices connected to an analytics platform. IoT technology should be matched to the production cycle of your operation. Many categories of manufacturers throughout the world are producing unique goods across different industries. IoT solutions that work for some manufacturers will not work for others. Analyze all of the various digital technologies available and see which fit into your particular production process.

Second, assess ways in which solutions could improve the work environment rather than focusing solely on the return on investment (ROI). Instead, focus on implementing IoT solutions that make the manufacturing process more streamlined for your employees, even if it returns a minimal ROI or an initial increase in the cost of goods produced.

Third, be prepared to work with multiple IoT system providers. Few companies offer full-scale IoT solutions for manufacturers. However, divisions within major IoT providers can help each manufacturer integrate their IoT solutions with solutions from other vendors.

Building on the Data Flow Layers: From Manual to Digital

When considering a data-management strategy, you can examine your data flow as moving in four levels [6]. Industry 4.0 means going from level one and building to level four.

The first level is the data that is available, which is the status quo for many companies today. Data is available but difficult to use to make decisions or implement improvements. The data is in siloed systems and often requires manual work to integrate and translate into useful information. Problem-solving at this level is possible but extremely time-consuming. When a product quality or machinery issue arises, operators and engineers must scramble to gather data from various systems before they can decide what happened and how to fix it. This approach drains time, resources, and money from

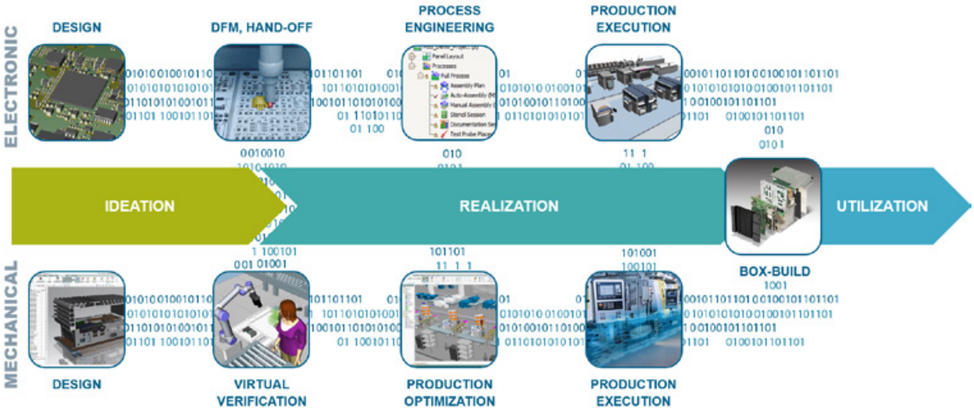


Figure 5.2: Digitalizing the entire manufacturing process.

the factory. Manufacturers at level one should move to level two as soon as possible or risk wasting millions of dollars in lost production output from unplanned downtime each day.

Level two makes the data accessible. A level-two data-management system integrates all of the disparate information sources into one single source of truth and continuously gathers and tracks production data. With the data in one location and always available, problem-solving becomes almost frictionless. When an issue occurs, operators and engineers can access the data in the system using data visualizations and dashboards, essentially leveraging the system as a query engine. With easy access to all the data, they are able to answer questions quickly, increasing plant productivity.

A level-two data flow allows engineers to address high-value issues that improve the product, conduct more efficient materials changeovers, or adopt a mass customization strategy. However, this reactive—and somewhat proactive—analysis still requires time, effort, and engagement from engineers.

> **"With the data in one location and always available, problem-solving becomes almost frictionless."**

To move from level one to level two, manufacturers must implement a new data architecture, which usually takes less than a year. To do this, you need to evaluate whether to build your own system or select the right solution providers and partners. Also, when selecting a new architecture, make sure it allows you to scale the amount of data you can collect without paying higher marginal costs or sacrificing system performance.

At level three, your data is active. A level-three system shifts manufacturing operations from reactive problem-solving to proactive analysis and improvements. The system enables operators and engineers to be truly preventative and proactive in solving problems.

To move from level two to level three, new system capabilities—such as machine learning and AI—are added to the previous level's data architecture. These new tools allow you to start generating insights in as little as two or three months, depending on your product mix. Built onto the level-two system that aggregates all your production data, these new features create an intelligent system that finds valuable insights and predict failures more accurately on its own while delivering information to the appropriate person at the right time. Engineers do not have to query the system or perform manual process analysis to find the answers to solving production issues.

An example of level-three system attributes includes machine-learning models that predict product defects or machine failures and identify ways to produce products more efficiently. In a level-three system, a person is still needed to make the changes that the intelligent system recommends.

Level four is when your data becomes action oriented. At level four, the data system deploys the recommendations that it finds from analyzing manufacturing data. For example, a machine-learning model will identify an optimization, then generate and send the recommended new settings to the machine where it is automatically executed. In such a closed-loop, AI-controlled production line, the time it takes to execute on an insight discovered by the system becomes minimal.

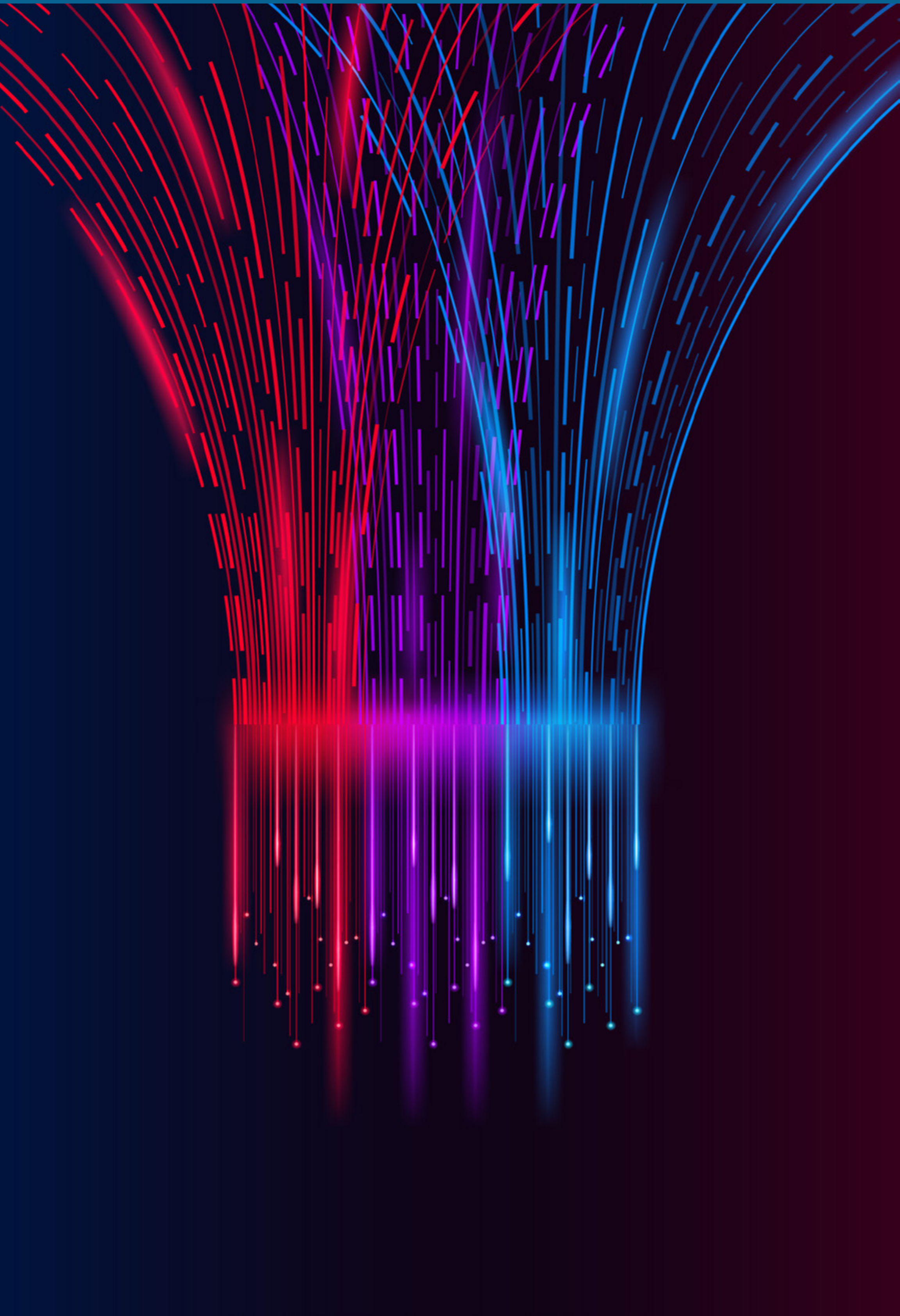
"A systematic approach allows manufacturers to progress realistically."

Achieving level four requires datasets that are large enough and have enough validated cases to provide the information needed for the system to "know" the effects of a production change. The time needed to move from level three to level four varies based on the amount of time it takes to gather the necessary datasets.

Looking at building a smart factory in these four stages is helpful when making such a fundamental, and even monumental, change. No shortcuts can take a manufacturer from level one to level four. Those that have tried find their systems have so much process and data variability that they quickly become mired in complexity; they built on an unsound foundation with weak construction.

The level three and level four manufacturing-management systems of Industry 4.0 require a huge amount of data, which can only be generated and made useful in level two. A systematic approach allows manufacturers to progress realistically. In the earlier levels, you learn more about data systems in general and the data needed for your specific processes. You begin to amass the datasets necessary to enable the system to identify and execute production-process improvements based on data. With this methodical approach, manufacturers can implement digital transformation more quickly and with less frustration.

Throughout every level, process traceability is crucial to maintaining an accurate history of changes that results from smart machine learning and machine-to-machine communication, contributing to the dataset that can lead to a greater understanding of the implications of change.



Chapter 6

The Building Blocks for a Digital Thread

Representations of real-world products and processes become a digital thread that moves information through design to manufacturing and out into the field. In a smart factory operation, people and machines are able to use this digital thread to provide feedback in a continuous flow of information. Languages that can communicate from people to machines as well as between machines and processes facilitate the data flow; they are the building blocks for a digital thread.

A set of factory data initiatives developed by Siemens engineers over the last decade in product and process engineering and shop-floor data control enables the inclusion of all machine vendors and solution providers, while addressing the needs of manufacturers, in the transformation to Industry 4.0.

First came the product model specification ODB++Design that is used to digitally package and transfer all of a product's design information to manufacturing, then the OML (open manufacturing language), later renamed ODB++Manufacturing, that makes it easy to build etc.

Each of these communication elements is designed to be neutral, open, and available to all machine vendors, software vendors, and manufacturing customers so that they can be used to build a digital transformation.

With these tools, the manufacturing data flow now looks like this:

- ODB++Design enables full-product design-data representation created by design tools and used for design for manufacturing, fabrication, test, and assembly analysis; it is the single digital vehicle for design data to be passed to electronics assembly and fabrication.
- ODB++Manufacturing is the communication specification that is used to represent all shop-floor events bi-directionally between machines as well as between machines and smart-factory software solutions.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Chapter 7

Gateways, Networks, and Platforms to Achieve Industry 4.0

To help you build the infrastructure needed for your smart factories, networking systems, gateways, and software platforms are available that automate data collection from machines and applications and transform that data into immediately useful information. This technology turns the tedious but critical process of extracting insights from data into one that is instantaneous, streamlined, and achievable for every manufacturer. These solutions are an integral part of the total digital transformation at every level of the manufacturing operation. Some have been around for years, some are being improved for Industry 4.0, and others are still in development.

You all know what a computer network and software platforms are. Another essential part of the connected factory is the gateway. A gateway is a compact, flexible class of hardware platform that enables communication between end-devices in the field (e.g., actuators, sensors, etc.) and the cloud/internet with added functionality, flexibility, or ruggedness of an embedded industrial computing device (computer). Gateways reside on the edge of wired and wireless networks, which does not include small office or home computers and networks.

Intelligent gateways are an emerging subset of the gateway that can be field-programmable and include a software platform that is hosted either locally on the device or via the cloud to readily facilitate creation/deployment of new apps/services including those from third parties. The majority of industrial gateways must support Ethernet and serial connectivity to enable brownfield networking as connected-factory customers look to connect legacy embedded control and robotics systems to IIoT services apps. Siemens SIMATIC IoT is a gateway device that provides an intelligent interface between machines and factories to collect, analyze, and transfer data to IT systems and the cloud (Figure 7.1) [7].

Figure 7.1: Siemens SIMATIC IoT gateway from machines to networks and the cloud.

The Opcenter Execution Electronics IoT Solution is a networking platform that includes the fully configurable ODB++Manufacturing as well as some pre-coded software, which combines the hardware and software needed to enable an electronics factory's IoT manufacturing system. The system enables the gathering of live information from the shop floor by combining data acquisition and normalization in a single piece of hardware. Within the hardware, embedded software is included for advanced interfaces to SMT machines as well as related equipment such as test and inspection machines. Also, the system includes a wide selection of hardware interface ports, providing a single connection solution on a "plug-and-play" basis to virtually every machine on the shop floor.

Opcenter Execution Electronics IoT takes care of selecting the correct physical communication parameters and applying the correct protocol. Then, it automatically acquires the data and converts the various patterns of data coming from the machine into a standard normalized format represented with ODB++Manufacturing. This combination creates a platform in which any machine can be connected that will work without modification or specialist setup (Figure 7.2).

Built for the factory environment, its rugged construction ensures reliability in physically demanding places and susceptibility to dust, heat, or vibration.

Each unit has a backup power supply to actively detect power outages, record them correctly, and then initiate a controlled shutdown. The series of machine events and associated data is retained within each Opcenter Execution Electronics IoT for as long as three days so that data is not lost in the event of end-user systems or networking issues. The device is robust and resilient to error, and it can be relied on for the most sensitive and demanding applications.

As well as providing the data acquisition and normalization function at each machine and shop-floor process, Opcenter Execution Electronics IoT provides a distributed processing architecture. An Opcenter Execution Electronics IoT System Processing Unit (SPU) can act as a line controller, coordinating the data from many other units attached to machines and processes on the production line. In addition, a unit can be used as a factory-floor gateway that manages the connections between the enterprise applications that use ODB++Manufacturing data and the sources of data from the machine connections.

Figure 7.2: The Opcenter Execution Electronics IoT System Processing Unit (SPU) functions as both a factory gateway and a line controller.

This infrastructure, independent from the generic factory networking system, supports many thousands of simultaneous connections, offering a high degree of scalability. The architecture is designed to cope with many parallel real-time flows of huge data volumes, eliminating potential networking bottlenecks and connectivity issues. This is done by the establishment of point-to-point connections that are managed by the gateway, such as Siemens SIMATIC IoT. For example, a test machine may create huge test result files, which could include several high-resolution pictures and a long set of diagnostic results. This large dataset can be automatically routed to a dedicated server that deals with the specialist storage of the information, perhaps as part of a “big data” cloud solution without affecting the real-time performance of the infrastructure as a whole.

The Opcenter Execution Electronics IoT gateway has visibility and control of all instances of the line controllers and the different interface connections that are supporting equipment within the line. The Valor interfaces are capable of supporting a wide range of line equipment in addition to the machines, such as fixed scanners to read unique IDs of PCBs as they arrive or leave a process so that product work-in-progress (WIP) and enforced routing control can be implemented.

Hand-scanners can be connected for material verification or system serial-number scanning. Further, sensors can be placed on the production line equipment or within the machine—such as in light towers or conveyers—to capture knowledge of events where machines are unable to provide the necessary detail through the proprietary interfaces. Through this flexible infrastructure, the connection can be applied to whatever data acquisition task is required (Figure 7.3).

Figure 7.3: Hand scanners, in addition to in-line sensors, can be part of real-time smart manufacturing.

Enterprise applications access the information through the supplied software development kit (SDK). Each of the varied applications—whether a part of an Industry 4.0 or smart-factory computerization, MES, ERP, a Lean supply-chain solution, or a production flow control computerization—will need only one format and source of information that includes data from the whole of the shop floor, all of which is coordinated through the gateway.

In addition to data acquisition, the Opcenter Execution Electronics IoT SPU can communicate data back to the machine, which may include commands such as to stop or start or change programs. This communication enables poka-yoke solutions as well as remote-control and management solutions. For machines that do not have the capability of receiving commands, simple start/stop and flow-control mechanisms may be implemented using the hardware control.

When a new Opcenter Execution Electronics IoT SPU is connected to the network, it goes through a simple connection flow. The unit automatically contacts the gateway to receive the simple designated configuration, including the location on the network, its role—which can be data collection or line controller—and information if required about the machine to which it is connected as well as any peripheral devices, such as scanners. The connection is then registered by the gateway, which means that data from the process is available to those who request it. In the ready state, data is collected continuously and stored within the device. An application can request the information immediately as live information, or it can collect a series of past events as part of a batch.

Although the information collected by Opcenter Execution Electronics IoT is intended for use in several sophisticated computerization systems, a fully configurable web-based dashboard is included with the platform through which details of individual machines, lines, or the whole shop floor can be seen. Several key performance indicators (KPIs) can be displayed across many different aspects of production operation, including status, downtime, product flow, test results, and statistics. This dashboard can support many shop-floor operational and management requirements. The supplied ODB++Manufacturing SDK allows for any additional scope for reports and dashboards to be developed according to the exact needs of the business.


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Chapter 8

Holistic Manufacturing Management for Industry 4.0

As a part of Siemens Digital Industries Software, Valor engineers are creating integrated solutions for industrial applications and deployment platforms (e.g., Mendix, SDKs, ODB++Manufacturing, digital product models and libraries, and preconfigured apps) that enable customers to develop applications specifically for their production needs and processes. These tools are updatable to ensure continued or continuous functionality in an evolving or changing environment, flexible enough to support a large ecosystem of current and future devices and machines and enable authentication and provide security measures. They support a wide range of connectivity options, such as ubiquitous communication connectivity (Figure 8.1).

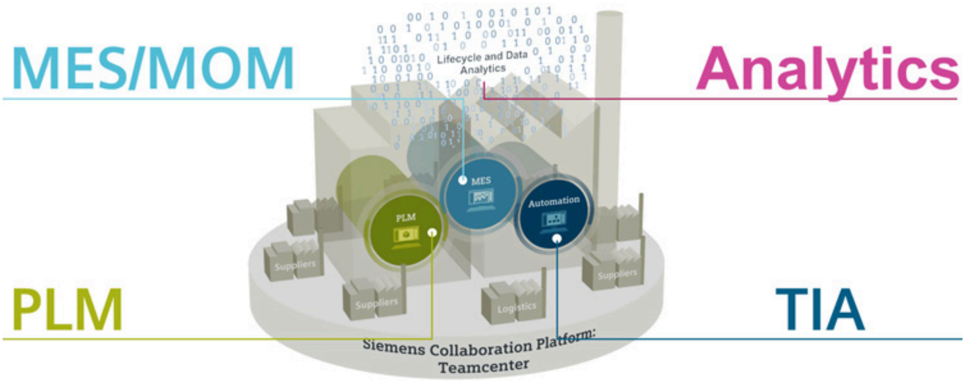


Figure 8.1: Ubiquitous communication connectivity options.

As many new technologies are being introduced into manufacturing operations, the decades-old manufacturing execution system (MES) is a crucial piece of the foundation for digital transformation. Technologies—such as augmented reality, AI, cloud and edge computing, and mobile and auto-ID—are being integrated into MES solutions. Likewise, smart machines, sensors, and IIoT platforms are expanding capabilities to integrate into enterprise-level systems.

This is because important functions and features provided by an MES cannot be replaced by new IIoT platforms, even with analytics and apps. IIoT devices and platforms do not provide operational context for data or trigger actions in response to data and are not designed to orchestrate processes across the factory and value chain. Many production processes need people in the loop, and the MES provides that connecting platform.

> **"...IoT-connected operations are integral to smart manufacturing..."**

For Industry 4.0, the MES needs to integrate into a company's digital platform and "system-of-systems," including engineering design, validation/verification, test, quality assurance, business, and factory management, production, assembly, and fabrication systems. Again, IoT-connected operations are integral to smart manufacturing, connecting machines to gather data and enable monitoring the production process throughout a plant. And in this connected world, the requirements for an MES have changed.

Material Management

In electronics—particularly PCB manufacturing—material-management capabilities are crucial as the cost of material is growing. Efficient material-management applications reduce waste but also provide the possibility to deploy the right material at the right time and at the right station/line.

Closed-loop Feedback to PLM

In PCB manufacturing, closed-loop feedback—generated thanks to the integration of MES with PLM—provides great benefits. This flow of information is from MES to PLM.

Closed-loop Feedback From PLM

Even more important is the flow of information from PLM to MES, especially information regarding the engineering of manufacturing processes. It is key that this process-related information is efficiently transferred from PLM to MES, as the resulting speed-up makes new product introduction (NPI) more reliable (Figure 8.2).

An MES for Industry 4.0 must integrate into other enterprise systems, such as product lifecycle management (PLM), enterprise resource planning (ERP), other manufacturing operations management (MOM), and scheduling programs.

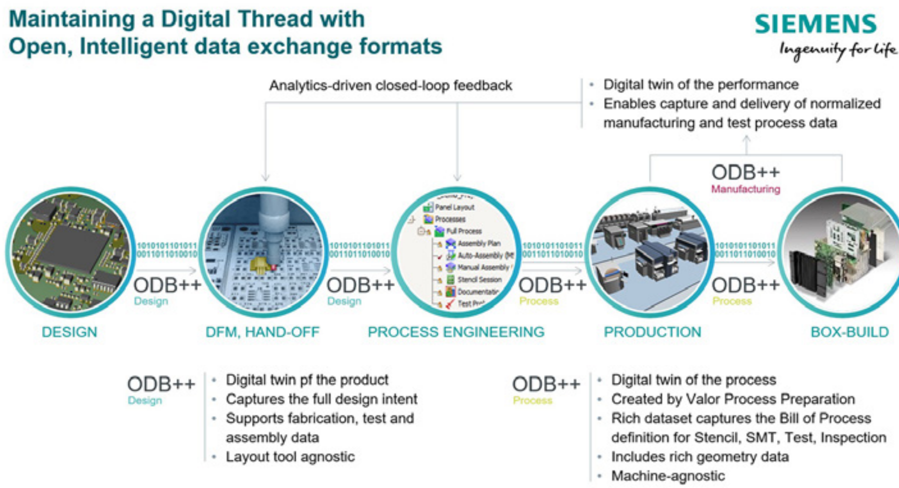


Figure 8.2: Continuous improvement with the digital twin.

Integration with a scheduling engine, for example, is especially important in smart manufacturing. In an advanced scheduling solution, the MES sends data to a scheduling engine, which manipulates it to create an optimized schedule and returns it to the MES. The MES then uses the optimized schedule to generate the queue for order dispatching and operation view. The benefits of advanced scheduling include lower inventory levels, reduced costs, and faster response to shorter lead times.

Siemens is working on all phases of the smart manufacturing flow, from engineering to production execution connected via closed-loop feedback. Engineers working on the Siemens MOM software and Valor technology collaborated to create a unique MES that covers the complete mechatronics manufacturing process. The MES Opcenter Execution Electronics activates the seamless flow of product and business data between PLM, ERP, and shop-floor execution through an integrated digital thread, enabling faster and streamlined change cycles [8]. Using this single data source, closed-loop feedback from production to design and engineering departments can result in improved quality levels and shorter NPI processes and go-to-market times.

For example, Harman, a manufacturer of automotive electronics multimedia systems, is a supplier for many automotive brands. The company manufactures a high number of product variants, and they were looking to shorten their NPI time without increasing manufacturing costs. They also wanted to be able to design and manufacture anywhere while achieving the same results

INTEGRATED SOLUTION:
Lean New Product Introduction (NPI)

	Part Libraries	SMT Programming	Test & Inspection Programming
Engineering time saved	80%	40%	40%
NPI time saved	50%	50%	40%
Annual savings	$60K	$260K	$75K

Figure 8.3: NPI methodology savings.

and the same quality. The implementation of a Lean NPI methodology allowed Harman to cut their NPI time by almost half (Figure 8.3).

In another example, a company that manufactures mobile phones for Sony Ericsson was facing a rapid volume increase that was stretching their operations and quality. They were unable to track serialized phones and data with manual systems, running into risk of errors caused by paper instructions to operators, and had an inflexible, high-maintenance, custom tracking system.

With an integrated MES, they were able to reduce the number of returns because of improved product quality while increasing the number of units shipped by 25% per quarter. The company now has complete, online accessible traceability and data for every phone. Further, they were able to lower the cost of system ownership and maintenance by no longer using custom code or having to deal with the issue of obsolete platforms (Figure 8.4).

Figure 8.4: Consumer electronics product.

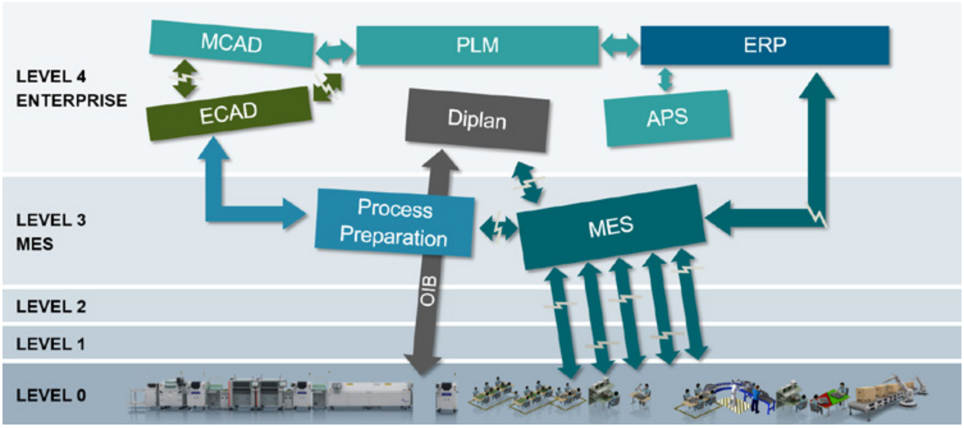


Figure 8.5: Fürth factory before optimization.

Siemens technology development efforts benefit from the company's advanced operational factories—the early adopters of the company's own innovations. "Opcenter Execution Electronics introduces a layer of value that we could never reach with our existing set of disconnected tools, even with custom integration," says Hermann Kraus, MES project lead at the Siemens Fürth factory (Figure 8.5). "Furthermore, the inclusion of Opcenter Execution Electronics IoT data acquisition in the suite has drastically simplified the deployment across our assembly lines. We have optimized material flow with Valor Material Management inside Opcenter Execution Electronics (Figure 8.6). We are currently introducing the second step that will deliver a true one-stop-shop solution for electronics manufacturing management, covering all process areas, and is integrated with PLM and ERP."

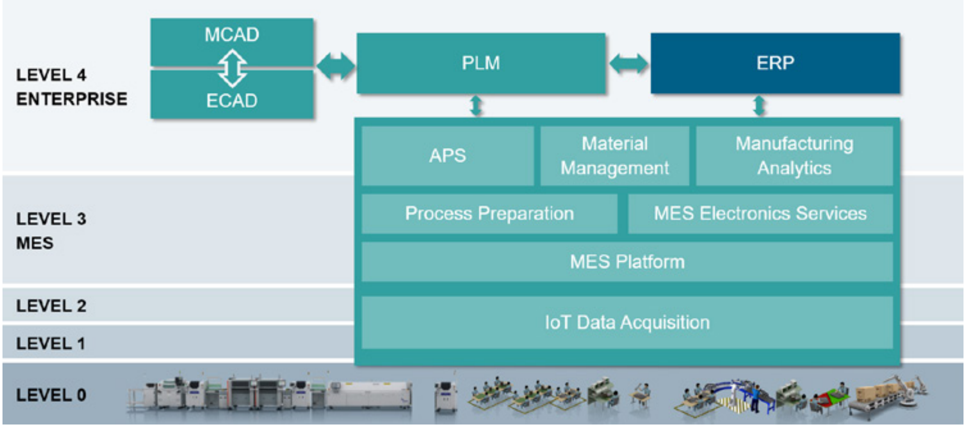


Figure 8.6: Fürth factory after optimization.

Figure 8.7: Siemens digitalization strategy.

Opcenter Execution Electronics is built on Opcenter's successful enterprise-level platform for integrated circuit (IC) manufacturing. The new powerful, configurable, and scalable MES enables PCB and box assemblers to meet traceability requirements, improve efficiency levels, and control manufacturing operations through direct IoT connectivity with machines and production lines.

Expanding on the Siemens Digital Enterprise platform, Opcenter Execution Electronics creates a true digital thread to empower electronics companies to further their digitalization strategy in line with Industry 4.0 (Figure 8.7). By closing the loop between engineering and the shop floor, and enabling quick reactions to design modifications, manufacturers can shorten product lifecycles, increase production complexities, and improve quality across the entire manufacturing lifecycle.

"This collaboration with Valor technology along with the introduction of Opcenter Execution Electronics further expands our positioning in the electronics market and fortifies our leadership as industry trendsetters," says René Wolf, senior vice president of MOM for Siemens Digital Industries Software. "In an era where mass customization and rapid time-to-market determine the ability of electronics companies to succeed, manufacturing processes must be flexible and smart enough to accommodate rapid change in product requirements while optimizing production efficiency and improving the overall product quality. This is exactly the kind of innovation that the Opcenter Electronics Suite delivers to the market."

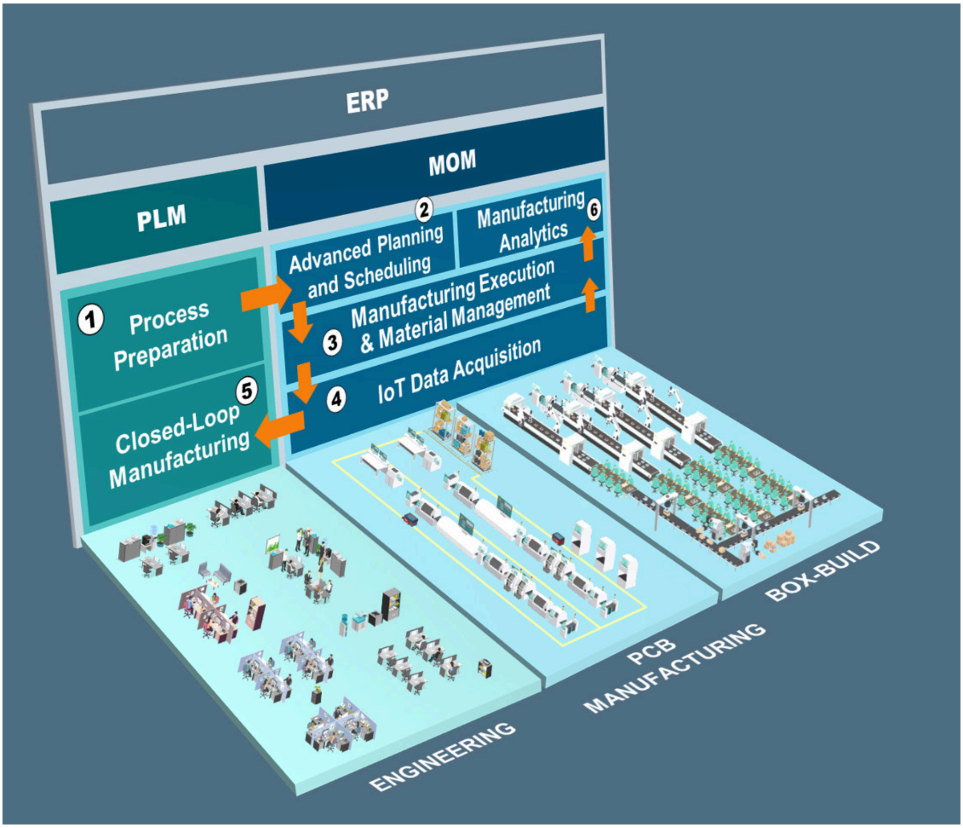


Figure 8.8: Electronics manufacturing management.

In the past, MOM for PCBs was often handled by one solution while another solution was implemented for box-build (i.e., enclosures, other components to be incorporated into a product, and final electronic products and/or systems). But an Industry 4.0 enterprise must take a holistic approach to digitalization, making maximum use of it at every level to control productivity, quality, and operational costs (Figure 8.8). Such an approach streamlines manufacturing through its entirety, going even beyond electronics and PCBs, by creating transparency between production tasks. Advanced planning and scheduling efforts can more easily monitor and account for real production environments, change orders, unexpected events, and other factors for which multiple solutions currently require a more involved, hands-on, and time-consuming response.

Figure 8.9: A portion of the Siemens Amberg automated plant producing programmable logic controllers (PLCs).

A unified, holistic approach to digitalization is one of the pillars of Siemens' Opcenter Execution Electronics solution. Leveraging the multi-domain production solutions in Siemens Digital Industries Software portfolio, which manage manufacturing execution, advanced planning and scheduling, materials and supply, quality, and machine intelligence, Siemens Opcenter Execution Electronics harmonizes collaboration across all of these manufacturing management areas. The solution incorporates in a single solution the Opcenter MES technology and box-build functionalities with manufacturing solutions provided by the Valor tools.

Siemens Opcenter provides tight integration of manufacturing operations software to more easily support distributed and closed-loop manufacturing. It includes a familiar—yet tailorable—interface, smart-device readiness, codeless extensibility and faster time to value, and a progression from cloud-ready apps to cloud-native apps.

The Siemens integrated manufacturing management portfolio is an open platform for these technologies so that investment today will continue to evolve and provide benefits as products and production lines evolve.

Siemens is the world's leading supplier of programmable logic controllers (PLCs), and the Siemens Amberg Electronics Plant is the company's showcase plant for implementing Industry 4.0; 12 million PLCs are manufactured there each year (Figure 8.9). The Amberg operation is a successful example of Siemens' Digital Enterprise platform in action. Using the smart manufacturing for electronics approach, the plant's real and virtual manufacturing worlds are completely integrated. Product codes tell production machines what requirements they have, and which production steps must be taken next. Products and machines determine which items on which production lines should be completed and when in order to meet delivery deadlines. Independently operating software agents monitor each step to ensure compliance with regulations.

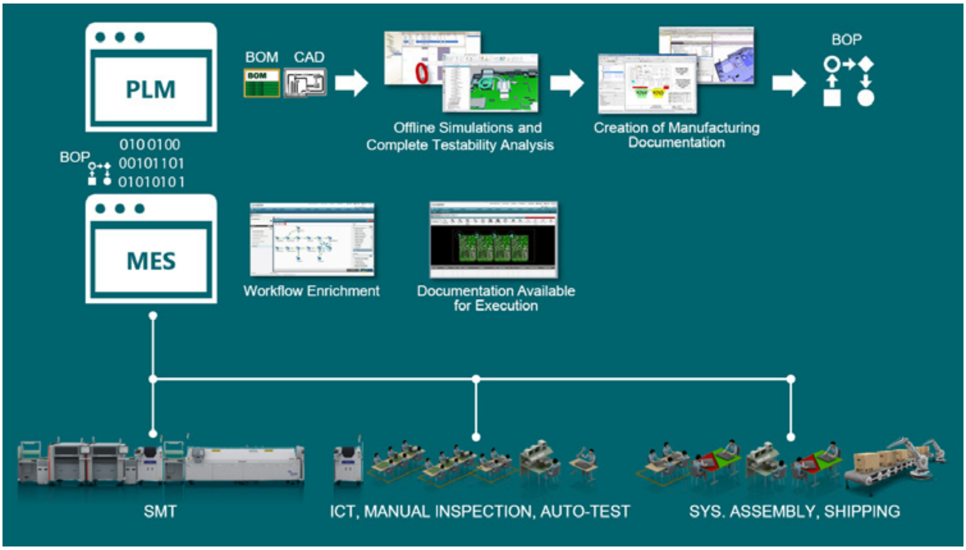
These practices rapidly turn innovation into products. Between the use of digital prototypes and the ability to simulate and optimize production processes in software, the time it takes for the Amberg plant to introduce new products is 50% less than other Siemens PLC factories. Changeover time takes half the time. New order lead-time is 24 hours, with the ability to handle a lot size of one. Production quality at the plant is nearly 100%, and a series of test stations detect the few defects that do occur. The factory has seen cost savings as much as 25%.

Out-of-the-box, mix-and-match, customizable, full-flow, and fully integrated are the types of solutions available for manufacturers today to build the layers of their digital factory. Siemens Digital Industries Software provides many of these tools, including Teamcenter, Active Workspace for Teamcenter software, NX™ software, Teamcenter Manufacturing, the Tecnomatix® portfolio, MindSphere, SIMATIC, Preactor software, Opcenter, Valor™ Material Management Software, Valor Process Preparation Software, Opcenter Execution Electronics IoT Platform, and Opcenter Intelligence Electronics for adding a layer of business intelligence. Valor also supports the free tools ODB++Manufacturing for platform/vendor-agnostic machine communication and ODB++Design for making a product model that can be used as a digital twin from design through to manufacturing. This software provides much-needed functionality for electronics manufacturers seeking to build an Industry 4.0 operation.

Conclusion

IIoT has the power to drive true, quantifiable change in the manufacturing industry. The immediate bottom-line production benefits are clear: fewer machine failures, reduced scrap and downtime issues, and improved throughput. The use of Industry 4.0 can also create a positive, cultural shift across an organization. Even as Lean manufacturing and Six Sigma revolutionized the plant floor by turning production workers into problem solvers striving for continuous improvement, Industry 4.0 is transforming how factory employees work, collaborate, and serve their customers.

The best-in-class Industry 4.0 solutions aggregate data not only from machines but also from existing third-party systems, MES, ERP, maintenance, and supervisory control and data acquisition (SCADA). Industry 4.0 aims to eliminate the silos that create frustration and disagreements between employees about the source of production issues. The availability of open, connected data means that plant managers, engineers, and upper management can now work together to objectively solve production problems. It also results in improved customer satisfaction, increased supply chain transparency, and enhanced employee engagement.



Harmonized NPI process preparation via integrated platform.

For Industry 4.0 to be successful, silos of information have to be connected and shared in a data stream, a thread of information available from product conception to delivery. It is no longer a debate that collaboration has to happen in the IT and OT domains as well as between mechanical, electrical, and software engineers; designers and factory managers; and vendors and their customers. A holistic and systematic approach is the only way to make the revolution of smart manufacturing a reality.

Overall, here are a few points to keep in mind when advancing your manufacturing processes:

- Break silos through digital threads and generate a seamless flow of information from engineering to manufacturing execution
- Create digital twin processes and production systems
- Distribute a perfect, validated product model (i.e., design anywhere, build anywhere)
- Use built-in and user-defined templates for static and interactive documentation
- The ideal scenario is a single platform covering all manufacturing engineering tasks, including stencil, SMT, test, inspection, and electronic work instructions.

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About Siemens Digital Industries Software

Siemens' Opcenter Execution Electronics IoT Solution enables any existing factory to become a smart, Industry 4.0 operation without investment to replace machines, processes, or enterprise software systems. Opcenter Execution Electronics IoT Hardware provides a connection across the whole shop floor, normalized into a single simple “plug-and-play” standard based on the ODB++Manufacturing specification. The Valor point-solutions build on this platform to deliver Industry 4.0 functionality factory-wide, including Lean JIT material management, finite production planning, manufacturing control and dashboards, enterprise-grade business intelligence, active quality management, and full traceability to IPC-1782. Valor’s industry-leading engineering solutions also ensure the most rapid new product introduction (NPI) flow with seamless integration across multiple machine vendor platforms and standalone processes as well as full shop floor integration with enterprise solutions, such as enterprise resource planning (ERP).

Siemens Digital Industries Software. Formerly Siemens PLM Software, its new name reflects the depth of the software offerings across a broad spectrum of industry domains. The industrial world is in the midst of unprecedented change. The pace of innovation is moving rapidly. Digitalization is no longer tomorrow’s idea.

The comprehensive digital twin merges the virtual and real world, blurring the boundaries between engineering and process domains. It enables a complete digital transformation in discrete and process industries. Siemens is the only partner with domain knowledge in all disciplines of the digital enterprise.

Personalized and adaptable applications can help drive new business models. Siemens has the ability to meet rapidly changing consumer preferences with adaptable solutions. It can predict and adapt products to future customer needs using data and insights.

Siemens Digital Industries Software is headquartered in Plano, TX with offices in 36 countries and over 250 locations.