**GUIDE TO READING THIS PAPER**
Depending on your role in the company as well as your knowledge about Industry 4.0 and MES/MOM, you may want to read different sections of this paper most carefully.

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**SECTION I**
Is the executive summary and this guide. Everyone may benefit from reading this overview.

**SECTION II**
Is an explanation of Industry 4.0 that starts with the enabling technologies, moves into the cyber-physical systems they enable, and then examines the ‘smart’ results that are intended. Those who have not studied Industry 4.0 will find this very useful.

**SECTION III**
Focuses on the benefits of Industry 4.0 and will resonate with those who either need to make a business case or who review business cases. It will also appeal to those setting strategies and seeking to craft initiatives for achieving company goals.

**SECTION IV**
Explains the role of manufacturing execution systems in Industry 4.0. This is particularly useful for those in information technology, production, and those who may have questions about this core set of manufacturing applications and how it will evolve.

**SECTION V**
Describes a path to the future. Those who seek to understand not just the vision and benefits, but how to craft some next steps will want to review this section.
Industry 4.0 offers an unprecedented opportunity for transformational success, but companies must have plant floor software that is ready for that journey. The fact that Industry 4.0 is already predicted means companies can prepare themselves now.

Industry 4.0 calls for a future of agile, affordable manufacturing fueled by technology enablers such as the Internet of Things (IoT), 3D printing, Cloud computing, Mobile Devices and Big Data. That future reality actually does have the potential to change everything.

It’s likely to change how companies and supply chains work, what people and software applications do, and what customers can expect and when. That does not mean all the processes, IT systems, and approaches a company uses today will vanish. It means they need to be capable of making the following set of shifts:

- from centralized to decentralized control
- from people directing or even doing much of the operations work to automated mechanisms
- from separate systems at each level (in the production lines, the plants, the enterprises) to vertically integrated information flows that enable full business processes
- from separate systems in each department and organization in the supply chain to horizontally integrated information flows among everyone in the organization and extended supply chain
- from large companies and particular types of processes being connected to the widespread democratization of connectivity, mobility and location-sensitive technologies
- from on-premises to cloud-based computing
- from limited and localized analytics to advanced analytics, both real-time and offline

Any one of these shifts taken individually might be a big change. The convergence of all of them is truly disruptive, and opens up entirely new opportunities and challenges.

While these shifts are clear elements of the as-is vs. to-be vision, it can be challenging to fully understand Industry 4.0 and what it will mean to a company and to its manufacturing IT systems. Our goal with this paper is to go beyond the vision and the technology hype and define a path to begin in the right direction for manufacturing systems.
Industry 4.0 is a vision of the fourth industrial revolution (see Figure 1). The first was enabled by mechanical equipment often powered by water or steam technology, enabling the move away from craft production. The second was mass production, enabled by electricity. The third was further automated by electronics in programmable logic controllers and related automation. This fourth industrial revolution is based on cyber-physical systems - the merging of real and virtual worlds. It has a set of technology enablers (see next sub-section on page 4).

Beyond the new technology enablers, Industry 4.0 is different in two major ways:

1. It has been predicted, which allows companies to develop a plan and roadmap for their own adoption.

2. It not only increases the efficiency and productivity of manufacturing, it actually opens up entirely new business opportunities and revenue stream possibilities.

Industry 4.0 was developed as a public-private endeavor in Germany and is widely accepted across Europe, China and much of the world.

The major thrust of the final report of the Industry 4.0 Working Group, published in April 2013, is how to use current technologies such as Internet of Things, Cloud computing, Mobile Devices and Big Data to lower the cost of production for deeply tailored or customized products..

1 “Recommendations for implementing the strategic initiative INDUSTRIE 4.0”,

Figure 1. The four Industrial Revolutions.
Industry 4.0 is similar in many ways to the US Smart Manufacturing initiative. Smart Manufacturing focuses on a platform for interoperability between information technology and operations technology. The concept is to leverage standards to develop a cloud-based open platform for factories and enterprise integration. An industry consortium called Smart Manufacturing Leadership Coalition is leading the effort to develop the concept in concert with US-government funded manufacturing centers such as Digital Manufacturing and Design Innovation Institute (DMDII).

Manufacturers can now begin to define their target manufacturing model and then plan a transformation roadmap. Industry 4.0’s vision of ecosystems of smart factories with intelligent and autonomous shop-floor entities is inherently decentralized. As Figure 2 shows, technology enablers support the foundational breakthrough of cyber-physical systems, which in turn enable the new business models and “smart” future envisioned in Industry 4.0.

Figure 2. Industry 4.0 Smart Results rest on cyber-physical systems, which rest on enabling technologies.

Technology enablers

In the past decade, many new information technologies have been at the forefront of discussions for industry. Each brings new capabilities. Taken together, they are very disruptive and create a totally new environment for manufacturers both inside their plants and across their ecosystems. Some of the key technologies that underpin Industry 4.0 include:

- **Embedded electronics** - As electronic tags and sensors have become miniaturized and lower cost, they are now included in many products and today we can track nearly anything. Even more possibilities open up when sensors and actuators are included.

- **Embedded communication** - In addition to the electronics, a foundation for the internet of things (IoT), and machine-to-machine (M2M) is connectivity between these embedded electronic devices and other electronics - or among the devices. Internet everywhere really changes what is possible in coordinating across devices and products.
Embedded computing - As microcontrollers and other computers are added to products along with the other electronics and communications, the result is smart products, smart equipment and the intelligence in those items to operate with little to no central control or human intervention. Special-purpose embedded systems are not new, but the continuing drop in cost and size has made it feasible to use them to make many more “things” intelligent and connected to the IoT.

Cloud - Of course all of the new computing, sensing, and connectivity among things creates an explosion not only of data but of locations generating data. Cloud computing has the ability to store massive amounts of data with “anywhere and anytime availability” for analysis. Another benefit is the instant upgrades and ability to pay only for what is needed and used.

Advanced Analytics - Once all of that data is created and stored, the question is: how to use it? Advanced analytics are a way to transform the data lakes of structured and unstructured data from different data sources such as sensors, MES and ERP into information about what is happening. It can also move into prediction, as a “crystal ball” for effective decisions.

Mobile - Naturally if products are moving through a supply chain, they benefit from the embedded computing and communication to interact anywhere, which allows the value creation process to occur with more geographic flexibility.

3D Printing - 3D printers build products up out of raw materials rather than removing materials from another form as machine tools do. They have the ability to not only accelerate new product introduction and make prototypes, but also to create parts and entire multi-material products. 3D printing also changes the need for many complex and expensive pieces of equipment, democratizing discrete product manufacturing.

Community Platforms - Social-media-like systems for business are now available to enable effective collaboration and best practice sharing among geographically dispersed teams both internal and across an ecosystem. These generate faster ways to find people with answers to questions, broader sharing of best practices, and global learning and improvement.

“In the manufacturing environment, these Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently.”

Source: Recommendations for implementing the strategic initiative INDUSTRIE 4.0; Final report of the Industrie 4.0 Working Group
Cyber-physical systems (CPS and CPPS)

All of these new technologies mean automation is allowing virtual and real to converge into cyber-physical systems (CPS). CPS are physical objects with embedded software and computing power. Based on connectivity and computing power, the main idea behind smart products or CPS is that they will incorporate self-management capabilities.

The Industry 4.0 Final report describes a network of CPS as described in the box below. To differentiate production capabilities from the smart product CPS that needs to be produced, the production facilities are often called Cyber-Physical Production Systems (CPPS). These software-enhanced machines leverage a wide range of embedded sensors and actuators, beyond connectivity and computing power. CPPS know their state, their capacity and their different configuration options and will be able to make decisions autonomously.

Smart services

With smart products leveraging the cloud for data storage and advanced analytics, many manufacturing companies have already been offering smart services. These offerings usually generate additional after-sale revenue and deliver a higher value for the customer. They can also help to strengthen the ongoing relationship between the manufacturer and its customers. Common examples today are:

- support services such as predictive product maintenance and condition monitoring
- complementary offerings such as new software adapted to the usage environment conditions
- entirely new business models such as selling a service agreement that the product will be operational rather than selling the product itself

“Smart factories allow individual customer requirements to be met and mean that even one-off items can be manufactured profitably. In Industrie 4.0, dynamic business and engineering processes enable last-minute changes to production and deliver the ability to respond flexibly to disruptions and failures on behalf of suppliers, for example.”

Source: Recommendations for implementing the strategic initiative INDUSTRIE 4.0; Final report of the Industrie 4.0 Working Group
Smart innovation

Research shows that breakthroughs often come from outside the domain of the problem being solved. In the future, leveraging not only the data flows from CPS and an ecosystem, but also community platforms can help the process reach those not already involved to improve innovation. Examples today include open-source software and crowd-sourced solutions to difficult problems. These are likely to become more commonplace in R&D and production environments.

Smart supply chain

A set of CPPS equipment could also create a larger plant-level CPPS network. Just as a plant has capacity and capabilities to work in the supply chain today, this would allow more informed decisions not just within the plant but also across the supply chain.

The supply chains of Industry 4.0 will be highly transparent and integrated since the physical flows will be continuously mapped on digital platforms. This will make each individual service provided by each CPPS available to accomplish the needed activities to create each tailored product.

Some of the characteristics include:

• Agile collaboration - transparency across partners allows the company to focus and assemble ad-hoc, project-based supply chain partnerships
• Physical flows are continuously mapped as CPS and CPPS interact, delivering end-to-end track and trace, allowing visibility, reliability and agility via supply chain control towers
• Online bidding portals and marketplaces for knowledge or manufacturing capacity and capabilities similar to current on-line marketplaces but even more dynamic
Smart manufacturing

The combination of CPS and CPPS is likely to trigger significant changes in manufacturing production and control, towards completely decentralized systems. Industry 4.0 advocates that the shopfloor will become a marketplace of capacity (offer) represented by the CPPS and production needs (demand) represented by the CPS. Figure 3 shows this decentralized system. For example, a CPS may know it needs to be tested, and any appropriate CPPS testers with capacity available will offer their services.

CPS and CPPS will be empowered to autonomously make decisions. With competing targets and contradicting constraints this will generate a holistically optimized system, ensuring only efficient operations will be selected and conducted. The result will be data-driven operational excellence.

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Compelling vision

Industry 4.0 is widely agreed on in part because it presents a compelling business case. As with any other type of project, to get it not only funded but to gain the ongoing commitment, passion and resources it needs to succeed, Industry 4.0 must focus on gaining real and measurable business benefits.

Industry 4.0 is designed to change the basic business equation of manufacturing—to improve agility, cost, quality and speed all at once. Historically, more variety has meant higher costs, more challenges to achieving high quality, and either long wait times for customers or high inventory levels for suppliers. Most companies analyzing their expanding product lines over the past few decades discover that while this was an essential strategy for revenue growth, this variety has also put immense strain on their operations. The new designs, new suppliers, and specific products for small markets have driven up complexity exponentially in every area of a manufacturing business.

The Industry 4.0 Final report from 2013 says “Smart factories allow individual customer requirements to be met and mean that even one-off items can be manufactured profitably. In Industrie 4.0, dynamic business and engineering processes enable last-minute changes to production and deliver the ability to respond flexibly to disruptions and failures on behalf of suppliers, for example.”

We see at least six major areas of value or business benefit for adopting Industry 4.0 (see Figure 4). These benefits come from a combination of smart products, smart services, smart innovation, smart manufacturing and smart supply chain.

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2 Securing the future of German manufacturing industry
Recommendations for implementing the strategic initiative INDUSTRIE 4.0
Final report of the Industrie 4.0 Working Group © 2013 Prof. Dr. Henning Kagermann, National Academy of Science and Engineering Prof. Dr. Wolfgang Wahlster, German Research Center for Artificial Intelligence; Dr. Johannes Helbig, Deutsche Post AG

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**Efficiency**
- Automation
- Fewer people
- Faster decisions
- Lower costs

**Agility**
- High mix
- Short leadtime
- Built-in specs
- Responsiveness

**Innovation**
- Full visibility
- Known capabilities
- Rapid experiments
- Fast NPI

**Customer Experience**
- Full visibility
- Availability
- Quick resolution
- Service that works

**Costs**
- Fewer people
- Less wasted material
- Higher initial quality
- Lower operating costs

**Revenues**
- Larger markets
- Higher value products
- Profitable services
- Customer loyalty

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*Figure 4. Benefits to Industry 4.0 in major categories*
Smart products

Companies in many different manufacturing segments have already discovered that embedding intelligence allows them to create premium products. Customers, whether consumers or businesses, want and increasingly expect smart products, and are ready to expand their use. Beyond the value of smart products to the customers, their production provides much more transparency throughout the lifecycle. This means that the manufacturer can improve internal capabilities such as innovation, quality, compliance, maintenance, scheduling and supply chain management with far less effort.

Smart services

In thinking more broadly about what customers really need, a common result is development of service-based offerings that leverage the embedded technology. The advent of smart products such as mobile phones, connected cars and smart infrastructure has led to changing expectations and definitions of value. Over the past few decades people have realized that what they want to pay for is a reliable service, not necessarily the product that allows that service. The next phase for success and profitability in both products and services lies in using smart products, or cyber-physical systems (CPS), in more ways for internal and external value. Many companies have opened up new revenues and business innovations that are even more profitable than the products they accompany.

Smart innovation

One of the most significant drivers of success in industries such as electronics, semiconductor, and discrete smart products is new product introduction (NPI). Once products and the equipment that builds them can communicate, smart plants and facilities can come into being. Connecting smart factories within a company and with the sub-contractors and suppliers will enable faster, more reliable NPI in an extended network. For companies whose products work in a Smart Service environment, this additional information from use in the field will be much more readily accessible, and the big data advanced analytics will assist with engineering analysis. In addition, using Community Platforms will allow a larger base of input from which to innovate. All of this together can generate sustained innovation and competitive advantage.

Smart supply chain

Many companies, especially those with smart products, now offer a nearly unlimited number of product variants and configurations. The product variety has been designed to deliver greater market responsiveness and broaden the customer base. However it has created enormous complexity and response challenges in the supply chain. Industry 4.0 with its always-on tracking and CPS can improve inventory positioning, agility and response time, operational cost, and on-time delivery reliability. The product variety will begin to be more profitable when this automated and decentralized approach to product customization takes hold.

Smart manufacturing

To the degree smart systems and smart machinery can automate more of what happens in production, cost and human time required will continue to go down. Over the past decades as other types of automation have taken hold, this increase in productivity has allowed fewer people to produce more at a lower cost per unit. Continuing advances in automation such as those envisioned in Industry 4.0 have proven to save tremendous time and money. Further, automation tends to increase quality and predictability. What has been tricky to date for most automated systems is ensuring that each individual product goes through the right process to meet specifications without delays to accommodate the resulting high mix. With CPS and CPPS communicating directly, far greater agility and flexibility in the production operation is possible. Using 3D printing will make one-off production far more feasible.
Successful manufacturing, particularly as it has gone global, has relied heavily on Manufacturing Execution Systems (MES) - also sometimes called Manufacturing Operations Management (MOM). This multi-faceted software for production plants has been a pivotal enabler for the performance, quality and agility manufacturing leaders have achieved.

Why MES/MOM for Industry 4.0

We expect MES will continue to play an essential role in the manufacturing enterprise’s IT landscape. Why? Because it sits at the critical point where revenue-generating products come into being. MES already handles rapidly flowing streams of disparate data and turns it into useful information in a near-real-time fashion. The influx of CPS and CPPS data will require this and more.

The primary functions of MES are a critical foundation around which manufacturers can build the Industry 4.0 application structure. As it is today, MES provides critical information both within the production environment and to the supply chain, customer service, product development and management teams. Industry 4.0 will not be fully implemented overnight, so there will be a transition period.

Over the longer term in Industry 4.0 situations, MES will play several roles. Figure 5 shows a simplified concept of this:

- sit at the center of the smart supply chain
- monitor, and as needed, coordinate the CPS-CPPS marketplace
- incorporate CPS and CPPS data into off-line compliance and quality activities
- act as the stand-in for any products, materials, or equipment that are not fully CPS enabled
- be the essential coordinator for both the horizontal and vertical integration of Industry 4.0
- sit at the center of the product lifecycle
- deliver aggregated information for customer service and other ecosystem activities

Figure 5. MES plays a central role in Industry 4.0.
Although MES is a critical element in the manufacturing IT landscape, a completely new generation of MES is required to cope with the new challenges created by Industry 4.0 (see Figure 6). The following are the main characteristics MES needs to support Industry 4.0 effectively.

### Decentralization

Industry 4.0 is inherently a decentralized system, with intelligence in independent entities. Smart materials and products (CPS) are service consumers and smart equipment and plants (CPPS) are service providers. CPS and CPPS are not physically coupled; rather, a dispatching operation delivers logical binding between a material to be processed and a resource to process the material.

Since each product in the Industry 4.0 vision may be unique, it will be very difficult to centralize or optimize shop floor operations in the traditional way. This dynamic marketplace of CPS and CPPS means that rather than hold a single unifying model, the MES needs context resolution possibilities. This allows a product that requires a certain service at a certain step to combine the flow of its product category to be adapted, or unique to its specific context. Going one step further, the smart product may hold the recipe needed at a given processing step. When negotiating with the smart resource, it will transfer the recipe to the resource so that it can perform its unique transformation process.

So the CPS and CPPS have their own intelligence. As an example, a smart product CPS knows its state, its position, its history, its target product and its flow alternatives. Likewise, a smart resource or CPPS will know its state, its history, its maintenance plan, its capacity, its range of possible configurations and setups, etc. What this means is that a smart product or CPS has the capability to identify itself, providing its position and state to a physically centralized system. MES decentralization needs to be logical, not necessarily physical. In fact, with cloud computing, it’s even arguable whether such a system can be considered physically centralized. What is critical is that the logical decentralization must exist.

So the MES may still be one centralized application, but it acts decentralized with agents or objects representing the shop-floor entities.

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**Figure 6.** Required MES characteristics for Industry 4.0

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Vertical integration

MES has always been most effective when integrated into the ERP systems ‘above’ it as well as the monitoring, control and actual production processes ‘below’ it. This vertical integration is an enabler for the orchestration of business processes that may be simple or complex but nearly always require multiple layers and groups to be involved. Business processes for compliance, quality, logistics, engineering, sales or operations all have components inside the plant as well as others that reside beyond the factory that are crucial to a business process being executed effectively.

In Industry 4.0, CPS and CPPS communications create new data flows to integrate. For example, a CPS or smart product may know that it needs to stop a lot or collect a measurement variable. The layer above then specifies and checks whether the outcome is correct. This is where statistical process control (SPC) rules reside, and if it’s not within limits, it might open a corrective and preventive action (CAPA). All of that activity will be in a layer above the CPS in controls and/or MES.

Within the plant, the MES will need to aggregate and put these additional data flows into context. Vertical integration of these autonomous entities is critical as they could otherwise make decisions independent of the rules and best practices for the factory or company. MES providers must continue to expand the product capabilities to ensure that all plant activities are visible, coordinated, managed and accurately measured. Only then can the enterprise systems respond effectively.

Horizontal integration

In the Industry 4.0 final report, horizontal integration focuses on supply chain status communication among facilities and trading partners. Horizontal integration enables the smart supply chain or network to be transparent so status is always visible. What horizontal integration requires is service-oriented ways of alerting the rest of the information system to the information available.

However, that is not likely to all come from the CPS and CPPS directly. In Industry 4.0 the MES must be truly modular and interoperable so that all functions or services can be consumed by CPS smart materials, CPPS smart equipment or any other shop-floor entity. As an example, a typical maintenance management process, often centralized, could consist of a series of services that each piece of equipment might use.

Horizontal integration may also extend from the plant systems of suppliers to connect into the plant systems of their customers. With high tech’s extensive outsourcing and supplier base, this is a vision these industries could benefit from greatly.
Connectivity, sensing and mobile

Advanced manufacturing environments have had highly integrated connectivity for a long time. As an example, some of the more sophisticated semiconductor facilities have RFID transponders in the material containers and the equipment has bidirectional communication through interfaces, exposing readings from sensors, alarms or reports or allowing recipes to be externally selected or downloaded.

Now, Industry 4.0 is creating a true democratization of such connectivity, allowing it to be widespread in manufacturing facilities of different sophistication levels. Two elements contribute:

1. The IoT, in the industrial world called IIoT (Industrial Internet of Things) translates into very low cost hardware and lean OS (such as Windows 10 IoT running on a Raspberry Pi), allowing true connectivity with equipment not requiring heavy systems and interfaces.

2. Increasingly affordable passive identification and location tags allow all shop-floor resources (CPS and CPPS) to hold their positioning coordinates. The MES needs logically autonomous entities to store this location data and show it in real-time in interactive maps.

On the operational MES front, connectivity and mobile combined will allow more adaptable interfaces. MES will consist of different apps, making a reality the vision of getting to a piece of equipment, downloading and later using an app specifically built to operate that equipment.

The same combination of mobile devices with the increase in reliable and inexpensive positioning systems will also allow the representation of real time positioning in 3D maps, opening the door to augmented reality scenarios. A person with augmented reality can walk around and get immediate identification of items, and be pointed to their location. Maintenance operations can benefit particularly.

Cloud computing and advanced analysis

The Smart Factory vision of Industry 4.0 requires achieving a holistic view of manufacturing operations. Clearly this can only happen by integrating data from several different sources rapidly and flexibly. This suggests the MES of the future must also leverage cloud computing and advanced analytics.

While many MES have manufacturing intelligence components today, this must expand to better accommodate the diversity and volume of big data. Both CPS and CPPS will generate huge amounts of data, which needs to be stored and processed. Advanced analytics are then needed to fully understand the performance of the manufacturing processes, quality of products and supply chain optimization. Analytics will also help by identifying inefficiencies based on historical data and pointing staff to corrective or preventive actions for those areas.

Future MES must accommodate both:

1. Advanced offline analysis using very sophisticated statistical process models. These will need to be both in structured data, generally residing in a relational database or in data warehouse cubes, and in unstructured data, which is very difficult to analyze with traditional tools.

2. “Real-time” analysis to trigger actions in the plant as quickly as possible, even before data is stored. This needs techniques such as “in-memory” and complex event processing.

Cloud computing is the obvious infrastructure for the speed and agility suggested by Industry 4.0. On-premises systems have far more limited ability to expand, change and respond, and would result in undue costs. Manufacturing data analysis is an area where some leading manufacturers are already starting to leverage the cloud.
No matter what your Industry 4.0 enabled future brings, there are steps you can take now to prepare (see Figure 7).

**Know Industry 4.0**

Get educated on Industry 4.0 and stay up-to-date. Many companies are getting involved in the research in their country; these public-private partnerships can provide money for exploration and the joint learning environment can be very powerful. Beyond those official sources, nearly every major consulting company, industry analyst and system integrator has a position paper on Industry 4.0 and/or Smart Manufacturing. Since it’s evolving, no one has all of the answers. This is ongoing learning for everyone.

**Get to know MES**

Whether you use MES today or not, most companies are not fully aware of what current systems can do. Most MES on the market today can manage a current factory. Most can also handle some aspects of vertical and horizontal integration, mobile, cloud and analytics. However, the specific capabilities for scaling and shifting to coordinating autonomous, decentralized and dynamic activity are important and require some deep study to distinguish future-ready MES from others. Some systems’ ability to handle not only operations but also analysis and coordination activities across the supply chain is remarkable.
Set a vision

Develop a future business vision that leverages the new realities Industry 4.0 offers. Be both clear about the basis on which you expect to compete and open to taking some new turns as you learn. This involves identifying the potential benefits that are most likely to generate competitive advantage. Some possibilities:

- Deeper customization of products
- Lower cost of high mix
- Higher margin from a service offering
- Faster time to market for new or highly engineered products
- Customization and responsiveness

The very purpose and mission of your company may change (as well as your top competitors and target customers), so be open to entirely re-framing the business.

Assess position

The path toward a goal has a starting point in the present situation. Evaluate current business processes and the IT systems that support them, particularly the MES. No matter what methodology the company uses, this needs to be a comprehensive view of how IT delivers value to the enterprise today. This is where most companies will begin to realize that some areas where the current reality cannot match the future vision are decentralization and flexibility.

Flexibility: The level of flexibility available today is in most cases not nearly capable for handling one-off products or customizing products not just at the finishing steps but at the core. For plant operations, Industry 4.0 means there may not be a set of repeatable actions like a standard routing, and MES cannot optimize the floor based on simplistic engineering standards. Optimization will be through a decentralized marketplace of CPS and CPPS in which MES must enforce standards.

Integration: For IoS-based services to be effective, a constant flow of data both vertically and horizontally is required. The advantages of automation will be lost if there are gaps in the flow for a business process or if some of the elements are not visible. This goes beyond networking to the actual application interoperability and openness. What’s new is the need for real-time alerts and updates on production information from any location, partner or CPS. This will require dynamic means of ensuring data can flow among disciplines, applications and supply chain trading partners.

Envision options

There are always multiple possibilities for the future ‘to be’ state of processes and systems. It is important to sketch out and evaluate several options, even some that may initially seem far-fetched. Some will prove unrealistic, but they may provide insight or ideas for the paths that do make sense. It’s important at this stage to include people who might bring different domain expertise, experiences, and level of risk-averseness. Ensure that the entire enterprise is represented in this process. Selecting which option to pursue can be done by a smaller group, but they are ideally well informed through as many lenses as possible. Remember that many people are not fully exposed to modern MES in most companies - so it may take some special education to ensure everyone understands its roles and capabilities.
Craft projects

Based on the option you feel is most likely to move the company toward the Industry 4.0 vision, you can craft Industry 4.0 projects to focus on priorities. The important thing to realize is that while the basic technologies are available now, the standards for connecting and configuring them are not. So in structuring Industry 4.0 projects, companies may want to consider how to get some near-term experience, realizing it may not all survive into the long-term.

In parallel, exploring what the foundations are for long-term success will be critical. While it is tempting to focus on IoT and mechanics, each company must ensure that its IT infrastructure and core applications are ready for both massive amounts of new data flowing in and decentralized intelligence. In many cases, projects to shore up gaps in the information flows will be essential enablers for even pilot projects of some of the new technologies and more decentralized approaches.

A critical enabler for Industry 4.0 is the MES. Companies must ensure that they have this core set of production applications in place, in a current version, and integrated both horizontally across the supply chain and vertically for business process optimization. All of the characteristics we listed for MES are important for future viability and expansion into new models for the business, including smart products, services, supply chains and manufacturing.

Refine with learning

Perhaps the most important element of the path to the future is to get feedback regularly about Industry 4.0 and the technologies involved, the viability of the vision, and the specific areas where your projects did or did not work to expectation. Keeping this feedback in context is essential so that no one occurrence throws an entire project, program or vision into doubt.

The specific goals and vision the company sets will determine the best next steps toward Industry 4.0. Suffice it to say that things are already changing rapidly. As more assets become CPS and CPPS, the ability to execute on a bolder Industry 4.0 vision is tempting.

For many companies, the big question is: Are your systems capable and ready? From your business processes to your IT infrastructure and your applications, you need a full assessment.

The MES is at the core, so not only that application but its integration vertically and horizontally are critical. MES must be prepared to manage the flood of CPS and CPPS data in a logically decentralized way. Information must flow vertically and horizontally, with connection to mobile and sensing. Big data management and analytics will need to handle the real-time IoT and plant MES/MOM data as well as offline analysis.

The opportunity to be future-ready awaits with Industry 4.0 Do not hesitate to take the next steps toward this brave new world.

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**Iyno Advisors** combines experience, intuition, intellect, and research to focuses on how manufacturing and production companies and their network of partners can best benefit from software applications and services.

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