Smart Manufacturing

– The Landscape Explained

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FOREWORD

Industry analysts are predicting that the next decade of innovation, productivity and growth in manufacturing will be driven by the demand for mass customization and a convergence of technology advances that are enabling a new generation manufacturing infrastructure for "Smart Manufacturing"— technology advances in connected factory automation, robotics, additive manufacturing, mobile, cloud, social and digital 3D product definition. In fact, this new era of manufacturing is dubbed the Fourth Industrial Revolution.[1] [9] [10]

The technology advances and integration standards behind the connectivity of the "Internet of Things" (IoT) empower devices – from smartphones to smart shelves to sensor embedded automation controls – to be active participants in a new connected digital reality. The coupling of IoT technologies with advances in plant floor automation and information systems is referred to as the "Industrial Internet of Things" (IIoT). The new generation of IIoT-enabled smart machines for manufacturing will have onboard computers that directly support Internet protocols and allow direct communication with enterprise applications. Internet connectivity methods let companies thread external web services like social and cloud platforms into their processes, and enable more ways to connect internal systems inside the firewall of corporate intranets to mobile and analytical applications.

Emerging capabilities in additive manufacturing, advanced robotics, sensor-enabled equipment and other new approaches to fabrication, open new process improvement opportunities both in the plant and across the supply chain. Sophisticated computer modeling and simulation tools are evolving to give engineers far greater scope in designing a manufacturing process before building the production lines. These new technologies and capabilities are dramatically changing the management of manufacturing operations.

The next-generation Smart Factory feeds real-time information to a more empowered workforce through a combination of smart facilities, machines and equipment with built-in sensors, self-diagnostics and connection to other smart systems. Production processes in the Smart Factory can be optimized for best use of manpower, equipment and energy resources through simulation with digital representations and models. Smart Manufacturing encompasses and goes beyond smart machines, IIoT and the Smart Factory, recognizing that manufacturing processes in the 21st century go beyond the plant floor and must integrate the entire value chain that creates the final product. Smarter Digital Threads of product and process definitions and smarter connected manufacturing machines will come together with smarter manufacturing business processes to achieve the Smart Manufacturing enterprise.

We are not just dusting off old automation plans and putting new labels on them. Smart Manufacturing is the convergence of multiple technologies into a new generation of business processes and business models for manufacturing.

Why are these initiatives converging now? The reasons are, first, the convergence of the game-changing technologies briefly mentioned above, and, second, there is a renewed global recognition of the importance of

manufacturing to the economy. After decades of companies outsourcing manufacturing operations to countries with lower labor rates in order to reduce cost, the industrialized nations have realized the need to promote manufacturing within the country to maintain a healthy economy and robust middle class.

From a Wall Street Journal article titled "A Revolution in the Making", "Welcome to the New Industrial Revolution—a wave of technologies and ideas that are creating a computer-driven manufacturing environment that bears little resemblance to the gritty and grimy shop floors of the past," John Koten [9] writes, "The revolution threatens to shatter long-standing business models, upend global trade patterns and revive … industry."

Leaders around the world, from private industry, academia and government, recognize the opportunity for the next Industrial Revolution, and have formed initiatives to accelerate the Smart Manufacturing revolution. This revolution will shift paradigms in quality, productivity and global competitiveness. These initiatives aim to help industry, consortiums and standard bodies research and apply technologies and methodologies that will achieve transformational economic-wide impact, manufacturing innovation and global competitiveness.

In Germany, for example, the Federal government has set aside funding to underwrite Industrie 4.0., a government-sponsored initiative that focuses on research and development investments related to IoT and Smart Manufacturing concepts. The Industrie 4.0 strategy promotes connecting machines, autonomous sensor-actuator components and information systems to create intelligent networks and *cyber physical systems* – intelligent objects that communicate and interact with each other. The network of connected devices and systems will generate large data streams that can be harvested and analyzed for diagnostics, preventive maintenance, optimization and forecasting. The expectation is decentralized decision-making along the entire value chain and computerized and green methods driving clean, resource-efficient and sustainable production.

The United States government has sponsored several institutes, including the Digital Manufacturing and Design Innovation Institute (DMDII), a public-private partnership and manufacturing hub focused on advancing Digital Manufacturing technologies, and the Clean Energy Manufacturing Innovation Institute (CEMII).

An industry-led Smart Manufacturing initiative example is the Smart Manufacturing Leadership Coalition (SMLC), a group of U.S.-based industrial companies, universities, technology suppliers and laboratories working on Smart Factory connectivity and a next generation Smart Manufacturing Platform. The Industrial Internet Consortium™ (IIC) is another industry-led initiative example founded to bring together the organizations and technologies necessary to accelerate growth of the Industrial Internet. These industry initiatives, further explained later in this paper, demonstrate how manufacturers are moving forward and collaborating to achieve the next Industrial Revolution.

In addition to the efforts in Germany and the United States, Smart Manufacturing initiatives continue to develop around the world, and include China's "Made in China 2025," Korea's "Manufacturing Innovations 3.0" and France's "Usine du Futur."

Today's manufacturing systems usually have low levels of integration between office information technology (IT) systems and operations technology (OT) automation systems on the shop floor. For example, a small percentage of manufacturing equipment in use has Internet connectivity. The convergence of the plant-floor operations technology (OT) and business-level information technology (IT) would enable the data from a myriad of remote-device sensors, actuators, controllers, and security and safety switches to connect people and processes across the enterprise and throughout the supply chain. In addition, it would facilitate a secure, standards-based industrial network across the entire enterprise, serving as a common unifying intelligent infrastructure that supports electronic data exchange.

It is clear that Smart Manufacturing will serve as a key driver of research, innovation, productivity, job creations and export growth. The vision, whether called Industrie 4.0, Connected Enterprise, Smart Operations or Smart Factory, is rapidly accelerating, thanks to the Internet of Things (IoT), and the swift convergence of OT and IT technologies and organizations. The goals include a new level of productivity, safety, security, optimization and the transformation of data into insightful and timely information that gives decision makers across the enterprise new visibility into operations, improved opportunities to respond to market and business challenges, and the ability to drive inefficiencies out of operations. Industrial operations must change radically over the next five years, more than they have during the last 20. The good news is that much of the technology necessary to turn these visions into reality is a natural evolution of technology that already exists. Hardware and information system developers and architects will soon conquer the connectivity, safety and security hurdles that get in the way of connecting technologies for next generation Smart Manufacturing Platforms. This paper will further explain the terminology, concepts and multiple initiatives converging into Smart Manufacturing and the Fourth Industrial Revolution.

CHALLENGES WITH LEGACY MANUFACTURING SYSTEMS

New levels of connectivity, powerful and advanced computing, smarter sensors and devices, and improved data access and storage have created an opportunity to increase substantially the breadth, volume and resolution of available data. This data is providing significant business opportunity when properly aligned with technology advancements, including cloud-hosted software applications, mobile applications and predictive analytics. However, achieving the desired business outcomes involves overcoming challenges.

A typical manufacturing landscape is composed of diverse equipment that is different from area to area and coupled with multiple layers of software systems having different levels of adoption and maturity. Disparate software systems create challenges for organizations as they attempt to enhance how they harness and share information.

A list of common challenges in operations includes:

- Lack of visibility – inability to combine business transactional data with operational data to gain full visibility and control
- Lack of flexibility – inability to keep pace with changing processes and business needs
    - Difficult to innovate across continuously changing disparate operations and business system landscapes
    - Existing system of record applications (ERP, MES, homegrown) are designed for specific functionality but difficult to improve and extend to align with changing business needs
- Lack of interoperability – inability to get real-time correlated data from closed, proprietary systems and equipment
    - Isolated systems and proprietary equipment, automation, robots, PLCs and sensors
    - A diverse IT landscape, with systems at different maturity levels and varied equipment per site (especially when growing by acquisition)
    - Old and mission-critical systems and equipment that cannot be altered
    - Multiple data types, including unstructured transactional and time series
- Root cause analysis – requires correlation across multiple dimensions of data from multiple data sources. Poor user interfaces – user interfaces are numerous, archaic and often not available on mobile devices. Roles require the use of many user interfaces to many systems in order to perform a task
- Knowledge attrition – an aging and retiring workforce ultimately leading to knowledge, skills and business processes that have not been preserved and are not transferred to the replacement workforce
- Demands on IT resources – the IT project organization faces an escalation in demand for applications, resources and budget. Internal customers typically desire rapidly developed solutions deployed to mobile devices. Rogue IT organizations are created within operations. IT resources with the desired skills are hard to find and are expensive to retain
- IT/OT Convergence – analysts document well the convergence of IT and OT. This convergence has many facets with organizational and technical implications. OT (Operational Technology) is a term used to describe control

and automation technologies supporting operations, initially and intentionally separated from IT (Information Technology). This separation pertains to both human organizations and technical interoperability. Some examples of IT/OT convergence include the use of Microsoft technology in operations, the use of Ethernet in operations, increasing collaboration between IT and OT resources, and cross training of resources. A successful Smart Manufacturing program requires IT/OT convergence, while addressing OT safety and security concerns

- Rapid product and process change – change is constant in operations and has a compounding negative impact. Change drives the need for rapid development of enhanced applications. Often, technologies and organizations become obstacles to rapid change. Customers are more demanding, and desire a greater number of tailored products, in a shorter amount of time, with greater visibility into how they are made. Responding to customer demands is becoming more challenging, creating stress on legacy systems
- Process Diversity – in a large enterprise there are often multiple manufacturing styles (for example, blending, filling and packaging within one facility) and modes of manufacturing (make-to-stock, make-to-order, engineer-to-order, etc.). It is often suboptimal to address process diversity with one software solution, but organizations try to standardize because it is not easy to drop in solutions from different specialized vendors
- Data Validity – a closer look at some of the vast amounts of data collected on equipment often reveals that a significant amount of collected data is not accurate or consistent at all, due to evolving processes and the difficulty in maintaining accurate data collection systems

It is critical to provide immediate and actionable information to drive rapid and accurate decisions. This is difficult to achieve with legacy systems that lack the ability to communicate with other systems or provide role-based information with context. There are negative consequences associated with the typical state of operations solutions, including the following:

- Real-time performance monitoring and optimization is costly and time-consuming to implement, maintain and evolve
- Performance management is reactive instead of proactive, leading to:
    - Poor quality (scrap and rework)
    - Unplanned downtime
    - Reduced throughput and asset utilization
    - Higher inventory, including excessive WIP
    - Missed customer delivery dates
    - Frequent, unidentified and continually repeated day-to-day issues and failures

- Decision makers lack a consistent and unified method for monitoring, comparing and optimizing the performance of people, systems and assets within facilities and across the enterprise
- High costs for operator training and reduced productivity
- Modernizing production processes and performance management with traditional business systems is a costly, resource intensive and a multi-year effort
- Limited ability to innovate rapidly due to the diversity across people, systems and assets
- An enterprise cannot identify and unlock business potential from processes and data that span a highly diverse operations IT landscape

Traditional software is not sufficient to address the scale and diversity required of future Smart Manufacturing solutions given the forecasted number of connected assets and increased volume of available data; for example, automation systems that focus on the safe and reliable control of machines, but are not IT-centric nor oriented for data publication. They are optimized for data acquisition but not contextual data reporting and propagation. IT software typically cannot connect to the process and does not capture data at the resolution necessary to support operations.

Customer demands, competition and faster market activity have rendered traditional approaches to operations software architectures obsolete. Legacy architectures are not agile enough to adapt to rapidly evolving needs. Given the number of global sites, the existence of legacy systems, multiple data sources and types, costly integration, manual process and manual data collection cause significant challenges. There is a significant cost in updating and adapting these systems to provide the right information and processes to the right people at the right time.

However, manufacturing remains an optimal target for IT solutions due to the presence of a significant amount of accessible data, smart assets and the need for real-time information. There are many diverse systems and devices in manufacturing, and the more systems there are and the more diversity there is, the more potential value there is from connecting them (Metcalfe's Law).

Fortunately, it appears that conditions are changing. Internal OT and IT organizations have aligned and there is a new era of understanding and cooperation. Sensor technology is becoming cost effective and data is available from more devices than ever. Analytics solutions are viable and production-ready, and the promise of machine learning and predictive knowledge is real. Continuous improvement initiatives are pervasive and solutions are more agile, providing for proactive exception-based notification.

THE GOALS OF SMART MANUFACTURING

The adjective “smart” is applied to devices, like smartphones, to indicate they are enabled with advanced capabilities for two-way communication via the Internet, including self-identification, data from onboard sensors like GPS, easy configuration by the end user, and the ability to run downloadable applications (aka apps). In a similar fashion, when the adjective is used in the term “Smart Manufacturing” it means that manufacturing operations and systems are elevated to a new level of openness, connectivity and intelligence.

Smart Manufacturing is the endeavor to design, deploy and manage enterprise manufacturing operations and systems that enable proactive management of the manufacturing enterprise through informed, timely (as close to real-time as possible), in-depth decision execution. Systems with Smart Manufacturing capabilities are realized through the application of advanced information, communication and manufacturing process technologies to create new and/or extend existing manufacturing system components that are then synergistically integrated to create new or extend existing manufacturing systems that possess the desired advanced automation, analysis and integration capabilities.

To reach the goals of Smart Manufacturing, manufacturing resources (machines, equipment, people and factories) and the processes they carry out must be better when **automated, integrated, monitored and continuously evaluated** to enable people to work smarter, make timely informed decisions and run operations that are more efficient.

The improved Smart Manufacturing processes will handle and manage more operational complexity, should be less prone to disruption, and should be able to manufacture goods more efficiently. In such a manufacturing plant, information about the state of the enterprise passes **communications between people, equipment and enterprise and operations management applications in a natural yet structured manner.** This includes communications among the ecosystem of designers, producers, factories, suppliers and customers.

Smart Manufacturing allows **ubiquitous use of mined information throughout the product value chain.** This supports accurate and timely decision-making, benchmarking and continuous improvement of the supply, production, distribution and support functions.

Applying the Smart Manufacturing concept to the future **Smart Factory** can mean equipping it **with smart machines, robots, advanced sensors and intelligence** that can adjust or switch operations based on sensing the product, diagnostic or environmental conditions. This equipment should be able to publish data and receive instructions via open M2M standards and Internet protocols.

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