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Introducing Manufacturing 4.x for Smart Digital Manufacturing

Regardless of your manufacturing industry segment, manufacturing process, supplier tier, or the maturity of your business, one thing is clear: Your manufacturing enterprise will go through a continued digital transformation, no matter how digitalized you are today. The question is what, when, and how will that transformation take place?

That is precisely what this book is intended to answer for you, the manufacturing professional, in a practical and actionable way. We give you the tools to evaluate your market and competitive landscape and plan your digitalization roadmap.

Let us start with some real-world examples of how market conditions have pushed manufacturers to their tipping point – the point at which a step forward on their digitalization journey was required.

The Proform example

With 30 work centers running eight hours per day, Proform, a relatively small manufacturer of complex tubular parts based in Lyon, France, was successfully managing its production schedule with a three-person staff and an Excel software spreadsheet. Happily, the company was growing, but a key growing pain was determining when to migrate from the Excel scheduling approach to a targeted digital scheduling solution. The Excel approach held up through quite a bit of growth; but finally, when the company reached 260 work centers running 24 h per day, they had reached their tipping point. The company recognized that it needed visibility through as much as 18 months of planning and scheduling, but a 256-column spreadsheet gave them visibility only through one month – and that in an unwieldy form. To gain needed visibility, Proform adopted a software application designed specifically for manufacturing planning and scheduling. The system receives orders directly from the company's enterprise resource planning (ERP) system and, using powerful algorithms to process large amounts of data quickly, it interacts with the manufacturing execution system (MES) to implement the work schedule and keep planning up to date. With this solution in place, only one staff member is needed to manage 1500 continuous work orders from 7000 referenced finished products, including 1000 that are custom made – freeing up two staff members to focus on other duties. Proform increased its administrative efficiency by 87% and improved its on-time delivery to 96%.

Smart Digital Manufacturing: A Guide for Digital Transformation with Real Case Studies Across Industries,
First Edition. René Wolf and Raffaello Lepratti.

The chemical company example

When a global manufacturer of specialty chemicals decided to double its paint and coatings production capacity in the United Kingdom, the decision-makers opted for a new plant. They chose manufacturing technology for this facility with the goal of making it the world's most advanced and sustainable paint factory. But because this plant is only one facility in chemical manufacturer's global production network, what digital system would best support not only the new manufacturing operation but also all the interactions of that new facility with the rest of the company? With this need for a common digital ecosystem in mind, the company chose a fully integrated digital system for the new plant that manages all manufacturing technologies from a single computer system, so that every activity – from ordering raw materials to shipping finished products – can be initiated without operator intervention. The digital system enables the plant to produce paint products across the entire, extensive product portfolio, while also reducing waste by 50% and hazardous volatile organic compound (VOC) emissions by 75%. The digital system's open platform means that interfacility integration is straightforward.

In very different ways and along very different routes, both Proform and the specialty chemical manufacturer have equipped themselves to achieve ongoing performance gains in their manufacturing operations. Because the means by which they are making these performance gains include digital technologies that are new to them, one could say that each company has successfully navigated uncharted waters in the realm known as ***Industry 4.0*** – but Industry 4.0 was neither the goal nor the point of focus during their journeys into digitalization. Instead, they started out with a set of issues and ideas similar to those experienced by a broad array of manufacturers across the globe and across the industrial spectrum, issues and ideas pertaining to their particular manufacturing operations and goals, not to Industry 4.0 or smart manufacturing or a digital transformation. Only as they began seeking ways to address these manufacturing issues did digital technologies enter the discussion – as a means of solving manufacturing questions, not as an end in and of themselves.

As we work with diverse companies in the manufacturing space, we hear similar questions about manufacturing issues, over and over:

- How do we keep up with new or growing demands from our customer base?
- How do we raise productivity without sacrificing quality?
- What new practices and technologies should we adopt to reduce time to market for new products?
- How can we improve our on-time performance?
- What must we do to cost-effectively manufacture smaller and smaller lot sizes?
- If the solution is found in Industry 4.0, what exactly does that mean for our particular manufacturing operations?

This last question epitomizes the predicament in which many of the manufacturers with whom we work are finding themselves. To remain competitive, they know that they must embrace the Fourth Industrial Revolution and make tough choices about digital investments (Figure 1.1). But their area of expertise is bending

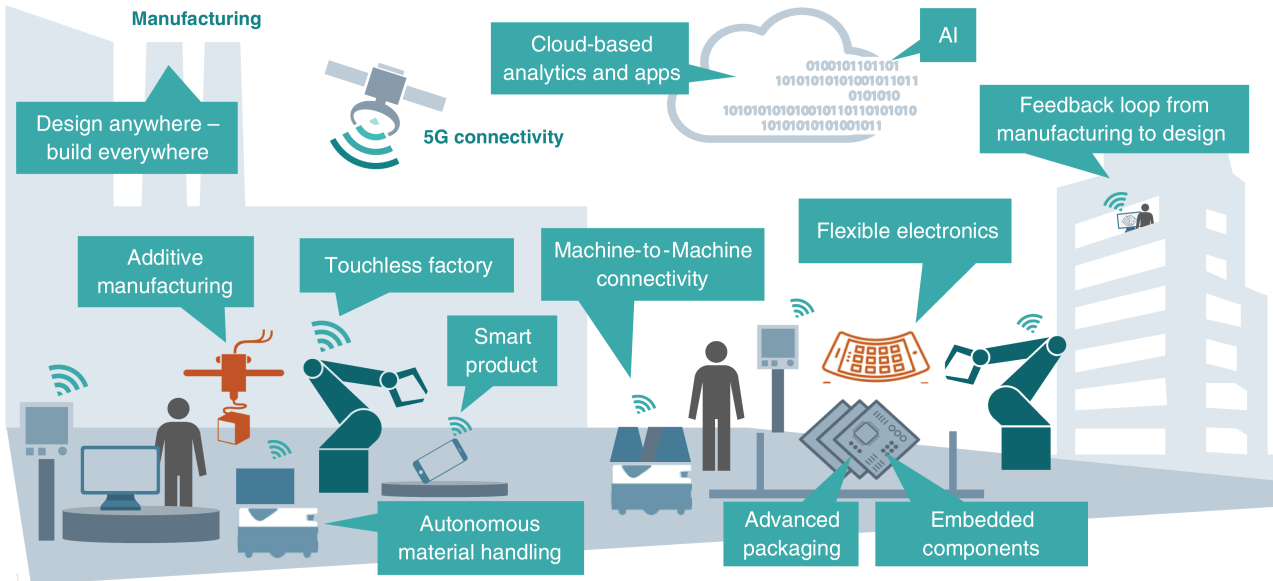

Figure 1.1 A radical change for manufacturers.

and forming metal tubes, or formulating and producing paints – not IT. Or, at larger companies with IT departments, the intersection of digital and manufacturing engineering is not yet established well enough to support such critical decisions.

The proliferation of digital manufacturing technologies is overwhelming to many of these companies. Those individuals responsible for digital planning are often perplexed by the alphabet soup of digital solutions – for quality, execution, planning, scheduling, and intelligence – and they have been given no tools to prepare for making informed decisions about which of these technologies to implement in their factories, and when. Worse yet, some manufacturers have arrived at our doors in a state of decision-making paralysis, having heard as many stories of digital failure as digital success.

At the same time, new market pressures are compressing the timetable for manufacturers to make digitalization plans and decisions. We delve into these market pressures and their impacts in the next chapter; for now, think about the impact on the management of manufacturing operations when a major automotive original equipment manufacturer (OEM) made the decision to expand its model offering. The company was entering a car segment that requires higher volumes and more highly automated processes than before. In today's market conditions, the company needed a digital solution that would help them ensure a fast time to market for new products, manage more than 70 000 configurations, and implement automated processes to help reduce costs while keeping the highest quality standards of their brand. The market pressures to accomplish these kinds of outcomes are growing and intensifying.

If you count yourself among those needing clarity in the midst of this confusing marketplace, we have good news for you. Like it was for Proform, the specialty chemicals company, the automotive OEM, and thousands of other manufacturers – ranging from small businesses to global conglomerates, startups to centuries-old concerns, nanotechnology manufacturers to makers of airliners, water bottlers to specialty petrochemical companies, and those located in tropics to frozen tundra – successful digital transformation, and the vast benefits that come with it, is a handful of practical steps away.

1.1 From Industry 4.0 to Manufacturing 4.x

Before addressing the solution, it is good to understand the nature of the problem. How did the manufacturing world arrive at this state of disarray and discomfort with the digital journey? Here are some of the key factors:

Digital pace of innovation: "Exponential" may or may not be technically accurate in characterizing the pace of change in digital technologies, but it sure feels that way to many of us. You install a production planning and control (PPC) system and along comes advanced planning and scheduling (APS). Does APS replace

PPC? Overlap with it? Do you need both? The proliferation and advancement of digital technologies is not just unrelenting but also accelerating. Many of these technologies apply to your manufacturing floor – but some do not. How do you know which is which?

The inertia of homegrown solutions: Many manufacturers we have encountered developed digital solutions of their own years ago, often out of necessity because the specific set of capabilities they were seeking did not exist. These homegrown systems were often quite capable and successful. So, as manufacturing needs grew, such a company would continue to modify and patch these solutions to meet new challenges. While these system upgrades work sufficiently well for a time, the manufacturer remains tied to a custom solution that can be maintained or modified only by a small number of individuals possessing tribal knowledge. The more capabilities these systems offer, the harder (and more expensive) it is to part with them, so more capabilities are added, making them more complex and more tied to those few individuals … and so on. With each system upgrade, the manufacturer's business risk is growing: an employee with knowledge of the system leaves the company; the system breaks down; or it simply cannot scale at the pace of the rest of the market or one's competitors. The thousands of homegrown systems still in operation, and the tribal knowledge on which they depend, also cloud the industrial world's ability to comprehend or evaluate all the digital solutions available.

Digitalization knowledge gap: As noted above, neither Proform nor the specialty chemicals manufacturer set out to implement Industry 4.0; they adopted digital tools to meet the specific productivity and quality goals they had. How did they know which technologies to adopt? The difficulty for many manufacturers is a disconnect between their defined manufacturing performance goals and knowledge of the digital solutions that address those specific goals. Flooded with offers by companies vaguely promising a digital transformation that will address their requirements, they still lack the information needed to connect their manufacturing goals with these digital solutions. And with the proliferation of digital technologies, they have limited tools to cut through the clutter to the systems that actually do address their needs.

Abstract terminology: The term Industry 4.0 was coined to identify a strategy of the German government to promote the general computerization of manufacturing. The term, and likewise smart manufacturing, has come to describe an emerging phenomenon in manufacturing. Industry observers and prognosticators had previously identified a first (mechanization with water and steam power), second (mass production and assembly lines), and third (computers and automation) industrial revolution, and they defined the Fourth Industrial Revolution as an extension of computerization into autonomous systems, smart devices, interconnectivity, and real-time data. All well and good – but what does all this mean at a real factory? Industry 4.0, smart manufacturing, digital transformation, and other similar terms are visionary and aspirational, but lack the specificity to be helpful in a practical way.

So, these familiar but abstract terms need a clear and practical counterpart, especially in the midst of an increasingly complex, competitive environment. The payoffs of successful digitalization are high, but the risks are also high. Something is needed to bridge the gap between the concept and ideal of Industry 4.0 and the reality of choosing and implementing digital manufacturing technologies.

We conceived Manufacturing 4.x for Smart Digital Manufacturing (referred to as Manufacturing 4.x subsequently) to translate the lofty ideas of Industry 4.0 into a practical, implementable strategy. It builds on the specific knowledge Siemens has gained, not only as we have innovated a broad array of digital technologies but more importantly as we have successfully implemented them. Our goal in this book is to share with you the successful, practical strategies that we have employed to realize a digital transformation in our own factories and across a full spectrum of manufacturing enterprises around the globe. We are emboldened to write this book for two reasons. First, we hear a rising pitch of urgency in the voices of manufacturers seeking to be equipped for the digital future. They need practical information and advice.

Second, we recognize that our unique position among digital solution providers gives us an especially helpful knowledge base to guide manufacturers making choices among digital technologies. Siemens makes much more than digital solutions. Although we are a global technology company with core activities in the fields of electrification, automation, and digitalization, we are also a leading supplier of power generation, power transmission, and infrastructure solutions, as well as printed circuit board (PCB)/box build electronics, medical devices, and transportation systems. In other words, we are manufacturers, too, and our manufacturing branches need digital solutions as urgently as all our manufacturing customers do, so we have sat on both sides of that table. We also have experience implementing digital solutions in companies as diverse as Proform and the specialty chemicals manufacturer, companies of every size utilizing discrete manufacturing, process manufacturing, repetitive manufacturing, and every combination of these kinds of operations. Finally, we continue to service digital systems with one of the largest manufacturing solution services organizations in the world.

In building out the Manufacturing 4.x practical roadmap, we have informed our strategy by applying our hard-earned knowledge of digital solutions, our applied experience across industries, and our own experience manufacturing Siemens products. If this book fulfills its mission, our readers will gain a clear understanding of what digital technology has to offer them, and how and when to invest in these essential components of tomorrow's factories.

1.2 Manufacturing Operations: The Permanent Functions to Which Manufacturing 4.x Is Applied

The heart of the digital enterprise for manufacturers, and the central focus of this book, is manufacturing operations management (MOM). As a term, MOM was coined in the early 2000s. In the digital realm, MOM helps bridge the virtual world of product ideas, computer-aided design (CAD), and planning to the real world of production. Specifically, it links ERP and product lifecycle management (PLM) solutions, which integrate data, processes, and business systems, to the manufacturing floor's production machinery and automation. Importantly, the *functionality* of manufacturing operations management has existed since the second industrial revolution – long before digitalization began. MOM functions (Figure 1.2) always need to occur in any manufacturing setting. What changes is the mechanism or system that performs MOM functions, and the delivery mechanisms for those functions.

To illustrate this distinction between MOM functionality and MOM technology, let us take the example of a boat manufacturer in operation today. For this manufacturer, the design of a new custom boat hull – even one incorporating new manufacturing technologies or newer high-performance materials like composites – is drafted on paper using ship's curves, ducks, and splines. Work instructions and a materials list are created in a word-processing program and printed. The boatbuilder estimates and informs the customer of a delivery window. The shop supervisor walks into the materials storage area and selects or orders the needed materials. These materials are then staged on the production floor and double-checked, as is the operational status of any manufacturing equipment to be used. Floor operators follow the paper instructions to build the hull, pausing as indicated to allow for visual inspection of the work in progress. Various floor personnel sign off on critical steps on a paper traveler that memorializes the fabrication of this particular hull, which is then moved to the next manufacturing floor or work area to be assembled with the rest of the boat's components. The boatbuilder also interacts directly with regulatory authorities and fills out any required compliance paperwork.

During the hull-building process, the boatbuilder continues to take orders for this boat, hand calculating an estimated time to initiate production and complete delivery. The boatbuilder may also incorporate changes to tailor the hull to each specific customer's desires, or to improve upon the initial design. The work instructions are updated accordingly and reprinted for the next work cycle.

Digital technology enters this manufacturing process in only the most rudimentary ways, yet the boatbuilder is completing the same functions as the latest digital MOM system:

1. Provide the instructions for manufacturing a product on the shop floor.
2. Make sure the right material and parts are available to manufacture the product according to the specification.

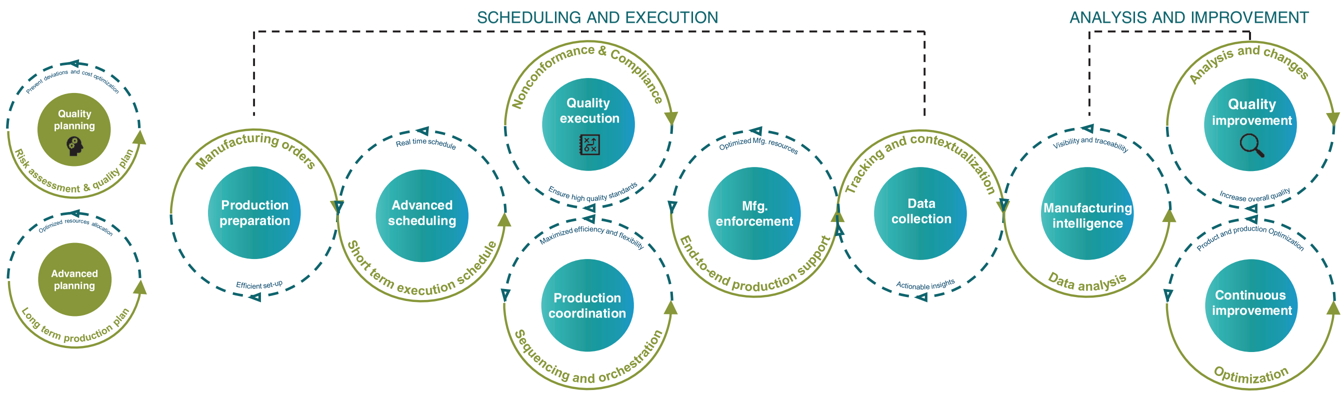

Figure 1.2 An example of typical MOM functions.

3. Verify that operators are properly certified and trained.
4. Verify that machines are maintained and correctly calibrated.
5. Schedule production according to manufacturing orders and available shop floor resources/machines.
6. Manage actual production activities, equipment, and processes.
7. Ensure the rapid incorporation of changes to production requirements, including product specifications, materials, orders, and/or resource availability.
8. Collect production data and provide access to other functions for planning and quality purposes.
9. Enforce quality processes and support analysis of defects.
10. Track, trace, and create a genealogy for regulatory compliance.

Despite a radically different pace and manufacturing approach, a smart factory manufacturing boat hull nevertheless goes through these same MOM functions:

1. Send the hull's electronic bill of process (BOP) to the shop floor, including an electronic recipe for the operators to follow.
2. Use an MES resource allocation and control module and its materials-tracking capabilities to ensure that the right material and parts are available to manufacture each hull.
3. Use the MES labor management module to oversee training, certification, and work assignments of each operator involved in building the hulls.
4. Use maintenance operations management on the MES to track and verify that machines to be used in hull production are properly maintained and calibrated.
5. Use the APS system to schedule production of these hulls (including variations and customizations), along with production of other hull models, in accordance with manufacturing orders and available shop floor resources/machines.
6. Use MES to manage the actual production of each hull and to conduct real-time performance analysis and view key performance indicators (KPIs).
7. Enter engineering change orders (ECOs) and have the MOM system automatically adjust hull specifications, materials, orders, or resource availability as needed.
8. Employ the MES data collection and acquisition module to collect production data from each hull built. Automatically provide the appropriate subset of this data to the APS system and the quality management system (QMS).
9. Perform quality operations management on the MES and link to QMS to support analysis of defects.
10. Automatically track and trace all production and inspection details associated with each work order, and automatically populate genealogies and other documentation for regulatory compliance, as well as root cause and predictive/prescriptive data analysis.

The types of manufacturing systems associated with MOM

Manufacturing execution system (MES): A software solution that ensures that quality, and efficiency are built into the manufacturing process and are proactively and systematically enforced. An MES may connect multiple plants, sites, and vendors' live production information, and should integrate easily with equipment, controllers, and enterprise business applications. The result is complete visibility, control, and manufacturing optimization of production and processes across the enterprise.

Advanced planning and scheduling (APS): A digital solution that helps manufacturers to manage production planning and shop floor scheduling. Using advanced algorithms to balance demand and capacity and generate achievable production schedules, APS software results in shorter lead times to meet customer demands and easier, more rapid responses to unexpected production changes.

Quality management system (QMS): Software that enables manufacturers to electronically monitor, manage, and document their quality processes to help ensure that products are manufactured with in tolerance, comply with all applicable standards, and do not contain defects. QMS software provides the procedures, processes, structure, and resources needed to streamline manufacturing and ERP operations while cost-effectively managing quality issues.

Manufacturing intelligence: Software that integrates, connects, and unifies data sources from other MOM systems, as well as enterprise software, into one accessible analytical data model. Manufacturing intelligence provides capabilities to explore and drill down into contextualized data. It is used at the plant level to improve collaboration and data exchange between the shop floor and enterprise systems, and/or at the enterprise level to benchmark and compare production runs or predict various plant operations.

These two disparate approaches illustrate the what of manufacturing operations management does not change. But basically, everything else does: the how, where, by whom, when, and even the why continually evolve. As we begin exploring MOM technological phases and options, it helps to stay grounded in the fact that the manufacturing floor is accomplishing the same functions it always has, just with much greater efficiency and efficacy. As depicted in Figure 1.3, to enable an agile, connected and optimized enterprise, Manufacturing Operations Management functions are critical to be digital brain for smart manufacturing.

Our focus in this book is on *how* these MOM functions are performed. *Where* they are performed – in an on-premises system, through the Internet of Things (IoT), and in the cloud – will also come into play, but these two categories should not be conflated. We have heard vendors and manufacturers in certain industries say, "You don't need a MOM solution anymore; you can go straight to IoT." This is analogous to saying, "Your computer doesn't need data storage functionality anymore; you have the cloud." Whether your data is stored on your hard drive or in the cloud, your computer must still perform the functions of retrieving, formatting, and sending data to the storage location.

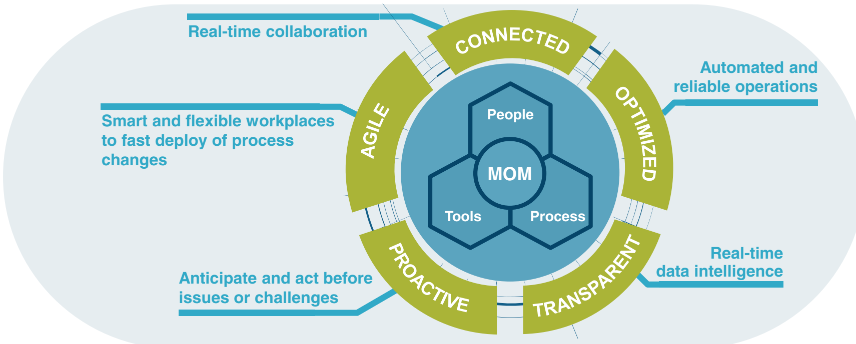

Figure 1.3 MOM – digital brain for smart manufacturing.

So, we are focusing on the technologies used to perform MOM functions. These technologies continue to evolve, and we provide classifications and descriptions of MOM evolutions. From the perspective of the manufacturer, though, the general maturation of each MOM technology is a secondary concern. The primary concern is the performance gains a particular MOM technology will afford *me* on *my manufacturing floor*. Whether the technology has been around a long time or has just been launched, if my factory is moving from a slower, less effective technology to one that is new to me, then I will glean the benefits of this implementation. After all, the purpose of adopting new MOM technologies is to raise product quality and value, and manufacturing productivity, not to raise MOM technological maturity.

To conclude: our practical roadmap – Manufacturing 4.x – is designed to maximize the rate at which your manufacturing enterprise improves performance. The roadmap will help guide your decision-making to keep this rate of improvement optimized for your particular operations in your particular industry.

- Manufacturing 4.x is the stepwise implementation of smart digital manufacturing.
- Rather than a large, all-at-once undertaking, smart digital manufacturing allows companies to invest incrementally in digital solutions through a process we call Manufacturing 4.x.
- Smart digital manufacturing is a transformative journey into digitalization of your manufacturing enterprise; Manufacturing 4.x is the roadmap for that journey. Tipping points are the signposts on that roadmap.