Smart Manufacturing: A Primer for Small Manufacturers

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Smart Manufacturing
Primer for Small Manufacturers

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ALLIANCE FOR MANUFACTURING FORESIGHT

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KEY TAKEAWAYS

It is easy to be overwhelmed by the hype and promise of smart manufacturing. This primer aims to provide a clear summary of smart manufacturing technologies, applications, and impacts, to provide small and medium-sized manufacturers (SMMs) with tools and knowledge to begin to make the necessary decisions to be successful in the coming smart manufacturing world. The purpose of this report is to help SMMs focus on realistic objectives achievable with appropriate implementation of digital technologies to cut costs, improve existing processes, and lay the groundwork for continued progress. It is also important to recognize that the biggest hurdles to effective implementation are not likely to be technical, but rather managerial and cultural.

1. Smart manufacturing, digital manufacturing, digital transformation, Industry 4.0, factory of the future and similar terms all refer to the growing application of computer-based digital technologies, high-speed communications, data analytics, and new material transformation processes such as 3D printing and collaborative robots.
2. Smart manufacturing technologies will transform how manufacturing is done, affecting quality and productivity, relationships across supply chains, skill requirements, and investment decisions. The pace of change will vary somewhat across industries and market segments, but SMMs are not immune to the changes.
3. Smart manufacturing can reduce scrap and rework, minimize work-in-process, monitor machine conditions, help improve quality, optimize use of materials and energy, eliminate production bottlenecks and improve equipment efficiency, speed new product introductions, and allow more product customization and variety, while reducing costs and potentially raising profitability.
4. SMMs cannot afford to remain on the sidelines. Smart manufacturing is already disrupting supply chains.
5. Smart manufacturing is not accomplished simply by adding new production technologies to existing factories. Buying new equipment without a clear strategy and objectives will be a waste of money.
6. Smart manufacturing is not new. Manufacturers have been implementing smart technologies over the last two decades. What has changed is the wide availability of cost-effective networking, data processing, modeling and visualization technologies. The pace of change has increased.
7. It is critical to engage and prepare the workforce. Working in automated shops using digital files and data analytics requires new skills and greater teamwork.
8. Cybersecurity is a real issue that can affect manufacturers of all sizes. Effective cybersecurity practices are absolutely essential. These include building cybersecurity awareness and best practices for every staff member.
9. More than larger companies, SMMs are dependent on vendors to implement smart manufacturers. SMMs need to choose vendors wisely based on well-defined needs and objectives, not sales pitches. SMMs should seek partnerships where vendors are engaged, resources can be replicated, and piecemeal approaches can be avoided.
10. Resources are available at local technical schools and universities, institutes, state and local development offices, and MEPs to help SMMs. They can help evaluate vendors, set strategy and define objectives, train workers, and work through implementation, including cybersecurity.
11. Get started. Start small. With the right approach, there will be immediate benefits from relatively small investments and risk. Waiting will not provide any advantage but will increase risks that competitors, or even customers, will take your business.
12. Effective implementation of smart manufacturing technologies requires cultural change within the company, including buy-in from production workers, supervisors and senior management. Starting on small pilot projects and demonstrating the benefits is the first step.

INTRODUCTION

Application of digital technologies to production processes, supply chains, product design, and products is changing what is possible to do in factories and what customers expect. Faster, better, cheaper have always been demanded from suppliers, and now smart manufacturing technologies are providing the ability to meet those demands…and still make a profit.

So far, large manufacturers have taken the lead in developing and implementing, or at least experimenting with, smart manufacturing technologies (also called Industry 4.0). As the cost of these technologies continues to fall, they have become more accessible to small and medium-sized manufacturers (SMMs), and as they become more pervasive, large customers will expect SMMs to use them. Most SMMs do not have the people, resources, or time to devote to a full-scale digital transformation and there remains a gap where vendors may or may not be able to work with SMMs. Knowing what the technologies are, what steps are needed to use them effectively, and what changes they will create in areas such as skill requirements, capital investment, and competition will help SMMs understand how to get started.

Smart manufacturing is already creating new opportunities such as:

- Lower cost through better uptime, higher machine utilization, and less waste;
- Higher quality with fewer defects, less scrap and rework, and ability to hold tighter tolerances;
- More efficient supply chain and inventory management with increased timeliness and better traceability;
- Vastly improved design and production flexibility enabling increased customization to meet growing variability in consumer demand while maintaining cost and quality requirements;
- Improved safety and better workforce satisfaction; and
- New business models, such as subscriptions with monthly payments replacing equipment sales (also known as Product-as-a-Service).

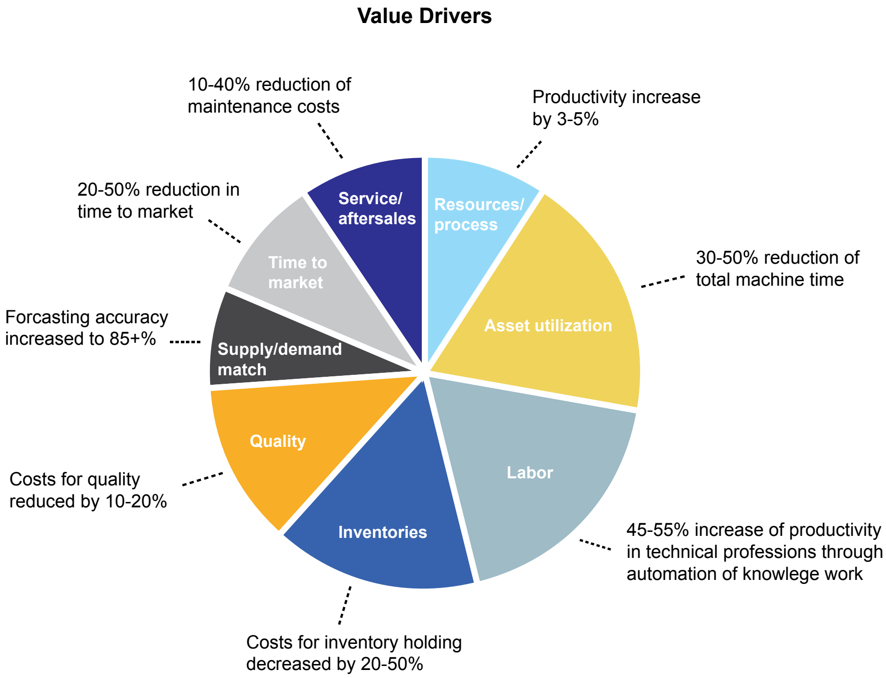

Figure 1: Benefits from Smart Manufacturing[1]

A 2015 McKinsey study estimated the benefits that manufacturers could expect from smart manufacturing across a variety of value drivers (Figure 1).[1]

That same McKinsey study provides examples of the inefficiencies created by common data management shortcomings in current typical manufacturing operations (Figure 2).

The benefits accruing from smart manufacturing technologies depend on the industry, the current state of technology being used, the company's position in the supply chain, and, of course, which technologies are implemented and how. The technologies that are typically included, listed from hardware to software, are:

1. Additive manufacturing, also known as 3D printing;
2. Robotics and automation, especially newer robots that are easily programmed for multiple applications and can work collaboratively with employees, called cobots;
3. Sensors, especially inexpensive sensors to detect conditions like temperature, vibration, and noise on both new and legacy equipment;
4. Wearables, such as virtual reality (VR) and augmented reality (AR) glasses and exoskeletons;
5. Modeling, simulation, and visualization, including AR/VR and digital twins;
6. Data capture and analytics, sometimes referred to as Big Data, but which starts with small data;
7. Cloud and edge computing and storage;
8. Artificial Intelligence/Machine Learning;
9. Blockchain.

Sometimes these categories overlap and vendors will sometimes use their own terminology, which can be confusing. In general, however, these are the technologies that comprise digital, smart manufacturing. Much of the literature also includes the Industrial Internet of Things (IIoT) in this list, but the term is not well defined and tends to encompass many of the technologies in the list. For instance, sensors embedded in products to provide information on usage patterns, uptime, replacement rates, and other factors extends the sensor and data-based aspects of smart manufacturing to products, the 'things' in IIoT. (The next chapter will review each technology.) There are also enabling technologies, such as communications networks, that will require investment in equipment and skills that SMMs have not needed in the past. **Ultimately, the greatest benefits will flow from effective integration of these individual technologies into manufacturing systems that encompass operational technology (OT), information technology (IT), and the skills needed to function smoothly throughout supply chains.** Put another way, individual

1 "Industry 4.0: How to Navigate Digitization of the Manufacturing Sector," April 2015, McKinsey & Co.

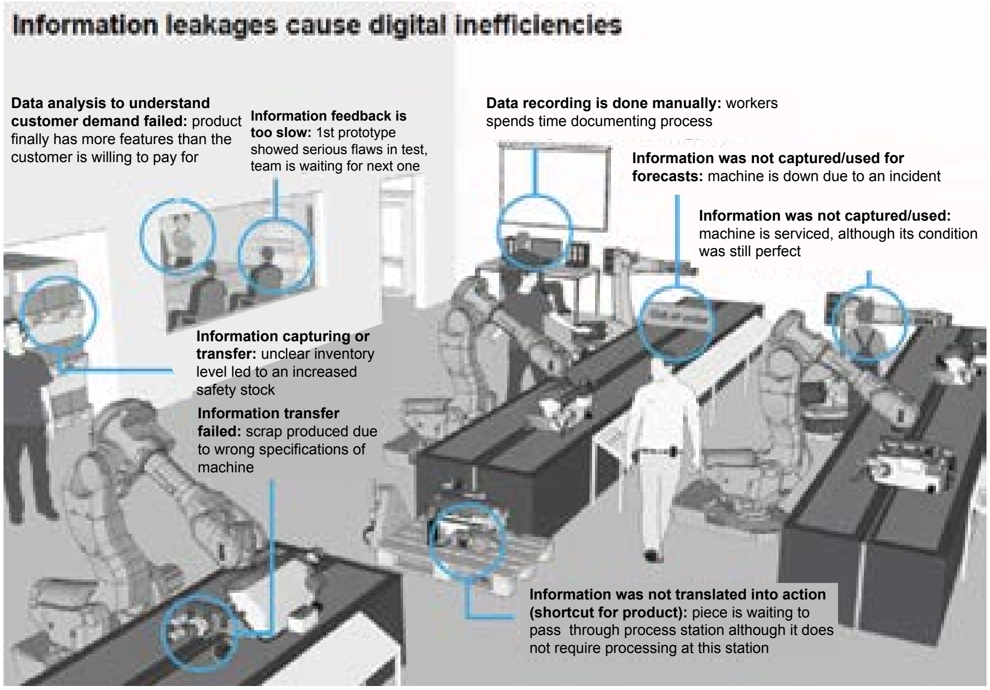

Figure 2: Inefficiencies that Smart Manufacturing can Overcome (Source: McKinsey Digital, 2015)

technologies are important but even more important is how the technologies are composed into systems and integrated into manufacturing practice. The starting point with technology, systems, and practice does not need to be complicated but it does need to be recognized as the start of a journey.

Most of the readily available examples of experience with these technologies refer to large manufacturers and product offerings from equipment suppliers, software vendors, and a growing number of consultancies. Technology appropriate for large, multi-plant manufacturers may not meet the needs of SMMs. Because technology is changing so rapidly and SMMs are focused on filling orders (getting product out the door), they are frequently dependent on vendors' sales pitches for information about smart manufacturing. **This primer aims to provide a clear summary of smart manufacturing technologies, applications, and impacts, to provide SMMs with tools and knowledge to begin to make the necessary decisions to be successful in the coming smart manufacturing world.** In a short introductory report, it's not possible to be comprehensive, so links throughout the report provide additional resources for more information on specific technologies.

Don't think about the technologies in silos; some of the biggest benefits will come from the mashups of these technologies. For example, AR will bring significant benefits to reducing unplanned downtime but adding AI image recognition might help identify problems and equipment types as operators approach machines to get a start on troubleshooting. Blockchain may simplify remote resource billing. Digital Twins might allow dynamic usage models to be leveraged in troubleshooting.

BEGINNING THE TRANSITION

Recognizing the pressures constantly facing SMMs, a digital transformation is easier said than done. For SMMs, in fact, it is more helpful to avoid the concept of transformation and to focus on realistic objectives achievable with appropriate implementation of digital technologies to cut costs, improve existing processes, and lay the groundwork for continued progress. For SMMs, the value in smart manufacturing today does not come from artificial intelligence, Big Data, or other buzzwords, but from more basic calculations of trends on a few data streams. Focusing on well-defined operational improvements, which could be in marketing and sales as well as on the shop floor, will help to identify targeted investments with immediate impact.[2] A key point to remember is to focus on solving real business problems and achieving continuous improvement, not to simply invest in a new technology hoping it will make things better.

Basic preparation for implementing smart manufacturing begins with having full understanding of current operations, challenges to be solved, future expectations, and long-term opportunities. For example, to effectively identify opportunities to apply smart manufacturing technologies, SMMs need to identify Key Performance Indicators (KPIs), to understand existing process deficiencies and improvement opportunities, and to recognize steps needed to prepare and train employees for change. Surveys indicate that less than half of SMMs have made these preparations. Outside consultants from the local MEP, technical college, or university can help.

Some SMMs are better prepared than others to begin implementing smart manufacturing, for instance, because existing systems are up to date, Enterprise Resource Planning (ERP) software is already used, and best practices for

2 "Get Smart: Driving the Value of Data with Smart Manufacturing," CESMII and OSIsoft, at https://www.osisoft.com/whitepapers/Driving-the-Value-of-Data-with-Smart-Manufacturing.pdf

cybersecurity have been implemented. As with many pressures facing SMMs, lessons can be learned from the experience of others, small steps can build to large cumulative impact, and existing in-house resources can be marshaled to make quick progress. Based on experience to date, a few lessons are emerging.

Lesson 1: Sooner is Better

The digital disruption embodied in smart manufacturing is already here, coming faster than many companies realize. Numerous studies have shown that applying smart manufacturing technologies conveys first mover advantages. For instance, a 2018 survey found that mid-sized companies that are more advanced in implementing digital technologies grow substantially faster than lagging companies.[3] **Manufacturers can either be proactive and begin to generate the benefits, move up the learning curve, and attack new opportunities, or wait until specific aspects of digital technologies are imposed by customers.** For instance, anecdotal evidence suggests that some Original Equipment Manufacturers (OEMs) and Tier 1 suppliers will soon require their suppliers to provide real-time data on the production status of parts (to enhance traceability) or be dropped as suppliers. **An apt analogy might be quality systems: many SMMs only implemented quality systems after their customers made registration to the ISO 9000 quality standard a condition of continued business, but then saw unexpected benefits from having a rigorous quality system in place.**

In a recent survey, McKinsey found that only 8 percent of respondents think that their current business model will remain viable through the disruption caused by digitalization. Their research also indicates that most firms that do not adapt their business models to the opportunities created by digital technologies will fail (Figure 3).[4]

Investing in new technologies and changing

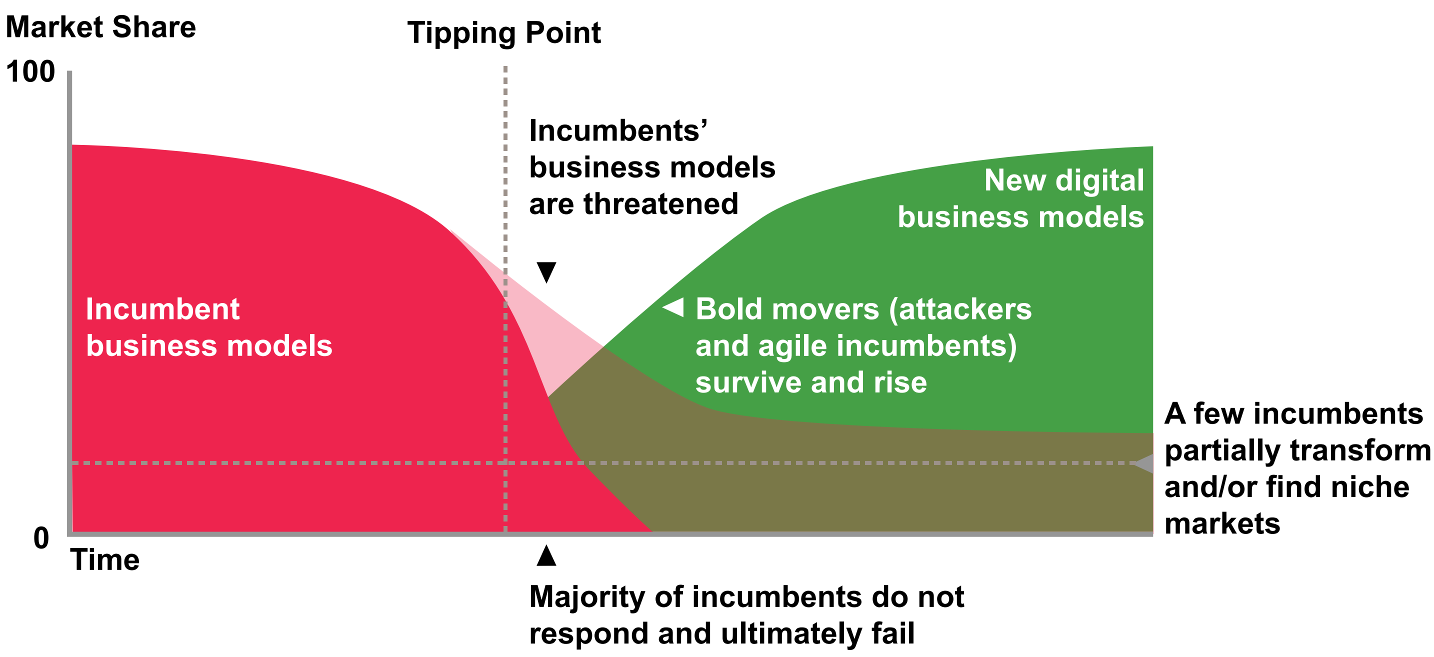

Figure 3: Old Business Models Overwhelmed by Digital Business Models[4]

3 National Center for the Middle Market, "2019 1Q Middle Market Indicators," at https://www.middlemarketcenter.org/Media/Documents/MiddleMarketIndicators/2019-Q1/FullReport/NCMM_MMI_Q1_2019_FINAL_web.pdf
4 J. Bughin, T. Catlin, M. Hirt, and P. Willmott, "Why Digital Strategies Fail," McKinsey Quarterly, Jan. 2018.

business models are daunting prospects for many SMMs, who tend to address short-term tactical issues with little attention to long-term strategy. Avoiding the failure that is likely without a strategy for digital transformation should be sufficient motivation.

Lesson 2: Honest Assessments Provide Needed Focus

A first step for SMMs considering smart manufacturing technologies is to conduct an honest assessment of their operations, both internal and external, to identify specific opportunities to apply smart technology. Every plant has bottlenecks, equipment more prone to breakdown than others, staffing issues, and other production problems. Sometimes problems arise in supply chains with delays, quality issues, or shortages. Critical issues can also arise in customer relations. Assessing which of these types of issues are most common, most important to business success, and most amenable to solutions from targeted investments in smart technology will maximize impact—especially financial benefit—and help avoid waste and disappointment when results fail to meet expectations.

A number of assessment tools are already available; others are in development. For instance, NIST has developed the **Smart Manufacturing Systems Readiness Level Tool**, a self-assessment to help determine the readiness of a factory to undergo smart manufacturing technology improvements. TeamNEO, a business development group in Northeast Ohio, has developed an IIoT **readiness assessment tool** that provides a high-level assessment of readiness to adopt IIoT. Many local **MEP** centers offer free assessments, such as this one by the **California Manufacturing Technology Center.** A typical assessment covers questions such as:

1. What types of data are created and collected digitally? Examples include product designs, work orders, production and maintenance schedules, machine performance, and work orders.
2. What data are digitally exchanged with customers and/or suppliers? Are they asking to exchange data electronically? What types?
3. Do machines exchange data digitally?
4. Are digital designs, three-dimensional (3D) models, and simulations used?
5. What software is used? How old is it? What hardware supports it?
6. Are policies, tools, programs, and training in place to increase cybersecurity?

Lesson 3: Start with the Data You Have

Start with a small pilot project that has a high probability of a successful, measurable business outcome and realize that the digital transformation is not the result of one project, but a series of continuous improvements through on-going projects. Every factory, no matter the age of the equipment, has data. It is estimated that 70 percent of that data is not used, either because the information is trapped in the machines, the paper outputs are unusable, or manual collection is inconsistent and prone to error. Examples include machine data, such as run time, tool use, and mean time between failures; environmental data, such as temperature and humidity; and measurement data. Other typical data collection includes work-in-process (WIP), inventory levels, yields, input costs and volume, and direct and indirect labor costs. Most companies collect and analyze production data for quality control and production costs, even if only intermittently. It's key to recognize that this existing data, often easily obtained, can be aggregated and elevated in use beyond its original production purpose for greater insight.

For many firms and factories, the major barrier to increased use of data to inform KPIs has been the time required to pull the data together and define it for further use. Data must be gathered manually, formatted consistently, and entered manually into analysis software—often Excel spreadsheets. This process is slow, requires people that may be needed elsewhere, is prone to errors, and likely only applies to a small portion of the available data. In many cases 90 percent of the time is devoted to gathering and formatting data; only 10 percent qualifies as analysis. The cost to gather and analyze exceeds the perceived benefits so the process is often inconsistent and pushed aside by other priorities.

Although smart manufacturing technologies promise to automate the data gathering and analysis process, flipping this ratio so that 90 percent of time is spent on analysis to generate actionable information, committing to a data collection and analysis process with existing data sources and manual entry will inform decisions. Investing in technology that devotes resources to data analysis that is not crucial or perhaps even relevant to KPIs creates a serious risk to automating the wrong things. Building on data already available can avoid this mistake.

To get started, focus on areas that will inform KPIs and improve performance. Recent research has found that the top three areas where data analytics can improve manufacturing performance are:

1. better forecasts of product demand and production (46%),
2. understanding plant performance across multiple metrics (45%), and
3. providing service and support to customers faster (39%).[5]

Lesson 4: Don't Forget the Basics

One of the first steps a SMM can take to prepare for smart manufacturing is to understand the technology currently in use. A comprehensive inventory of all the hardware and software in use in the plant, including programmable logic controllers (PLCs) and other discrete controllers on individual equipment, supervisory control and data acquisition (SCADA) systems, modems and other networking equipment, and all the operating systems and application software used. Maintenance schedules, update histories, and a complete list of personnel documenting who has access to what systems should also be included. Look around the plant for clipboards, binders, sticky notes, and other informal communications. This comprehensive inventory will provide the basis for determining areas of the system most in need of upgrades to hardware and software, and any additional training requirements.

Too many SMMs have personal and embedded computers running outdated software. Perhaps the most critical first step companies can make is to update Windows. Microsoft ended support for Windows XP in 2014; support for Windows 7 ended on January 14, 2020. Too often, these PCs run in the background, sometimes running front office software but also often running on the shop floor. The end of support from Microsoft means that security patches are no longer available, putting the plant's and company's operations at risk.

The risks are real. After a lull in 2018, ransomware is one of the fastest growing cyberattacks. For example, Arizona Beverage Company was hit with a massive ransomware attack in March 2019. Back-end servers running outdated and unsupported versions of Windows were infected with malware, likely delivered through an email attachment. The malware gave unrestricted access to the entire network, enabling infection by additional malware, known as iEncrypt, which cut access to the company's information systems. It also infected its Microsoft Exchange email server, knocking out email across the company and preventing customer order processing. To make matters worse,

5 LNS Research, "Manufacturing Metrics That Matter 2016 survey," highlights at https://www.ibaset.com/blog/key-findings-from-an-iot-and-manufacturing-survey-2016-infographic/

backups were not configured properly so were of limited help. Recovery required large-scale replacement of both hardware and software.[6]

Updating Windows also provides the opportunity to assess the status and utility of other software. Since the era of Windows XP and 7, many manufacturing and business essential software packages have shifted to cloud-based, subscription models that are more secure, more flexible, always up-to-date, with more capabilities than older on-site packaged software. Examples include customer relationship management (CRM), accounting, human resources, computer-aided design (CAD), ERP and other software common to manufacturing facilities, and even Microsoft Office. Many also interface with mobile applications, a growing trend and expectation in smart manufacturing.

In some cases, up-to-date software will benefit from updated hardware; sometimes it may require updated hardware. This can create a serious dilemma for SMMs. In cases where Windows is running on a PC, especially in administrative offices, PCs should be replaced; they are inexpensive and provide noticeable performance upgrades. In other cases, older versions of Windows are embedded in CNC equipment and cannot be upgraded without replacing the equipment. Upgrading can be prohibitively expensive, which means networking this equipment can be dangerous and probably should not be done.

At the same time as addressing hardware and software updates, review backup procedures. For critical data, a minimum of a daily backup should be in place. Backup files can be stored onsite on separate hard drives—as with other hardware, hard drive prices are low—or files can be stored in the cloud, with Google, Microsoft, Amazon, Box, and many other providers easily accessed and affordable. Periodic testing of backup procedures and file integrity can provide essential insurance against malware, a lesson learned too late by Arizona Beverage.

Overall, effective cybersecurity practices are essential to success in the era of smart manufacturing. For too many SMMs, cybersecurity starts with basic password management and access control. Page 26 reviews key information about cybersecurity and provides links to resources that can help.

Lesson 5: Begin with Small Pilot Projects or Proof of Value with a Growth Path

Start with a small pilot project that has a high probability of a successful measurable business outcome and realize that the digital transformation is not the result of one project, but a series of continuous improvements through on-going projects. A small successful project with clear benefit can be as small as a single new sensor or using a single unused source of data.

With appropriate up-front assessment, updates of existing critical hardware and software, and some experimentation with existing data sources and analytical capabilities, specific initial projects can be identified that will provide experience with implementing and using smart manufacturing technologies most effectively. It is important that the initial projects are well designed to address KPIs, to fit into broader continuous improvement efforts, and to show positive financial impact, especially if the savings from these first steps are needed to fund subsequent steps. Choose pilot projects that can be implemented quickly and that demonstrate their effectiveness clearly so that they can be extended or cancelled. Good first pilot projects can often be done with very little investment. **Too many pilot projects—up to 84 percent—are stuck in pilot mode for more than a year, and 28 percent for more**

6 Z. Whittaker, "Arizona Beverages Knocked Offline by Ransomware Attack," at https://techcrunch.com/2019/04/02/arizona-beverages-ransomware/

than two years because of too few resources, too little knowledge, and inability to justify the investment needed to scale the pilot.[7] Effective project selection with senior management leadership can raise the likelihood of successful pilots, leading to scale up and continued success.

Plant managers know there are bottlenecks, equipment failures, inventory shortages, excess WIP, and other common issues. Pick something and get started. At the heart of smart manufacturing is gathering and analyzing data to inform business and production decisions. Managers need to decide what issue to address, then identify the data that will tell them the extent and nature of the issue, that is real data not just a "gut feel." A key objective of initial pilot projects is to start working with data allowing operators and managers to build experience with the data.

Most manufacturing plants have a variety of new and old equipment from multiple vendors with different functions, controllers, and communication requirements. Some equipment can gather and communicate multiple indicators of operational performance. PLCs are able to pull a large amount of data from production equipment. They can monitor machine inputs and outputs and can make logical decisions when necessary, based on programming. This information may or may not be gathered consistently in a form that allows easy analysis. **Retrofitting older equipment with smart sensors is now both possible and affordable to provide real-time tracking of temperature, vibration, current draw, noise, and other factors on any given machine.**

Adding sensors to monitor operational conditions is one thing; communicating and analyzing the data is another. Many vendors, both established and new, offer the hardware and software necessary to analyze the data and to present it in ways that are both easy to understand and actionable. A few examples (among many others) include:

- **ActionPoint** has teamed with Microsoft and Dell for a product called IoT-PREDICT, IIoT in a box. The box contains hardware, software, current, temperature, and vibration sensors and instructions that the company claims will enable customers to gather and analyze sensor data within 10 minutes.
- **MachineMetrics** uses Artificial Intelligence (AI) to gain insights from manufacturing data to improve quality and performance. It provides a scalable, out-of-the box set of sensors, data analysis, and data visualization tools. The hardware can be self-installed, software is customizable and integrates with existing ERP systems, and the dashboards (Figure 4) that visualize the analyzed data are customizable. The resulting information includes cycle analysis, job and operator performance, machine utilization, and other factors that inform maintenance schedules, production planning, cost estimating, work schedules, and investment plans.
- Massachusetts-based **Tulip** has a subscription-based "Platform-as-a-Service" that enables multiple activities on the shop floor to be turned into custom apps without any coding required. Apps available in Tulip's library include machine monitoring, interactive work instructions, machine setup, root cause analysis, 5-S audits, and other operations and training topics. Tulip also offers a "**Factory Kit**" to get started with IIoT. It includes temperature and humidity sensors, a break beam, a light kit to guide pick-and-place, a light stack to send visual alerts to operators, a foot pedal for hands-free operation of apps, a barcode scanner, and an input/output hub for connecting devices and sensors and collecting shop floor data.

7 Enno de Boer, "Five Steps to Get Out of Pilot Purgatory," *Industry Week*, at https://www.industryweek.com/technology-and-iiot/article/22026267/five-steps-to-get-out-of-pilot-purgatory

Figure 4: Example of MachineMetrics Dashboard

- [PTC](#) has a strategic partnership with Rockwell Automation. Its IIoT platform, [ThingWorx](#), offers starter kits, hardware and software, and a marketplace with hundreds of community-built apps to speed implementation based on the experience of others. ThingWorx enables data collection, remote monitoring, and analytics with dashboards to visualize the results.

These examples are not meant to be endorsements, but illustrations to provide a flavor of what is available in the market. There are many vendors and it can be difficult to choose the best fit.[8] Some new systems are compatible with SMMs' installed base; some may not be. Sometimes legacy systems may be so old that new systems, particularly those that enable small initial installations—some vendors offer free trials—can displace what the SMM currently has, as long as they offer sufficient, affordable growth potential.

Selecting the right vendor can be daunting. **SMMs should seek advice from local technical schools, universities, or their local MEP.** Online tools that can help include Capterra and Software Advice. These sites often provide pricing information as well.

Lesson 6: Cultural Change is Unavoidable

Implementing smart manufacturing successfully requires broad recognition across the company that systemic change is unavoidable and therefore should be planned for and embraced. Too many SMMs, probably most, are content to keep doing what works. As long as customers are happy, product is moving, and money is made, there is little incentive to change. In fact, there is often fear that any change will disrupt what is currently working and therefore should be avoided. With smart manufacturing, this is a recipe for decline and ultimate failure.

Even when applying digital technologies to shop floor operational improvement, some change in the business culture is inevitable. Data that was not available or was not used now informs production decisions. Differences in worker and machine productivity become obvious, requiring management attention. The status of multiple operations across the shop floor become more

8 For a list of promising startups working in IIoT, see https://www.forbes.com/sites/louiscolumbus/2019/02/03/top-25-iot-startups-to-watch-in-2019/#4c5f680d3cc0

visible, changing expectations and, in many cases, responsibilities. Managing this change process can be the greatest challenge to achieving positive results. Employees, including managers, need to understand the vision, why change is necessary, and what's expected of them. They also need to be confident that they will be engaged in the process and that the resources and training will be in place to achieve the vision. Ensure that employees have committed to the project and recognize their contributions. One of the prime goals of the first pilot must be to increase employee engagement to start to implement the required culture change.

A familiar analogy might be adoption of lean manufacturing principles. By now, most manufacturers, including SMMs, know most of the tenets of lean manufacturing. Continuous improvement, just-in-time production using pull systems, mistake proofing, and waste minimization have become common principles in factory management, yet making the commitment to lean principles with long-term, focused implementation has proven to be challenging for many companies, large and small. Effective application of smart manufacturing technologies will be at least as challenging. Already having lean production systems in place will help, both culturally and operationally. Efficient, lean production clarifies the areas of operations that will benefit most from the application of digital technology. Automating bad processes, for instance, wastes money and has ripple effects through the factory that can be difficult and expensive to address.

As part of the cultural change, skill requirements will change. SMMs will continue to need the mechanical and operational skills that have been keys to success in the past, but will also need new skills to implement new technologies smoothly, maintain digital systems and networks, integrate with customers and suppliers, and manage continued implementations. These will be different from those typically recruited, and may be hard to find. Many technical schools, even high schools, are beginning to train students in the new technologies that comprise smart manufacturing. They can be a source of new hires and, in many cases, a source of interns capable of helping with tasks such as data capture and analysis.

Also part of the cultural change will be relationships with other businesses, both suppliers and customers. They will request more data from SMMs, which in turn, should review ways they will benefit from data from their partners. In other words, data should flow both ways.

One advantage of some of the emerging technologies is the opportunity to use them to capture the production knowledge of older production workers before they retire. For instance, augmented reality software eases the process of creating electronic work instructions and training manuals using the knowledge of existing workers.

Lesson 7: Stay Grounded

It is easy to be overwhelmed by the hype and promise of smart manufacturing. Right now, most, at best, applies to large manufacturers with the financial and human resources to implement technology at scale. These large firms can make large investments, work through glitches, survive failed installations, and, in general, serve as laboratories for perfecting many of the interrelated technologies that comprise smart manufacturing. Eventually, many of these technologies will permeate their supplier networks, and therefore, it pays for SMMs to be aware and prepared. Small targeted implementations of smart technology to solve specific problems, backed by sufficient review of available vendors and technical alternatives, are accessible to SMMs now at attractive price points. But the technologies needed for a fully networked, integrated smart manufacturing system, with all of the skill and cultural change that entails, is unlikely to be appropriate for most SMMs for many years. The key is to focus on what will have tangible benefits today and not be concerned with the latest technology or trendiest terminology. Gradual implementation of technologies appropriate to the company's product line, production processes, and customer base will avoid wasted investment and lost time.

Lesson 8: Get Help

Beginning the transition to smart manufacturing can be daunting, especially for SMMs with limited resources, especially time. Fortunately, many sources of help are available at low to no cost. The local MEP center should be the first place to turn. MEP engineers are familiar with the technologies and, in many cases, are already familiar with businesses or operations like yours. They can help develop strategies for change, identify priority areas to apply appropriate technologies, suggest vendors, and work with SMMs to keep progress on track. A growing number, such as the Michigan Manufacturing Technology Center (**MMTC**) and the Manufacturing Advocacy Growth Network in Cleveland (**MAGNET**), have demonstration facilities where SMMs can experience smart technologies in use. They also have assessment tools and training curricula that can jumpstart the change process.

Another key source of help are the Manufacturing USA institutes, in particular **CESMII** and **MxD** which focus on the role of data in manufacturing. Both have been building programs and tools for SMMs and have been working with the MEP program to disseminate them.

Other sources of help include local technical schools, community colleges, and universities. SMMs should be engaged with these schools already, at a minimum working with them to ensure that graduates have the skills needed to work in small manufacturing environments. Many of these schools have faculty that can work with SMMs on site to devise strategies for data collection, train workers in data analysis, and recommend hardware and software tools that are appropriate for the SMM. In many cases, labs and workshops at the schools have technologies, such as 3D printers, modeling and simulation software and work stations, and specialized machine tools, available for demonstrations and use for an hourly fee. Local schools are also a primary source for interns and cooperative study students that can provide needed skills and create a pipeline of trained recruits.

Local trade associations and industry organizations provide opportunities for SMMs to get help from each other. Sharing best practices and comparing notes on experiences with new technology implementation can be one of the most effective ways to accelerate progress across a number of companies. Learning from others, not only about what went right and wrong in implementing smart projects but also experience with vendors, can help SMMs be fast followers in their smart manufacturing strategies.

Finally, in some industries, large customers will be a source of advice, training, and encouragement. For instance, the **Toyota Production System Support Center**, started in 1992, works with suppliers on lean production and quality systems and effective implementation of new technologies that raise the efficiency of the entire supply chain. Because smart manufacturing will become pervasive throughout supply chains, large customers and SMM suppliers will need to work together to maximize the benefits and work out the kinks.

REVIEW OF SMART MANUFACTURING TECHNOLOGIES

Deciding how to implement smart manufacturing requires careful planning, preparation, and clear analysis. It also requires at least some understanding of what the technologies are and what they can do in order to ask the right questions. Some affect internal operations; some affect external relations and interfaces with customers. The following brief review of the primary technologies comprising smart manufacturing can help SMMs understand the technologies and connect to additional resources for more information.

Additive Manufacturing

Few technologies capture the promise of manufacturing digitization more than additive manufacturing (AM), or 3D printing. First invented in the 1970s, the technology has exploded in recent years, encompassing a wide variety of materials and printing technologies. Historically used for rapid prototyping and conceptual models, the latest machines can print production parts in metal, ceramic, and plastics, in some cases with sufficient speed to rival traditional production methods.

Although constant progress is being made in additive manufacturing new materials and processes, the three main types of additive manufacturing processes are fused deposition modeling (FDM),[9] selective laser sintering (SLS),and stereolithography (SLA) (Figure 5).

In the past, 3D printing has been most effective for relatively small parts, but as the technology has improved and print beds have grown, larger parts and production parts can be printed reliably and repeatably. In 2017, nearly $1 billion was spent on AM for end-use production parts, rather than just prototypes.[10] Large companies in aerospace and automotive have been particularly

9 FDM is the trademarked term for fused filament fabrication (FFF).
10 https://www2.deloitte.com/insights/us/en/focus/3d-opportunity/additive-manufacturing-higher-education-degree.html

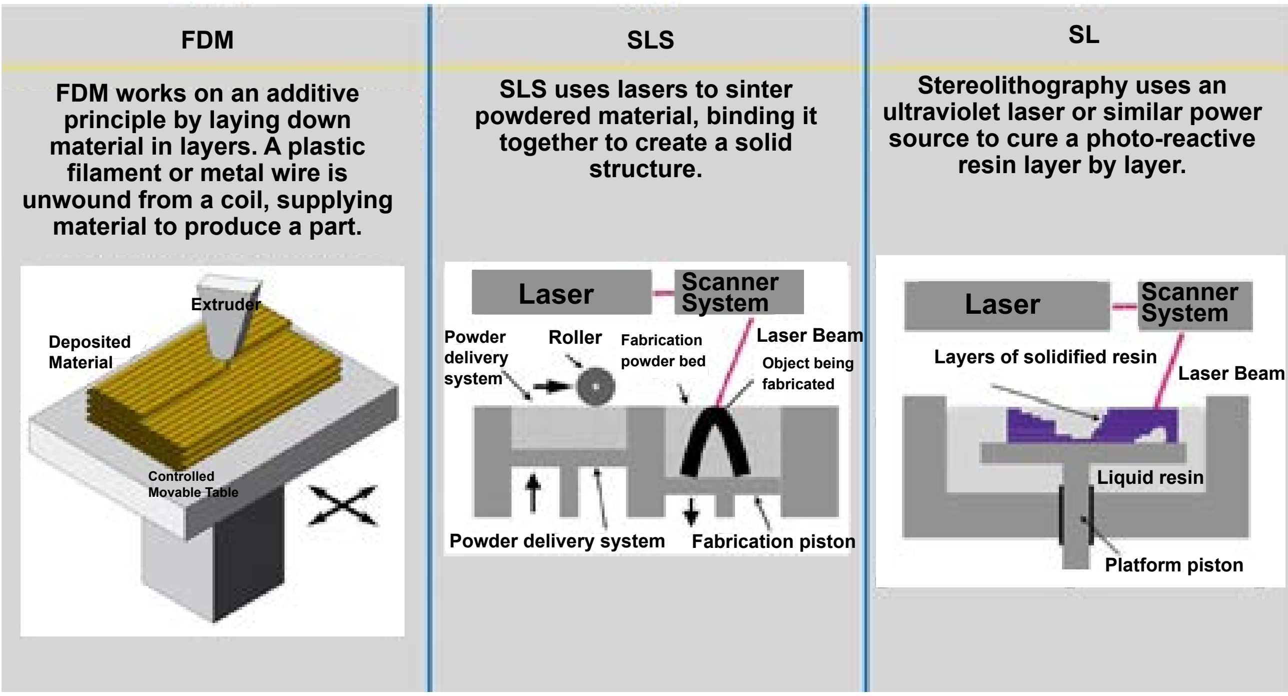

Figure 5: Additive Manufacturing Technologies

aggressive in applying AM to production parts. For example, one European automotive company used 3D printers from **Ultimaker** to make liftgate badges, reducing lead time by 89% and cost per part by 98%. BMW uses **Metal Jet** printers from HP to make guide rails for the i8 roadster. Several companies, including Rocketdyne and Orbex, are printing significant sections of solid rocket motors. Milwaukee Tool is using the Production System from **Desktop Metal** to manufacture a specialty drill bit, reducing 20 steps to just 4.[11] Figure 6 illustrates estimates for final part costs using AM versus conventional manufacturing.

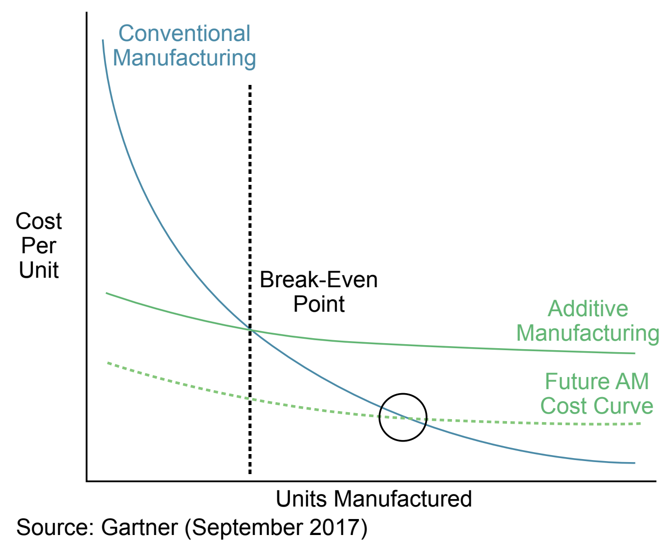

Figure 6: Comparison of Unit Costs for Additive vs Conventional Manufacturing

As AM technology becomes more versatile in terms of materials, part size, and reliability, and as more companies enter the market for 3D printers, prices are falling. Small, hobby-sized 3D printers from companies such as MakerBot are available for less than $3000. Industrial scale printers using polymers or ceramics cost less than $95,000, while metal printers cost around $400,000. However, new machines from Desktop Metal and HP promise to reduce that price significantly. For instance, **Desktop Metal's Production System** uses a jet of metal powder and an oven to fuse the metal. The system can print stainless steel at a rate of 12,000 cubic centimeters per hour, 100 times faster than older, laser-based metal printing, making the technology suitable for certain mass production applications.[12] In 2019, HP began offering a production service using its Metal Jet technology. Customers can upload a design file, which is checked for compatibility, then printed using the

11 https://spectrum.ieee.org/at-work/innovation/3d-metal-printing-tries-to-break-into-the-manufacturing-mainstream
12 Ibid.

Metal Jet platform by one of HP's manufacturing partners.[13]

Figure 7 illustrates a 3D printed part compared to the assembly it could replace. Compared to the machined and assembled part on the right, the 3D printed part reduced mass from 575 grams to 53 grams, reduced part count from 5 to 1, lowered cost by 91%, and reduced lead time by 91%.[14]

AM is progressing rapidly with machines available across multiple price points and capabilities. Factors to consider include the intended application; required performance in areas such as speed, material, weight, and appearance; the environment in which the parts will be used; part durability; and, of course, price and delivery. Adding AM equipment to a job shop's collection of machines should be relatively straightforward, as long as the shop has the capability to accept the digital design files. To add AM to internally designed part production requires the company to have the software and skills needed to produce the digital part designs used by AM. Most shops have this capability, but for those that do not, the number of vendors of computer-aided design (CAD) software and the choices available to SMMs has vastly increased in recent years. Prices for the software should not be a barrier—a number of companies offer free, open source CAD software[15] —but finding the necessary skills could be a challenge. Local technical schools are a good source of talent; student internships can be an effective way to get started in this area of digital manufacturing.

Figure 7: A 3D printed part used by HP. Compared to the machined and assembled part on the right, the 3D printed part reduced mass from 575 grams to 53 grams, reduced part count from 5 to 1, lowered cost by 91%, and reduced lead time by 91%.[14]

Robots/Cobots

Although industrial robots have been around for decades, so called collaborative robots, or "cobots," that work collaboratively with humans are relatively new. Unlike traditional industrial robots that required light curtains and safety cages, cobots can work side-by-side with human teammates. Because they are easy to program without computer programming skills, cobots can move to different tasks throughout the factory. They are best suited to repetitive, mundane, or ergonomically challenging work such as machine loading/unloading, packaging, and pick and place, doing the tasks at a slow but steady pace.

Some robot manufacturers are offering traditional robots with cobotic modes, thus allowing high-speed operations when workers aren't in close proximity and reduced safe speeds when they are present. This feature also reduces nuisance safety system trips because the robots can still operate in the presence of humans.

By some estimates, there are more than 30 cobot vendors with more than 90 models available. (**CobotsGuide** has examples with photographs

13 https://www8.hp.com/us/en/printers/3d-printers/products/metal-jet.html
14 https://www.engineering.com/AdvancedManufacturing/ArticleID/19394/The-Case-of-Art-to-Part-The-Rise-of-Systemic-Intent-Based-Design-with-3D-Digital-Manufacturing
15 https://learn.g2crowd.com/free-cad-software

and comparisons.) Producers include traditional industrial robot makers such as Fanuc, Kuka, and ABB, as well as startups such as **Productive Robotics**, **Modbot**, and **TM Robot**. **Universal Robots** is the market leader, controlling nearly half the cobot market in 2017. Universal offers three models ranging in price from roughly $20,000 to $50,000 and lift capacity ranging from 3 to 10 kilograms. Fanuc, by comparison, offers a model with a 35 kilogram capacity. Across the industry, the average price is $24,000, having fallen more than 10 percent over the last 5 years.

Some companies specialize in creating add-ons for cobots made by others. One example is Robotiq. Its products are designed specifically for Universal Robots, including 2-finger adaptive grippers, a 3-finger hand, a force touch sensor, and a camera vision system. **Robotiq** can also speed implementation for many common applications by offering custom program templates.

SMMs are the target market for most cobot vendors, due to their relatively low cost, inherent safety, and flexibility. Crucially, cobots can be added incrementally as needed, or automate entire processes. Companies find that cobots perform consistent, well-defined tasks without mistakes and without tiring. Some companies have reported large increases in productivity and improvements in job satisfaction as boring tasks are automated cost effectively.

For SMMs unwilling or unable to make the cash outlay for a cobot that meets their needs or worry that the workload is too inconsistent to recoup their investment, many firms offer to lease and even rent-to-buy cobots. Some firms offer "Robots-as-a-Service," providing the cobots, tools, programming, and maintenance on the basis of use. **Hirebotics** offers cobots from Universal Robotics as if they were temporary workers. Hirebotics bills its customers weekly based on the number of hours the cobot works with no upfront fees, but with a minimum period of 80 hours or two shifts per week. The cobots are cloud connected, allowing Hirebotics to measure their performance, diagnose issues, and send production data back to customers using a mobile app. **Ready Robotics** provides cobots for a fixed monthly fee, regardless of how many hours the cobot works. They also provide maintenance, support, and alerts about job completion and downtime.

In considering cobots, SMMs should work closely with the vendor to identify appropriate applications. For steady, repetitive tasks, especially those that require collaboration with workers, cobots can be ideal. Tasks requiring extreme speed and precision are best handled by traditional industrial robots, which not only cost more but require safety caging. MEP has created a short, instructive **Manufacturers' Guide to Robotics** that includes a description of the most common types of robots, differences between cobots and traditional industrial robots, various types of end effectors, and examples of effective applications. As hiring needed staff continues to be difficult, cobots can often be a cost-effective solution, as well as an introduction to the opportunities created by new smart manufacturing technologies.

Sensors

Data is the lifeblood of smart manufacturing, and sensors of many and varied types provide the needed data. Because legacy production equipment may not be equipped with sensors to detect operational parameters, opportunities exist to retrofit appropriate sensors to this equipment, sometimes as simply as using a magnet to attach a vibration sensor. Keep in mind that data from specialized sensors is not the same as PLC data: sensor data is all data from a specific sensor on a machine, within a designated timeframe. It is designed to monitor something specific, like vibration or noise, which might tell the operator something as simple as whether a machine is

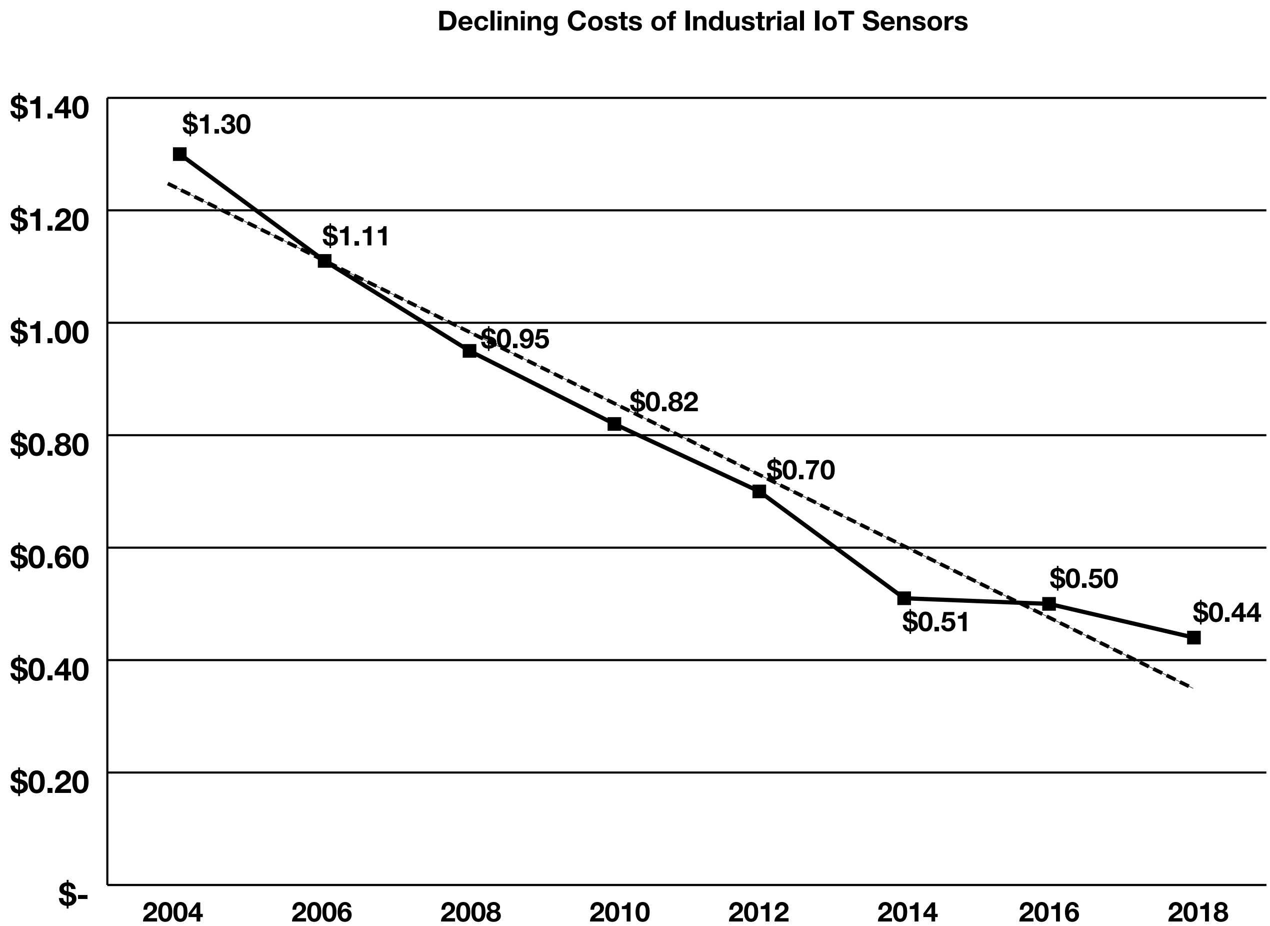

Figure 8: Sensor Costs are Dropping[16] (Source: CB Insights)

operating or something more complex such as the need for maintenance. PLC data is more general and may or may not be meaningful when reviewed or analyzed.

Available sensors can detect changes in vibration, noise, temperature, humidity, and electrical load to determine anomalies in performance that can indicate tool wear, imminent tool breakage, maintenance needs, or other parameters that affect uptime, overall equipment effectiveness (OEE), and production quality. They include accelerometers, gyroscopes, humidity, pressure and a myriad of other sensor types.

These types of analog sensors have been available for many years; the difference now with smart manufacturing technology is that inexpensive analog sensors have been combined with data storage and wireless communications capabilities to create increasingly affordable smart sensors (Figure 8).[16] Smart sensors incorporate microprocessors, memory, diagnostics, self-calibration, and connectivity. They can collect and store readings, perform limited analysis of the data—identifying anomalous readings, for example—and communicate results to a data acquisition hub for additional analysis. Instead of manual data collection, the data is communicated and used to inform operator decisions, production planning, maintenance schedules, etc.[17]

A rapidly growing and affordable type of sensor is machine vision or, more generally, image-based sensing. These sensors, including cameras,

16 "What's Next in Advanced Manufacturing," CB Insights, 2019, p. 7.
17 A standard interface and protocol for how a sensor is described on a network was defined in 2006 with IEEE standard 1451.4, which jumpstarted advances in smart sensor technology.

enable extraction of part features to provide additional process information.

One smart sensor provider is **[Samsara](#)**. It offers environmental monitors that capture temperature and humidity data, machine health monitors that track vibration and surface temperatures, electrical power monitors, and machine vision systems. All have wireless connectivity for easy deployment, assuming the plant has wireless communications which could be simple and similar to home Wi-Fi. Industrial controllers combine data collection, analytics, control and alerts for use with the sensors. Other sensor providers are those mentioned earlier, such as MachineMetrics and ThingWorx.

When considering sensor deployments, SMMs should consider which aspects of the plant would benefit most from the information sensors could provide. The maintenance requirements of the sensors themselves should also be considered. For example, for many factories, steam traps are a source of high maintenance with a relatively high failure rate. Sensors could provide information to predict failure, avoiding the expense of routine inspections, but the sensors may require frequent battery changes, thereby diminishing the cost benefits. Particularly in the early stages of implementation, SMMs should carefully determine a few key machines, motors, or other components that would benefit most from the predictive maintenance and the failure modes to be addressed, then select a few appropriate sensors to gather the needed information to reduce maintenance costs and increase uptime.

Augmented/Virtual/Extended Reality

Augmented Reality (AR) and Virtual Reality (VR)—also referred to as Extended Reality (XR)—are emerging technologies with a growing number of applications in manufacturing. Best recognized in the gaming industry, with products such as the Oculus Rift and Playstation VR, as well as smartphone-based consumer products such as Samsung Gear VR, Google Cardboard, and LG 360 VR, the technology is growing rapidly with numerous hardware and software options. However, the hardware and software requirements can get expensive. Most affordable and accessible for SMMs are AR applications that run on tablets or smartphones, some designed specifically for factory environments. Forrester estimates that 400,000 U.S. workers used AR in 2018, growing to 14.4 million by 2025.[18]

The largest applications of XR in manufacturing are in training and maintenance, repair, and operations (MRO). Studies have shown that VR-based training programs can reduce training time by 40 percent and improve employee performance by 70 percent while reducing costs.[19] For SMMs, Electronic Work Instructions and Connected Worker applications on tablet computers are likely the most affordable entry point for this technology, likely to provide most of the benefits of XR while eliminating much of the expense. A recent Forrester Research survey of manufacturers listed a number of realized or expected benefits from AR applications (Figure 9).[20]

There is a growing number of software providers that can help SMMs take advantage of XR technology. **Andonix** provides electronic work instructions, training, and other information to smartphones and tablets using its apps. **Proceedix** provides a platform to manage procedures, work instructions, and inspections on mobile devices. **Parsable** is another example, providing a connected worker platform to facilitate training, work instructions, collaboration, and analytics using their app on mobile devices. All of these examples are Software-as-a-Service, subscription-based software that may be more affordable for SMMs.

18 https://blogs.wsj.com/cio/2018/08/01/lockheed-martin-deploys-augmented-reality-for-spacecraft-manufacturing/
19 https://www.forbes.com/sites/solrogers/2019/05/09/how-vr-ar-and-mr-are-making-a-positive-impact-on-enterprise/#2c992c275253
20 "The Total Economic Impact of PTC Vuforia," Forrester Consulting, July 2019, p. 8.

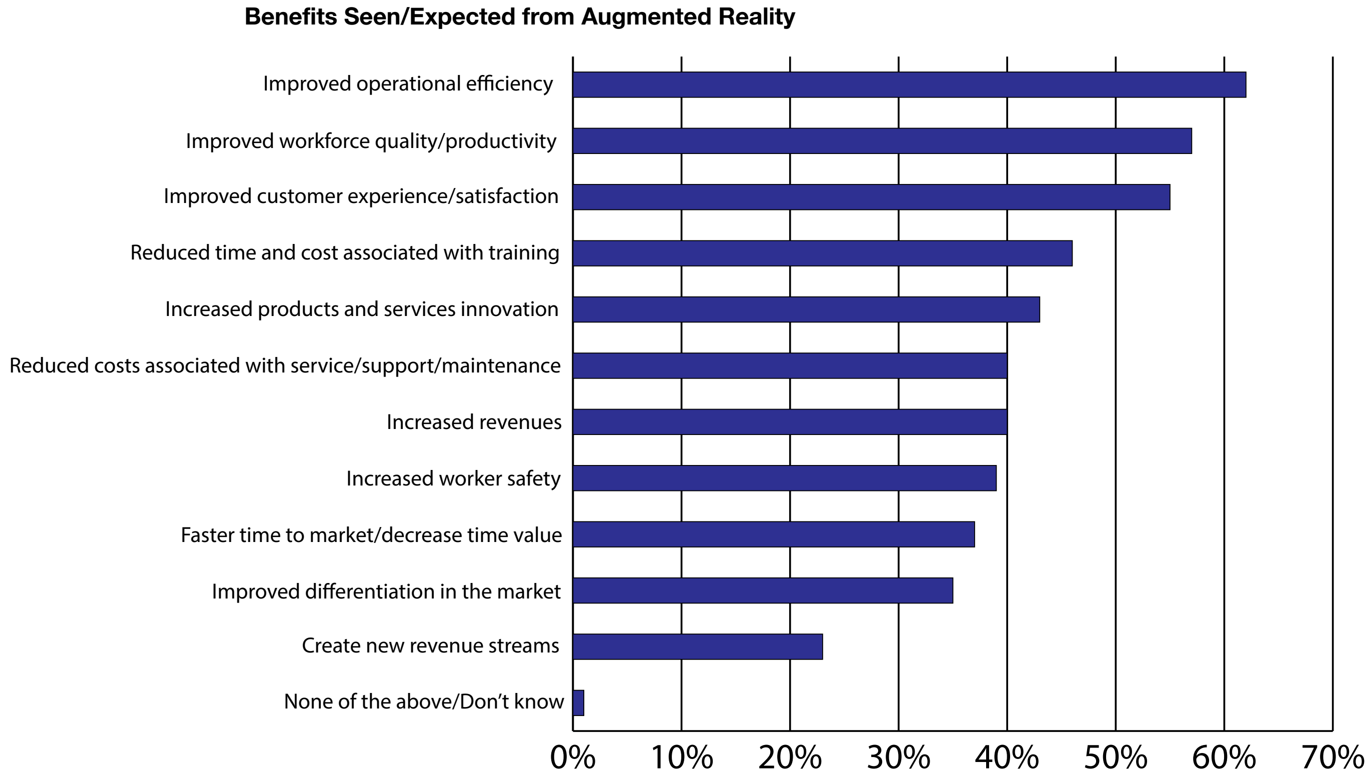

Figure 9: Benefits from Augmented Reality[20] (Source: Forrester Consulting, 2019)

Another example, offered by **RealWear**, is a $2,000 Android-powered rugged headset intended for use in noisy, dusty, humid industrial environments. The headset provides hands-free, voice-controlled information to guide workflow tasks, visualize production data, and access maintenance manuals. It can also enable video calling for expert guidance, interact with equipment through voice control, and fill out virtual forms. The company also offers a suite of applications and cloud-base services that can extend the functionality and speed implementation of the RealWear system.

Other manufacturers are working with Microsoft to develop industrial applications for its HoloLens headset. Lockheed Martin, for instance, has used the technology to digitize workflow requirements and provide real-time instruction, reducing assembly time by 30 percent.[21] In other applications, Lockheed Martin has reduced the time required for an assembly operation from 6 weeks to 2 weeks, and cut the time required to train operators for a drilling process from 8 hours to 45 minutes, all while reducing defects.[22] Other companies using HoloLens include ZF, an automotive parts supplier using it for plant maintenance, and Paccar, which is using it to train workers at its Kenworth plant in Ohio.[23]

In addition to internal applications that increase efficiency of manufacturing processes, many companies are also pursuing external applications to enhance the customer experience. Some firms are using AR to enhance service manuals and provide remote expertise. Others use the technology to highlight product features, proper use, and as a mechanism to gain customer feedback on the product. Cannondale, for example, uses AR to provide assembly instructions, demonstrate product features, and

21 https://www.manufacturing.net/article/2019/04/augmented-reality-and-smart-factory
22 https://blogs.wsj.com/cio/2018/08/01/lockheed-martin-deploys-augmented-reality-for-spacecraft-manufacturing/
23 https://www.nytimes.com/2019/07/10/business/microsoft-hololens-job-training.html

as a source of feedback to refine future designs of its bicycles.[24]

Another way for SMMs to get started with XR is to use a service such as **Amazon Sumerian**, one of the products offered by **Amazon Web Services**. Sumerian includes tools to create and run XR applications on hardware such as Oculus Rift, HTC Vive, and mobile devices. No specialized expertise is required; programming is done in a browser. PTC's **Vuforia** is another option that works with RealWear and HoloLens. It can create applications for the production floor as well as sales, marketing, and services.

AR headsets are becoming reliable and cost effective for many applications. As fields of view are increased, hand gesture recognition is improved, natural language (AI) recognition is better integrated, and costs are reduced, significantly wider adoption can be expected.

Data Analytics

Data analytics is essential to smart manufacturing, but it is important for SMMs to recognize that data analysis for the sake of it can become a costly waste of money. Generating and capturing data through PLCs, smart sensors, or even manual readings does no good if there is not an ability to 1) analyze the data on a continuing basis to establish trends, inform predictions, and provide situational awareness, and 2) deliver the analyzed data in a form that allows people to act on it. Typically, this output takes the form of "dashboards" which provide easy-to-read, real-time information on multiple aspects of factory operations: machine operating conditions, WIP, takt time, cycle time, mean time between failure (MTBF), on-time deliveries, tooling status, and many other variables.

Larger companies have the resources to generate large data sets from multiple machines that are compiled over time. This so-called "Big Data" not only reveals insights into multiple business parameters, but also is used for emerging applications of machine intelligence in which historical data is used to train machine learning models. Smaller manufacturers will not typically have Big Data, but will have both existing data from PLCs and other sources and can upgrade and retrofit equipment in targeted ways to generate data most relevant to KPIs. Even targeted data gathering and analysis can identify anomalies, such as spikes in downtime at certain times or higher scrap rates after die changes, that can have rapid impact on operations. **Companies that have implemented systems to capture operational data and to provide real-time information to operators/managers tend to see rapid return on investment (ROI), often two years or less.**

Manufactures should pay particular attention to capturing the contextual and causal relationships of data as they collect the data. These relationships are critical to delivering actionable results but they can be difficult, expensive, and at times impossible to establish afterward using big data analysis. Just as control is scalable from devices to the cloud, data analytics should also be scalable depending on the response time, amount of data, and security requirements.

As noted previously, there are multiple vendors offering sensors, communication links, data analytics, data storage, dashboards, and other services that ease the process of gathering and using data to improve operations. For example, Cisco has a service to easily connect CNC machines to provide real-time visibility to productivity differences between the same machines; a typical result is a 10% utilization increase.[25] Other vendors include large established companies such as Microsoft, as well as many smaller firms, some focused on local or regional businesses.

24 M. Campbell, D. Busiek, and J. Lang, "The State of Industrial Augmented Reality: A Spotlight on Industrial Innovation," PTC White Paper, 2018.
25 https://www.iotworldtoday.com/2018/04/27/three-industrie-40-hurdles-and-how-cisco-addressing-them/

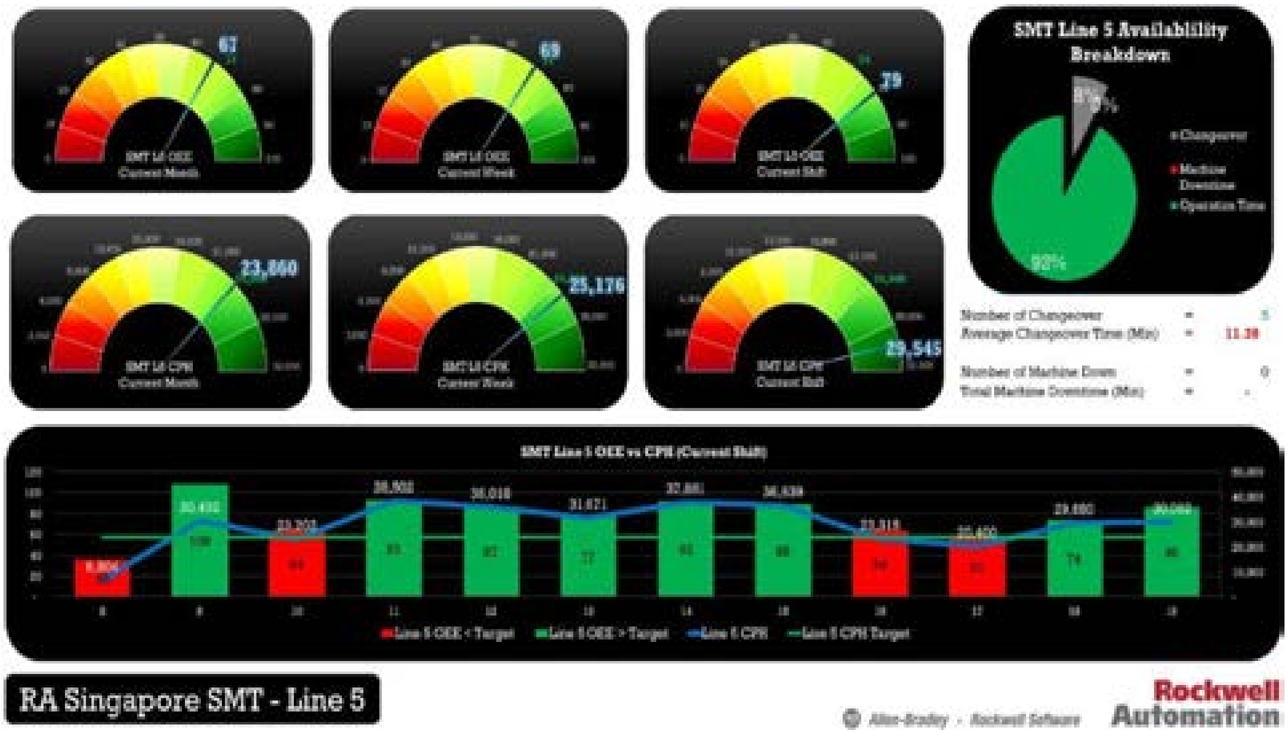

Figure 10: Example of remote monitoring dashboard

Most of these services use a subscription model in which customers pay per user, per machine, or some combination. One mistake too many SMMs make is to limit the number of users to save money so that only a small number of users have direct access and are trained to use the system. Data from other users with other machines either is ignored or gathered manually to be input by the designated users. The result is a system with data errors and delays that does not provide the real-time insight that can generate the savings needed to justify the few subscriptions. Results are poor so the technology is scrapped. But this is an issue of poor implementation, not bad technology.[26] **Plex Systems** avoids this problem by offering a company-wide annual subscription model for its cloud-based business management, operations, and IIoT products. A few examples illustrate the opportunities.

ZF, a German auto parts company started its data analytics by focusing on production issues, such as throughput speed, rework rates, and stoppages. Specific projects were selected based on the value potential, availability of data necessary to assess and correct problems, and enthusiasm for solving them. The company focused on each problem for three months both to ensure sufficient data to establish trends and root causes and to avoid getting bogged down. Problems solved included detecting imminent breaks in grinding rings 72 percent of the time and avoiding peak load electrical surcharges by up to $200,000 per year.[27]

Carolina Precision Manufacturing (CPM) uses MachineMetrics to monitor 36 CNC lathes, replacing a manual system. The system monitors parameters such as cycle time, parts produced, availability/downtime, and OEE, then provides the data in dashboards with charts, percentages, and diagrams. The dashboards can be seen on screens on the shop floor, tablets, smartphones, desktops, and laptops, allowing real-time feedback to operators and remote monitoring by owners and managers. After one year of using the system, CPM increased machine utilization by 20% equating to more than $40,000 of additional billing per machine.[28]

26 https://www.plantservices.com/articles/2019/avoiding-the-black-hole-of-data/
27 https://hbr.org/2018/11/how-a-german-manufacturing-company-set-up-its-analytics-lab

In another example, a coffee processor was experiencing excess downtime of its dryers because vapor released by the coffee beans was contaminating heat transfer surfaces. Data was collected from each dryer for different bean varieties since each variety has different moisture content and vapor characteristics. Cloud-based analytics provided actionable information that enabled optimization of multiple dryers and allowed controllers on individual dryers to determine when surfaces need cleaning. The result was higher dryer utilization and increased overall productivity.

Artificial/Machine Intelligence

Artificial Intelligence (AI) is technology that builds on data analytics to identify patterns in the data that can trigger autonomous action of machines. In manufacturing, use cases include generative design in product development, production forecasting for inventory management, use of machine vision for defect inspection, predictive maintenance, and production optimization across multiple machines and production lines. AI differs from straight mathematical and statistical approaches in that there is a cognitive, analytical ability built into the technology that helps people interpret and perceive patterns in the data. Currently, most AI applications are able to collect and analyze data and perform unsupervised machine learning to provide insights and recommendations to operators/supervisors. As with other areas of smart manufacturing, a number of vendors have emerged to take advantage of AI in production settings. Vendors such as **Falkonry**, **FogHorn**, **SparkCognition**, **Rockwell Automation**, **Praemo**, **Bonsai**, and **Uptake** offer AI software that allows operators to discover and predict machine behavior and to correct deviations from specifications in real time. Benefits include improved OEE, increased yields, balanced production lines, and reduced maintenance costs.

At this stage in its development, AI is important to SMMs only to the extent that it is incorporated into new equipment, for instance for self-diagnostics. There are many steps an SMM can take to gather and analyze data and draw actionable insight based on shop floor experience and human intelligence prior to depending on AI algorithms. After all, AI is only as good as the data and algorithms it uses, the ability to sustain the models with updated learning, and the ability to understand the confidence limits of use. While continually getting better, for now it is best to resist the hype and focus on practical, targeted technology investments and operator intelligence.

There is no doubt that AI can add value to manufacturing but much of the current state of the art requires data scientists to be actively involved in applications so adoption will be limited. Techniques that can leverage the experience of domain experts need to be further developed to allow widespread adoption.

Blockchain

Blockchain is best known for so-called crypto-currencies such as BitCoin. Although industrial applications may not be obvious, it is beginning to be adopted by large OEMs as part of their supply chain management, and therefore could be imposed on SMMs. For instance, Seagate is using blockchain to prevent counterfeit parts in its supply chain. Other applications inside the factory are also being developed.

First, what is blockchain? Put simply, blockchain is a distributed ledger in which items are given an encrypted identifier and every exchange of that item is logged on the ledger, which is housed in multiple computers across the internet. Each transaction is verified, time-stamped, and recorded, with the entire history of transactions maintained permanently and securely in the

28 MachineMetrics, "How Carolina Precision Manufacturing Saved $1.5 million in Their First Year of Machine Monitoring," at https://www.machinemetrics.com/download-our-free-swisscnc-machine-monitoring-case-study-0

distributed ledger. Each transaction adds a link to the chain. The transactions can involve anything of value: records, contracts, invoices, delivery confirmation, etc.

Because manufacturing requires a series of transactions for buying and selling raw materials, parts, components, assemblies, and final goods, many experts foresee broad application both within and among factories. Blockchain technology can establish an easily followed and automated audit trail, more secure and reliable than typical manual record keeping. For example, blockchain can provide detailed, real-time information on the status of parts in a supply chain, not only identifying trouble spots but preventing counterfeit parts and other sources of fraud. Figure 11[29] illustrates how a blockchain would work to secure data sharing across a manufacturing supply chain.

Surveys indicate that manufacturers either have blockchain applications in place or are exploring their use. In one survey 87 percent of respondents are in the early stages of implementation, motivated by cost savings, enhanced traceability, and increased transparency across supply chains.[30] Especially as more aspects of manufacturing become digital, the use of blockchain to share and track data will become more pervasive. For instance, digital designs used for 3-D printing could be encoded on a blockchain, along with important information that goes with the part: the designer, the owner of the design, who has the rights to produce it and in what quantity.[31] Watermarks could be embedded in the design and documented on the blockchain to ensure that parts are authentic and that the producer has the intellectual property rights to make it. HP is currently conducting trials for this application of the technology.

The food industry is an early adopter of blockchain for supply chain tracking. For example, IBM is supporting a consortium of companies called Food Trust to track food along the entire supply chain including details such as

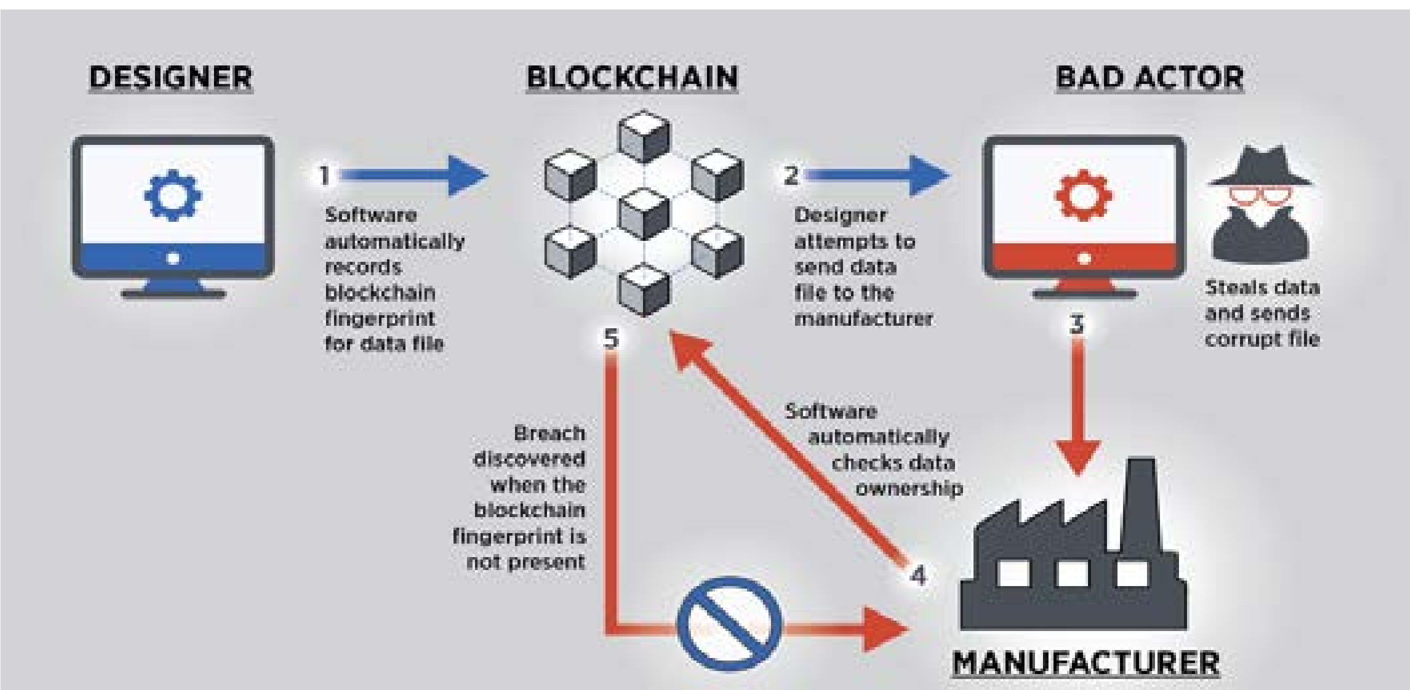

Figure 11: Blockchain Provides Data Security and Traceability (Source: NIST, 2019)

29 https://www.nist.gov/news-events/news/2019/02/nist-blockchain-provides-security-traceability-smart-manufacturing
30 http://www.scmr.com/article/capgemini_report_suggests_blockchain_is_real_for_many_leading_supply_chain
31 http://directory.newequipment.com/classified/protecting-the-additive-manufacturing-workflow-with-blockchain-technology-250963

the temperature meat is kept. Other applications promise to speed payment to suppliers; **Veem** is an example. Other blockchain-based solutions for supply chain management include **Simbachain** and **Jitsuin**.

However, there is also evidence that implementations of blockchain for supply chain management are slowing as companies grapple with unforeseen complications. Instead of a strong use case, many companies are essentially using trial and error with pilot projects to find an application that provides real value. For SMMs early adoption of blockchain technology is unwarranted.[32] It is best to wait until implementation is easier and clear value-adding applications are defined, probably within the next five years.

Cloud and Edge Computing

Cloud and edge computing are common terms used by vendors in the smart manufacturing market. The “cloud” refers to data storage, processing, and software applications that reside on remote servers accessed through the internet. The computing resources available through the cloud allows for better access to better services without the fixed costs of extensive on-site computing infrastructure, a major advantage for SMMs.

However, because cloud-based services are remote, there is a slight time lag between when data are sent and when the processed data are returned to where it can be acted upon, even when this communication is done between computers. In the case of a physical operation on the shop floor, this lag could be the difference between a good part and scrap. To avoid this, “edge” computing uses a small number of on-site servers that both process time-sensitive data needed for manufacturing processes and communicate with the cloud. Most manufacturing operations will have a combination of cloud and edge computing (a.k.a., hybrid computing).

Cloud computing is dominated by three providers: Amazon Web Services, Microsoft Azure, and Google Cloud Platform. With the exception of some specific services that might be useful to SMMs, such as AWS’ AR/VR product, most SMMs will interact with the cloud through vendor services. One well-known example is **Salesforce**, a cloud-based customer relationship management (CRM) provider. Other familiar products that are cloud-based or have a cloud-based option include Microsoft’s **Office 365** and Autodesk’s **AutoCAD**. Like most cloud computing offerings, these are based on subscriptions. Some subscriptions are per user and/or machine; others, such as **Plex**, offer annual subscriptions for a range of products covering business management and manufacturing operations such as ERP and MES systems.

Other examples of cloud computing that help SMMs are engineering simulation and analysis applications, such as **ANSYS**, **Altair**, and **LS-Dyna**, or cloud-based high-performance computing (HPC) providers such as **Rescale** that allow SMMs to run compute-heavy analyses using HPC cloud without having to invest in powerful computers.

For SMMs, the advantages of cloud-based computer services are 1) expensive hardware and software purchases are largely avoided, 2) less staff is needed to manage hardware and software, and 3) remote access to programs and data is assured. As with most current SMM factories, there will continue to be local servers, controllers, routers, and network communications, so any cloud-based services will not eliminate maintaining and updating on-site equipment and software. Most importantly, cloud services will not substitute for safe computing practices that will maximize cybersecurity, despite what vendors might say.

32 https://www.supplychainmovement.com/gartner-warns-of-blockchain-fatigue-in-supply-chain/

Cybersecurity

Surveys show that over half of manufacturers have experienced a data breach in the past year, and that one of the major concerns of SMMs about smart manufacturing is cybersecurity. Fear of data theft, malware, sabotage, and other malicious acts enabled by weak cybersecurity can paralyze decision makers who avoid what would be beneficial use of smart manufacturing technologies.

As with other aspects of hardware and software management, manufacturers are also guilty of really stupid mistakes and oversights with negative effects on cybersecurity. A recent study from Varonis assessed data risks at over 700 companies. The study found that manufacturing firms had thousands of exposed, sensitive files. Specifically,

- 22% of a company's folders are accessible, on average, to every employee
- 53% of companies made more than 1,000 sensitive files accessible to every employee, up from 41% in 2018
- 38% of users had passwords that never expire, up from 10% the previous year
- 50% of accounts are stale "ghost" users that allow former employees to log in and access information. Fully half of user accounts are no longer employees![33]

Correcting these basic flaws should be the first step in any cybersecurity plan. Most malware infections are people related: too many people have access, access is too easy, passwords are too simple or non-existent. Although companies such as MobileIron are making rapid progress on eliminating the need for passwords by using biometrics (fingerprint and facial recognition), in the meantime, password management is essential to stronger cybersecurity. Password managers, such as LastPass, 1Pass, Password Safe, Dashlane, and YubiKey are low-cost or free, effective tools readily available to SMMs.

As with many types of malware, the path into computer systems is often through infected email. Phishing emails try to trick recipients into revealing passwords and other sensitive information or to click on links to websites that contain the malware. For example, ransomware—a form of malware that locks an organization's computer files and systems until a ransom is paid, typically in BitCoin—is a growing threat from phishing. Manufacturers are one of the largest targets. In addition to basic cybersecurity practices, such as secure and consistent file backups, training staff to recognize phishing attacks and other scams is essential. Free on-line training is available at Google and the Federal Trade Commission; other sites, such as PhishTank and TrendMicro let users verify if a link is safe or not.

Once the basics of cybersecurity are addressed and consistently maintained, including security updates for Windows and other major software packages, additional steps should be taken to improve current cybersecurity and to prepare for future requirements as more smart technology is implemented. Use the NIST Cybersecurity Framework (CSF) as a guide. The CSF consists of standards, guidelines, and best practices to manage cybersecurity risk. The local NIST MEP can provide on-site implementation assistance. MEP also offers an on-line cybersecurity self-assessment tool that can help SMMs identify areas of high risk, develop corrective actions, and design an implementation plan. On-line resources can also help SMMs develop implementation plans.[34]

Beginning in 2018, suppliers to the U.S. Department of Defense must be in compliance with DFARS 252.204-7012, requiring implementation of minimum cybersecurity standards in areas such as identification and

33 https://www.controldesign.com/articles/2019/how-risk-resistant-are-you/

34 For example, M. Kumar and A. Sahai, "Turn the NIST Cybersecurity Framework into Reality: 5 Steps," 9/20/18, at https://www.dark-reading.com/analytics/turn-the-nist-cybersecurity-framework-into-reality-4-steps/a/d-id/1332796

authentication, media protection, system and communication protection, access control, risk assessment, and incident response. The local **MEP** can help SMMs with compliance.

SMMs must pay particular attention to cybersecurity. With connected supply chains, the weakest link can breach the security of the entire system. As larger manufacturers increasingly integrate their supply chains, solid cybersecurity protection, such as NIST's CSF, will become the ante to participate.

More information on cybersecurity for manufacturers is available in MForesight's report, "Cybersecurity for Manufacturers: Securing the Digitized and Connected Factory."[35]

35 Available at mforesight.org/download/7108/

NEXT STEPS TO GET STARTED

Every manufacturer has an opportunity to begin the smart journey based on existing staff and equipment. Multiple systems in the organization, both on the shop floor and in administrative offices, generate data. The essence of being smart is to gather data, analyze it to glean operational insights, then act on those insights.

Don't wait to get started. Identify opportunities based on a clear understanding of existing production and business processes. Remember that digitization will make good processes better, but bad processes worse. Start small. Although working with vendors can help, by sourcing needed hardware and software and tapping their experience to design effective projects, it is possible to get started with in-house resources. **Every manufacturer generates data. Simple pilot projects can start by picking a pain point, gathering related data, analyzing it for operational insights, and acting on those insights.** The goal is to use the insights to achieve continuous improvement. Learn quickly and apply those lessons to the next project.

As projects are executed, consider installing extensible infrastructure that will support future projects as well. As progress is made with successful internal projects, it will be clearer what outside technologies will be most helpful in building smart manufacturing and business processes. Internal experience will also help to avoid the trap of becoming enamored of a specific technology—or talked into it by a vendor—and hoping it will solve problems. Define the problems first. After all, the goal is not to have predictive maintenance, but to increase uptime and OEE.

A helpful approach to project selection is to estimate project feasibility and monetary benefits. For example, what are the effects on production costs from a successful project? How will turnover be affected? Will yields improve? Can resources be reallocated to focus on highest value products and customers? Asking questions like these can help determine the highest priority projects with the largest monetary benefits (Figure 12).[36]

It is also important to recognize that the biggest hurdles to effective implementation are not likely to be technical, but rather managerial and cultural. Therefore, it is important to prepare the workforce for whatever technological changes are planned, to delineate clear responsibilities, and to specify reporting channels. For small firms, the needed communication will be obvious, but larger firms should consider creating an organizational plan to complement the project plan before implementation begins. Companies with experience implementing lean and six sigma may have an advantage, because much like lean manufacturing and six sigma project implementations, smart manufacturing projects require buy-in from top leadership, and new skills, expectations, and engagement by the workforce.

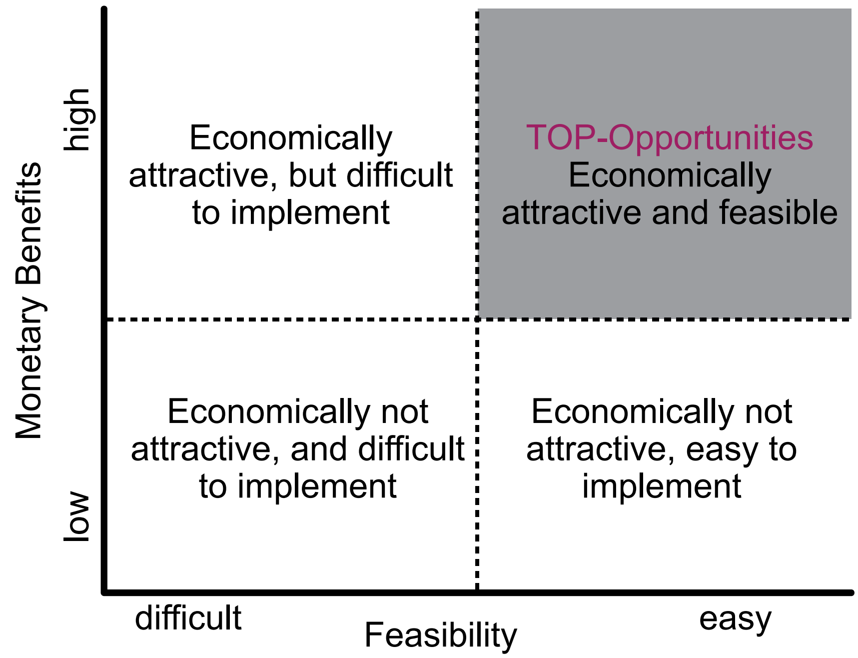

Figure 12: Criteria for Choosing Smart Manufacturing Projects (Source: IPL)

Outside resources are available to help understand specific technologies, find needed talent, and tap expertise. Sources include local MEPs, technical schools and universities, trade associations and professional societies. For example, the Society of Manufacturing Engineers (SME) has initiated several projects to provide manufacturers with information and training resources to accelerate implementation of smart manufacturing. SME also created a Smart Manufacturing Community, providing a forum for manufacturers to connect and share best practices. Websites such as **SME**, **IndustryWeek**, and **engineering.com**, offer articles, webinars, and links to other resources to help SMMs understand the technology and how other firms have implemented it. Local trade associations are often an excellent source of ideas and experiences, where members can learn from specific projects implemented by other members.

Keep in mind that most of the needed technology to begin a transition to smart manufacturing is available and affordable. In some cases, customers are beginning to expect a level of data sharing, for instance for part traceability, that has not been required in the past. In other cases, affordable technology, such as cobots, can provide solutions to critical problems on the shop floor—worker shortages, for instance—while also providing productivity and machine utilization improvements. As long as investment decisions are made to address specific problems or performance improvement objectives, SMMs have an opportunity to maximize success and, of course, make more money.

36 Thomas Korne, “How to Start with Industry 4.0 in SMEs,” Institut fur Produktions und Logistiksysteme, Nov. 2017.