Technical Standards for Smart Manufacturing: Evolution and Strategic Positioning

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21st century manufacturing is being transformed rapidly by two forces—globalization and technology. As a result of this transformation, manufacturers face a hypercompetitive environment where information governance is critical to their survival and success. One concept that is receiving great attention is smart manufacturing (SM)—the convergence of operating technologies (OT) and information technologies (IT) working together in a real-time integrated fashion. The promise of SM is considerable: between $500 billion and $1.2 trillion in added value globally within five years.[i] Estimates such as these reflect efficiencies related to preventative maintenance, operations on the factory floor, supply chain management, and logistics.

The pace of SM will depend critically on the development and global adoption of technical standards, which provide uniformity that allows for acceptance and use and therefore encourage trade.

From the perspective of a smart manufacturer, standards facilitate two goals: to enable the integration of technologies using safe and secure methodologies, and to demonstrate compliance with regulations that incorporate standards by reference. Without technical standards, SM would be far more expensive and uncertain.

The SM standards landscape is multifaceted, complex, and ever-evolving. It is also high stakes; first-mover advantages will accrue to those who lead the way in establishing truly global standards. The active role that other national governments are playing to develop SM standards to benefit their domestic manufacturing sector raises certain policy issues that the US, as a leading manufacturing nation, cannot ignore.

What is Smart Manufacturing?

Multiple definitions of "smart manufacturing" can be found (e.g., from NIST, the Clean Energy Smart Manufacturing Innovation Institute, etc.). According to Dan Green, Director of the Joint Advanced Manufacturing Region (JAMR) within the Navy, Smart manufacturing is "the convergence of operating technologies (OT) and information technologies (IT) working together in a real-time integrated fashion."[ii] In other words, it is the ability for information to be communicated between the manufacturing floor and the enterprise's connected and cloud based information systems automatically and in real time. Other definitions emphasize the integration of technologies (such as IIoT, robotics, additive manufacturing, big data and cloud computing, advanced analytics and AI, and virtual and augmented reality).

Traditional manufacturing processes have not always included this instant and "live" connection, and therefore the ability of the enterprise, or its customers, to know the status of the whole system has relied on more manual methods of reporting. This traditional approach creates inefficiencies and delays that compromise the ability for enterprises to compete domestically and internationally. SM also adds a data point to the calculation that has hitherto been mostly ignored: people. Many production lines today incorporate robots that work alongside human workers in a safe and secure manor. Ensuring connections between OT and IT while taking into account the human factor has increased complexity, requiring across-the-board standardization to avoid communication conflicts as well as potentially hazardous situations.

The Standards Development Landscape

Standards are documented agreements containing specifications applied consistently as rules or guidelines for materials, products, processes, or services (such as communication between machines, systems, hardware and software, etc.). They provide uniformity that allows for acceptance and use, and therefore benefit manufacturers by limiting barriers and facilitating trade. Seen in this light, standards facilitate innovation.[iii]

Defining the global standards landscape is not a simple task because there are numerous ongoing activities shaping and reshaping all aspects of SM. Not only are new and disruptive technologies being invented that are redefining the scope of SM, but national initiatives are being developed that are designed to benefit, or in some cases protect, the industrial base within the country's own borders. To understand the current state of play, it is useful to start by understanding the major players and their activities.

Standards can be developed in different ways. The most traditional is through a standards development organization (SDO), which facilitates consensus and makes the resulting standard available to everyone. SDOs can be international, national, or even professional organizations (e.g., an association) that represent their members' common interests. Standards developed in this traditional way often take years to be published. An open source process is sometimes used to develop a standard outside of the traditional SDO process because it is speedier. Ownership of an open source standard is viewed as a public trust and anyone can participate in the development process, which is usually overseen by an independent organization. Once developed, these open source standards can then be adopted into SDOs and become more widely accepted internationally.

Within the realm of SM standards, numerous organizations are involved, including SDOs, consortia, professional associations or trade associations working within their narrow fields, and academically oriented professional societies. Standards are seldom finalized in their first iteration and typically evolve to keep pace with changing technology and use patterns.

SDOs (for example the International Association of Automation (ISA) and the International Organization for Standardization (ISO)) are relied upon for the development of new technical standards that will enable the technologies without favoring any one group in particular. The International Electrotechnical Commission (IEC) publishes standards and coordinates with other standards development groups to provide structure and identify gaps where new standards may be required. SDOs may have agreements with countries to help prevent the localized development of standards from running out of control and creating barriers to trade.

Consortia tend to focus on integrating standards. Participants in consortia agree to use the standards, prove them in testbeds, and collaborate to resolve issues. Many different consortia are involved in SM standards. Consortia that involve the government, industry, and academia tend to focus on how to best leverage existing standards to fill data gaps rather than develop new standards.

Associations and foundations are heavily involved in standards development, and although more focused on specific technologies that support their market segment, can have far reaching influence on other sectors where overlaps exist. Organizations such as the OPC Foundation, the Open Process Forum, and ODVA are helping to shape the technologies that will help shape the framework for Smart Manufacturing, as well as identifying the technologies that will enable it.

National governments are also involved in developing SM standards because they realize the value that manufacturing brings to their economy and believe that digitalization will elevate the productivity of their domestic manufacturing base. Each national effort is known by a different name: Germany originated Industrie 4.0, China developed a plan known as Made in China 2025, the US established the Manufacturing USA program, and France has its Industrie de Futur. So far, the goals of these efforts have mostly focused on assembling existing standards and creating new standards to meet the larger system needs, but some have very specific strategies to identify standards that enable their vision for SM.

To facilitate the development of SM standards, models have been developed to map the standards landscape. NIST has developed the SM ecosystem (Figure 1) to illustrate the types of standards needed across a manufacturing value chain. The core of the ecosystem is the pyramid, which is based on the hierarchy within ISA 95 (a common reference model for developing automated interfaces between enterprise and control systems). The base of the pyramid is the device level, then the SCADA (Supervisory Control and Data Automation) level, then the MOM (manufacturing operations management) level, and the top of the pyramid is the enterprise level. Crossing through the pyramid are three dimensions—product, production system, and business—each with their own segments and information flows. Numerous SM standards are needed to support every level of the pyramid, each segment within each dimension, and horizontal and vertical integration across the value chain.

Industrie 4.0 has developed its own model, as shown in Figure 2. This model is built around the life cycle and value stream, hierarchy levels, and layers.

Although each model has a different perspective, they share many similarities such that the resulting list of standards identified by each are very similar. Certain standards are seen as especially important in enabling SM—these serve as the building blocks that apply to different levels and different domains within the manufacturing systems.

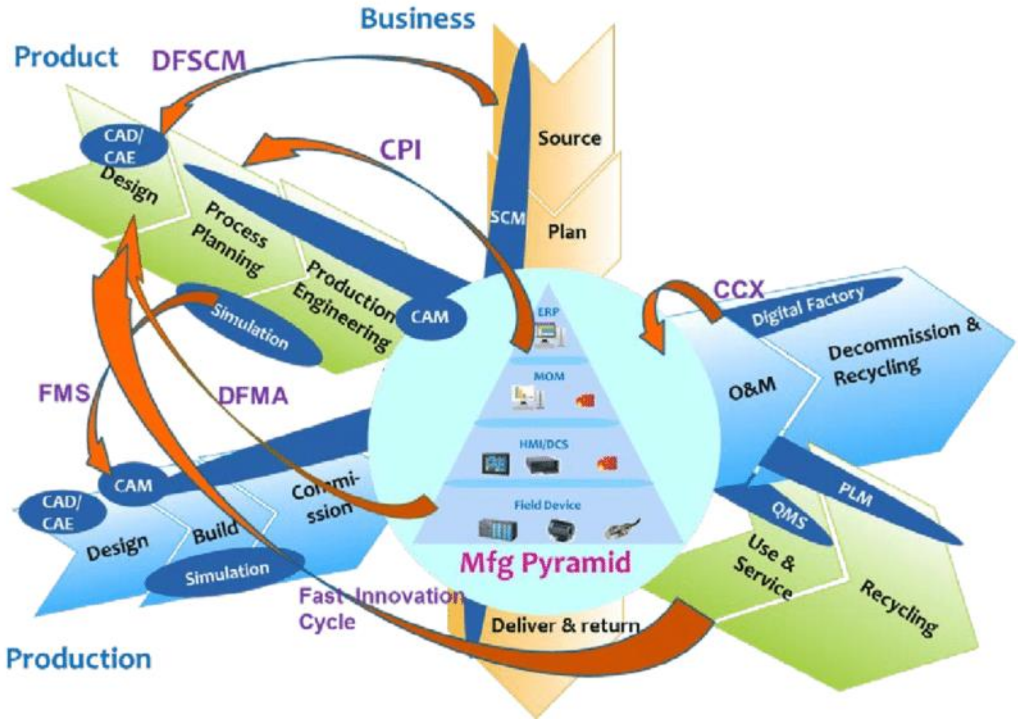

Figure 1: Smart Manufacturing Ecosystem (NIST)

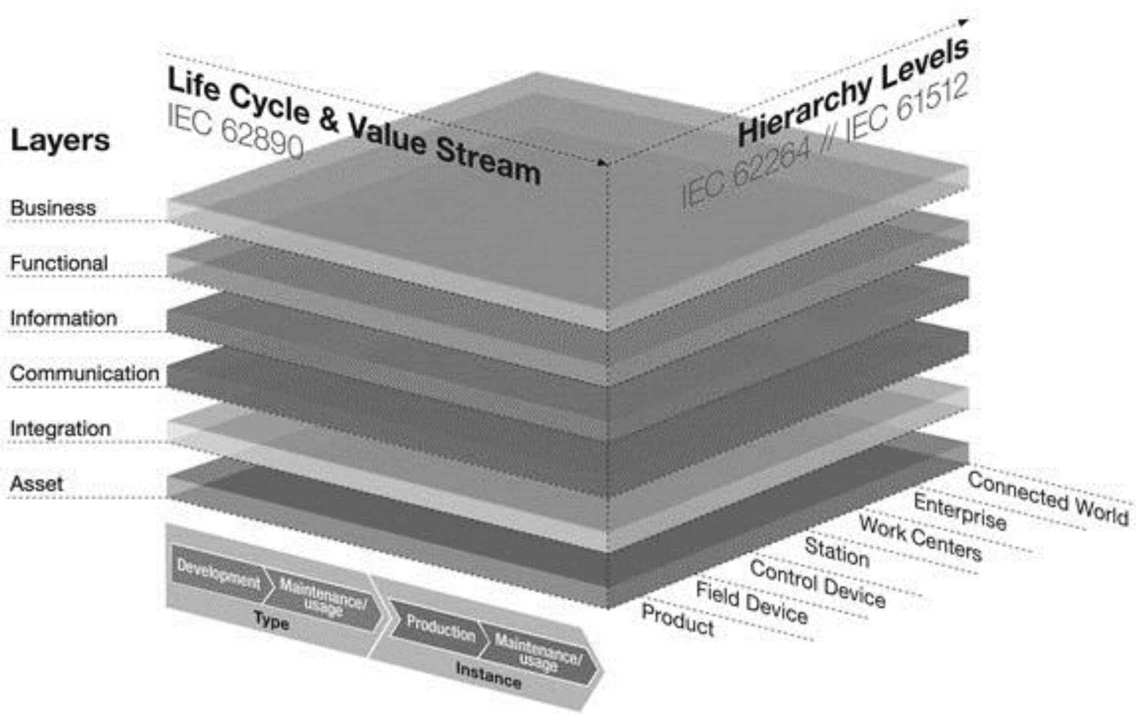

Figure 2: Reference Architecture Model Industry 4.0[iv]

Challenges for Manufacturers Seeking Standards

Manufacturers who seek to invest in smart manufacturing face significant indirect challenges related to technical standards:

- navigation of the multifaceted standards landscape is complicated by missing, superfluous, and redundant standards;
- the time to develop a standard is lengthened greatly by gamesmanship of the process by various stakeholders; and
- rapidly evolving technology frequently outpaces standards development.

As illustrated by Figure 1, the standards landscape for smart manufacturing—in its most simplified form—is multidimensional, interdependent, and rapidly evolving. The number of standards in existence or under development is in the hundreds if not thousands. Such an intricate landscape is further complicated by missing, superfluous, and redundant standards. According to NIST (2016), gaps in the SM standards landscape include "cybersecurity, cloud-based manufacturing services, supply chain integration, and data analytics." Of the existing standards, a large proportion (at least 25%-30%) have never been used. SDOs rarely remove a standard once it is developed. Another problem is that existing standards are often identical or nearly equivalent and this raises questions about the most authoritative source. Adding to this confusion is the pluralistic US standards system, where no single entity is authorized to provide standards (e.g., the US has more than 600 SDOs). Because so many standards arise from so many sources, products designed for one market are effectively blocked out of other markets, creating barriers to trade.

The time to develop a standard is lengthened greatly by gamesmanship of the process by various stakeholders. There are some competing efforts around the higher level standards, and who gets to define what the common models are as well as the common sets of underlying standards that adhere to the models. Companies actively involved in standards development in the industrial manufacturing domain seem to be in a constant chess game, analyzing each other's actions and strategies to prevent any one company from including requirements that will benefit their technology over another. This results in huge expenditures of resources and money that adds to the burden of compliance. IP that is written into standards is a very serious concern as it locks manufacturers into single, proprietary systems that benefit IP owners. This restricts the free development of new technologies or processes and limits organizations from being agile enough to rapidly adapt to disruptive technologies.

Perhaps the most fundamental challenge is that the IT world moves much more quickly than standards development. New IT evolves, on average, every three years, while standards development takes up to five years. IT developers will not wait because by the time the standard is ready and published, they will have moved on to the next version. In addition, IT developers often do not want to get "locked in" to a single vendor's solution based on a standard because it will limit their scope of new technologies. Unlike IT, operational technology (OT) evolves at a slower pace and is less likely to race ahead of standards development.

Given these many challenges, it is not be surprising that competitive pressures may require manufacturers to make investment decisions in the absence of globally adopted standards. As a practical matter, some technologies will be adopted before the needed standards are developed and some projects will employ proprietary standards from vendors. A manufacturer might start with custom integration using proprietary standards from a single vendor, followed by integration using a proprietary standard supported by a group of vendors working as partners, followed by integration using open standards with a myriad of vendors and vendor options.

List of Policy Issues/Questions

From a US perspective, several policy issues/questions arise relating to technical standards for SM:

- Should the US have an overarching strategy for SM standards akin to that of some other countries? If so, what should be the articulated goal?
- Which SM standards or type of SM standards should receive the highest priority of the US government in the near-term (e.g., by 2020) and longer term (e.g., by 2025 and 2030) if the goal is to promote industry investment in SM?
- Should the US government elevate in priority the development of SM standards for the application of AI?

Should the US have an overarching strategy for SM standards akin to that of some other countries? If so, what should be the articulated goal?

In recent years, several countries have adopted policies to digitalize their manufacturing sector. Ezell (2018) summarized these developments across ten countries.[v] Notable among these efforts is Industrie 4.0 (Germany) and Made in China 2025.

Germany is developing technical standards and pushing for their international adoption, starting within the EU. Its management organization, Plattform Industrie 4.0, supported development of the Reference Architectural Model for Industrie 4.0 (RAMI), which is a guide to standards and interoperability. According to published reports, Germany is aggressively pushing development of its standards, which are widely considered “rigorous, comprehensive, and inclusive,” according to Ezell. His conclusion: “the risk for Germany is that, while its standards-development process is intensely rigorous, comprehensive, and inclusive, it may take too long, such that by the time the standard is set the technology and market have moved on to something better.” In its efforts, Germany is investing heavily in standards adoption (more than the US) and seeking global partnerships.

China’s efforts in standardization are government-directed, though it has recently changed its standardization law to encourage association (nonprofit) standards. China has made development of its own standards a linchpin of its economic development strategies, designed to gain a competitive edge over other countries. This is believed to hold true for its own efforts in standards for digitalizing its manufacturing sector. According to Ezell, “China appears to be playing a short and long game with smart manufacturing standards development; collaborating now where necessary, but in the background developing standards for the future that are designed to give Chinese manufacturers strategic advantage."

The U.S. does not have a formal national strategy with regards to standards and SM other than to facilitate innovation and allow the best solution to emerge, but there are active initiatives from multiple groups and organizations, including government organizations such as the National Institute of Standards and Technology (NIST), SDOs such as Underwriters Laboratories, research institutes such as the Digital Manufacturing and Design Innovation Institute (DMDII)[vi] within Manufacturing USA, and individual companies. Ezell described the US posture as favoring "a voluntary, consensus-based, market-driven approach where government agencies participate in the standards development process by being invited to the table . . . but not by overtly directing the process."

At times, the focus on a particular technology or market segment results in a fairly coordinated approach within the US, but the lack of a single driving national strategy from which to gain direction for these activities more often than not results in outcomes that are, at best, lackluster. Unless the United States is actively creating, and communicating, a single strategy that helps to advance the manufacturing objectives of domestic companies, it will be very difficult to influence the direction of standards globally, as other countries are doing. In contrast, a national strategy could help align all stakeholders (e.g., NIST, trade associations, industry consortia, etc.) and drive global standards that benefit the manufacturing value chain and bolster the domestic economy.

Which standards or type of standards should receive the highest priority of the US government in the near-term (e.g., by 2020) and longer term (e.g., by 2025 and 2030) if the goal is to promote industry investment in SM?

Whether or not the US government develops a national strategy for SM standards, an important question relates to the appropriate US priorities. In a 2016 report describing the SM standards landscape,[vii] NIST listed some of its ongoing activities: "NIST is heavily engaged in efforts to develop new standards for the Digital Thread, Model-Based Enterprise, smart manufacturing design and analysis, additive manufacturing, and robotics. NIST leads an effort to define requirements eventually leading to standards for cloud-based services for manufacturing. NIST work on cybersecurity for supply chains and industrial systems will have great importance for manufacturers. Finally, NIST coordinates the networking of the Manufacturing USA institutes."

Also in that report, NIST listed existing manufacturing standards that are insufficient to enable smart manufacturing: cybersecurity, cloud-based manufacturing services, supply chain integration, and data analytics.

Finally, NIST identified the following priority areas where SM standards are critically needed: SMS reference model and reference architecture, IIoT reference architecture for manufacturing, manufacturing service models, machine-to-machine communication, integration of PLM/MES/ERP/SCM/CRM, cloud manufacturing, manufacturing sustainability, and manufacturing cybersecurity.

Given the large number of standardization efforts underway including those recently initiated, it is not clear that these lists reflect the current standards landscape.

Should the US government elevate in priority the development of SM standards for the application of AI?

Thus far, the standards described in this paper relate to standards for communication and transmission of information across the supply chain in light of the IIoT. But a rapidly emerging area of standards development relates to the real-time analysis of digital information through application of artificial intelligence (AI) techniques.

AI, which is well-suited to manufacturing[viii], requires standardization to realize its potential. Machine learning provides one example. “To scale Deep Learning into a practice that is predictable, reliable, and efficient will require standardization. The intent of standardization is to maximize participation of many independent parties. It is a common language or a coordination mechanism for parties to accelerate progress. Accelerated progress is necessary for Deep Learning to not just be confined to research labs but also to be industrialized and available to many.”[ix]

China plans to be the world leader in AI and in standardization of AI; the country has been moving aggressively to set policies in this regard.[x] For example, China recently released its “Artificial Intelligence Standardization White Paper,” developed with help from 30 research institutions, education institutes, and AI companies. This paper includes the following passage: “AI is a prospering new industry. China is at the starting line as all other countries and there is opportunity now for rapid breakthrough. With fast action plans, China can either seize the commanding heights of innovation standardization, or else miss the opportunity. There is an urgent need to seize opportunities, accelerate research on AI deployment in industry, and systematically review and establish a unified and comprehensive set of standardization.” [xi]

Chinese officials believe the country has a comparative advantage in AI: its sheer size and use of centralized planning allow it to access and utilize massive amounts of data, providing it with training data used in machine learning to develop more efficient algorithms.[xii] Given China’s plan to elevate innovation in its manufacturing sector (Made in China 2025), its focus on AI is hardly surprising.

Conclusion

Given the promise of SM, the critical role of technical standards to realize this promise, and the strategic actions of international stakeholders, now is the time for the US to reflect on its role in the global standards process and make any necessary adjustments. Such reflection should be conducted with input from both domestic and international stakeholders because both national and global action will shape progress. Lack of considered deliberation on this issue will maintain the status quo, where strategic decisions by other countries are likely to shape the competitive landscape for advanced manufacturing for decades to come.

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Endnotes

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[xii] Greg Williams, 2018. *Wired*, "Why China Will Win the Global Battle for AI Dominance", April.